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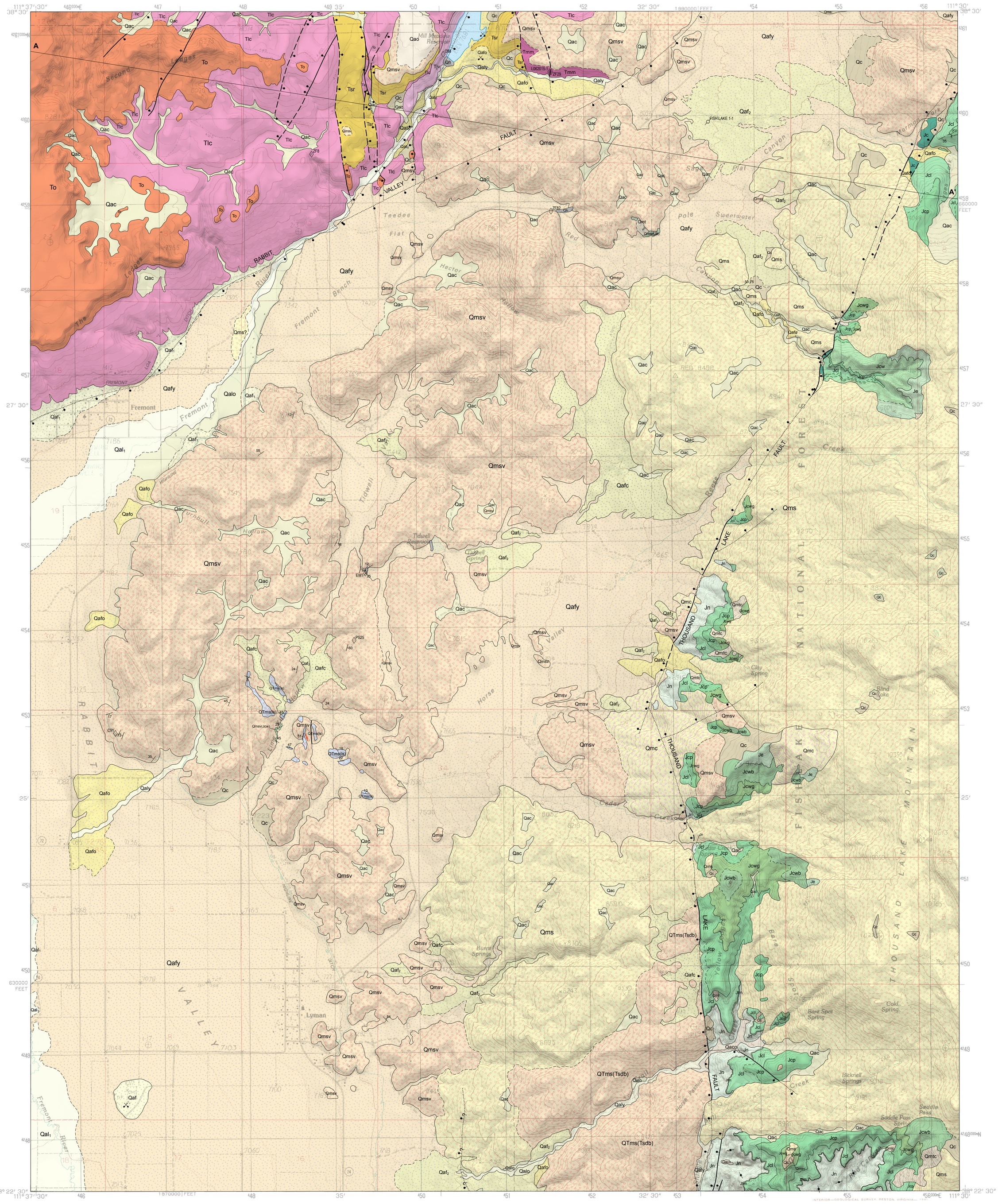

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

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11.01°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2017

INTERIM GEOLOGIC MAP OF THE LYMAN QUADRANGLE, WAYNE COUNTY, UTAH

by

Robert F. Biek[1], Hanna Bartram[2], Zachariah Fleming[2], Erika Wenrich[2], Christopher Bailey[2], and Peter Steele[2]

2017

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QUADRANGLE LOCATION

Base from USGS Lyman7.5' Quadrangle (1985)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Project Manager: Grant C. Willis
GIS and Cartography: Basia Matyjasik

Utah Geological Survey
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Salt Lake City, UT 84116
(801) 537-3300
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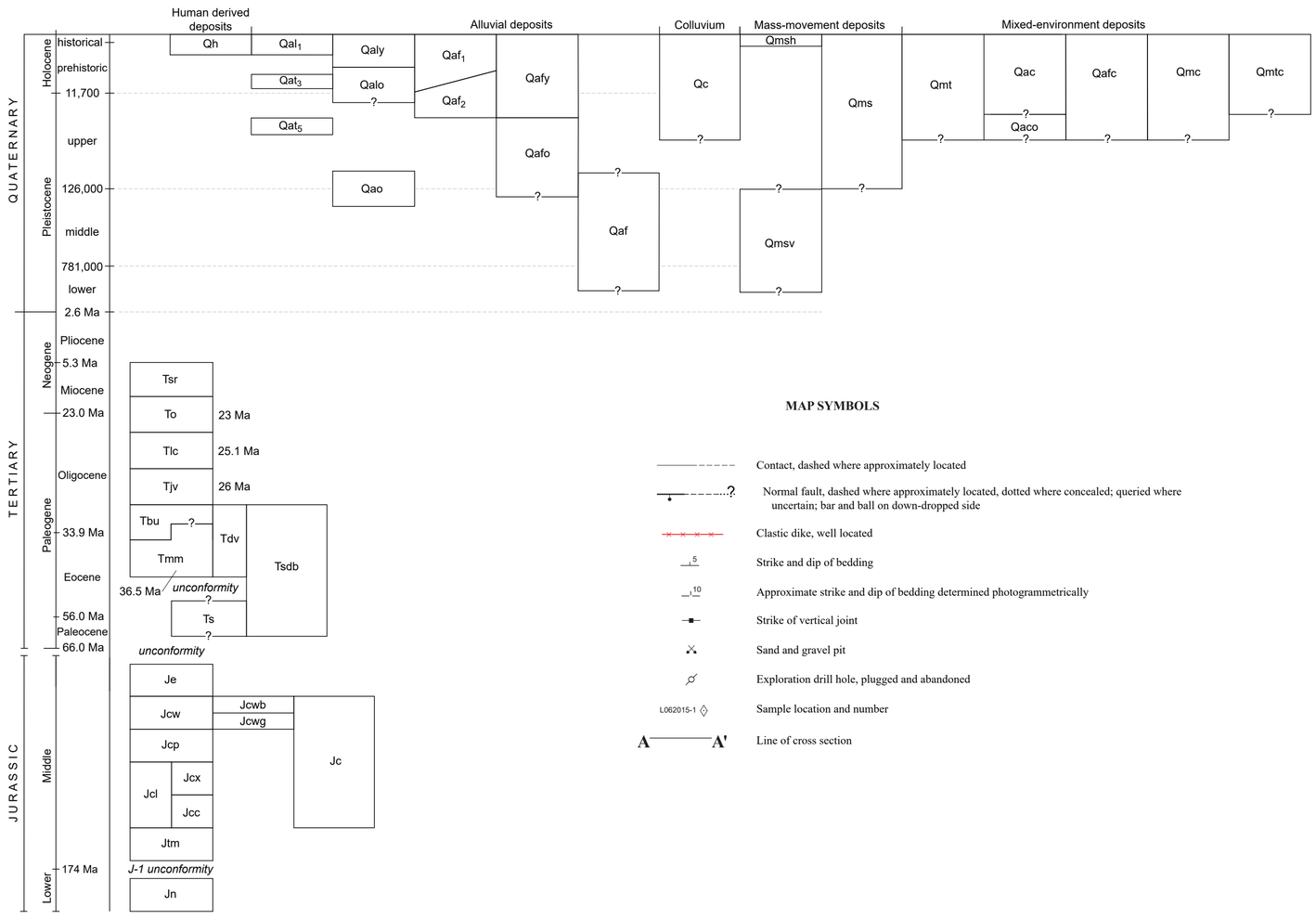
This map was created from geographic information system (GIS) data

1	2	3
4	·	5
6	7	8

1. Fish Lake
2. Forsyth Reservoir
3. Geyser Peak
4. Loa
5. Flat Top
6. Moroni Peak
7. Bicknell
8. Torrey

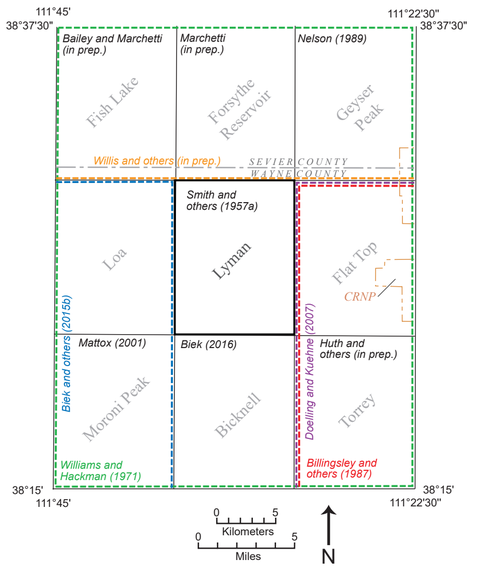
ADJOINING 7.5' QUADRANGLE NAMES

CORRELATION OF MAP UNITS

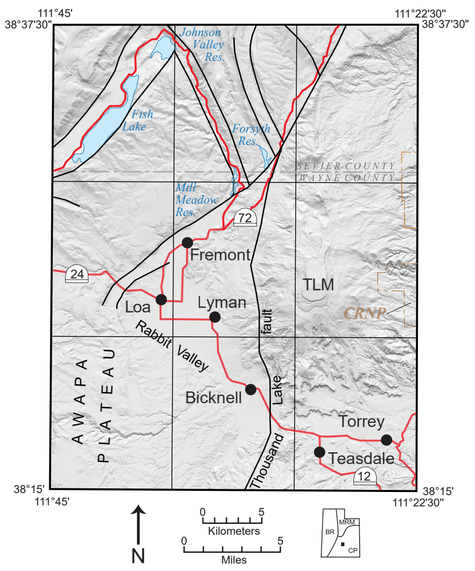


MAP SYMBOLS

- Contact, dashed where approximately located
- Normal fault, dashed where approximately located, dotted where concealed; queried where uncertain; bar and ball on down-dropped side
- Clastic dike, well located
- Strike and dip of bedding
- Approximate strike and dip of bedding determined photogrammetrically
- Strike of vertical joint
- Sand and gravel pit
- Exploration drill hole, plugged and abandoned
- L062015-1 Sample location and number
- A—A' Line of cross section



US Geological Survey 7.5' quadrangles and principal sources of previous geologic mapping. CRNP = Capitol Reef National Park



Shaded-relief image of the Lyman 7.5' quadrangle and surrounding area; TLM = Thousand Lake Mountain, CRNP = Capitol Reef National Park. Inset shows physiographic provinces: BR, Basin and Range; MRM, Middle Rocky Mountains; CP, Colorado Plateau.

STRATIGRAPHIC COLUMN

AGE Ma	System	Series	MAP UNIT	MAP SYMBOL	THICKNESS feet (meters)	REGIONAL TECTONIC SETTING	DEPOSITIONAL ENVIRONMENT	DOMINANT ROCK TYPE AND WEATHERING PROFILE	NOTES
.012	QUATERNARY	Holocene / Pleistocene	various surficial deposits see Correlation of Map Units		variable	Basin-range extension and bimodal basalt and rhyolite volcanism beginning about 17 Ma	alluvium and mass-wasting deposits in modern drainages and basins	unconsolidated sand, gravel, clay and silt	Typically maximum thickness reported and not all units present in any given area.
2.6 / 5.3									unconformity
23.0	TERTIARY Neogene	Miocene	Sevier River Formation	Tsr	200+ (60+)		fluvial basin fill with volumetrically minor lava flows and air-fall tuff beds	sandstone, conglomerate, lava flows	
	Paleogene	Oligocene	Osiris Tuff	To	300+ (90+)	Calc-alkaline volcanism, development of clustered stratovolcanoes and calderas in southwest Utah from about 30 to 14 Ma	Marysvale volcanic field and intermontaine basins: ash-flow tuff from Monroe Peak caldera	densely welded rhyodacite ash-flow tuff	23.0 Ma
			trachyte of Lake Creek	Tlc	400+ (120+)		ash-flow tuff from unknown vent	densely welded crystal-poor trachyte ash-flow tuff	25.1 Ma
			latite of Johnson Valley	Tjv	200+ (60+)		lava flows from unknown vents	latitic lava flows	26 Ma
			Bullion Canyon Volcanics; Dipping Vat Formation	Tbc; Tdv; Tsdb	900+ (275+)		vent and alluvial facies of stratovolcanoes; local volcanic sediments deposited in low-relief river and lake basins	lava flows and volcanic mudflow breccia; volcaniclastic sandstone, siltstone, mudstone and conglomerate	Tdv 29–36 Ma; Tmm 36.5 Ma; Tsdb part of large landslides
		Eocene	volcanic rocks of Mill Meadow Reservoir	Tmm	100+ (30+)				unconformity
56.0		Paleocene	Tertiary sedimentary strata	Ts	400? (120?)	foreland basin	intermontane basin	conglomerate, mudstone, limestone	unconformity
	JURASSIC	Middle	Entrada Sandstone	Je	200+ (60+)	Back-bulge basin (Sevier orogeny)	tidal-flat, sabhka, coastal dune	sandstone and silty sandstone	
			Carmel Formation: Winsor Mbr. banded subunit	Jc; Jcw; Jcwb	850–900 (255–270); 500 (150); 300 (90)		sandy mud flat	sandstone, siltstone, gypsum	
			Winsor Mbr. gypsiferous subunit	Jcwg	200 (60)				
			Paria River Mbr.	Jcp	150–200 (45–60)		restricted shallow marine	micritic limestone, gypsum, shale	166 Ma
			Crystal Creek Mbr.	Jcl; Jcx	200 (60)		coastal sabkha and tidal flat	mudstone, siltstone	167 Ma
			Co-op Creek Limestone Mbr.	Jcc			shallow marine	micritic limestone, sandstone, shale	169–170 Ma
174			Temple Cap Formation Manganese Wash Member	Jtm	3–10 (1–3)		tidal flat, fluvial	sandstone and siltstone	J-1 unconformity
		Lower	Navajo Sandstone	Jn	600+ (180+)	Low-relief continental interior of a back-arc basin	vast eolian dune field of arid west coast subtropical desert	sandstone	large cross-beds; base not exposed

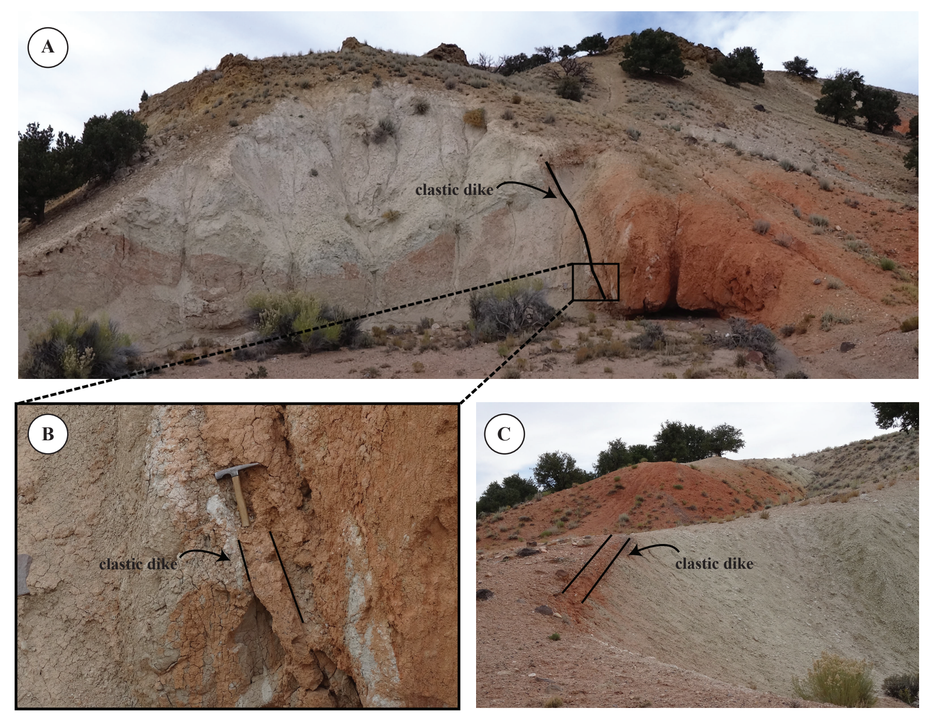
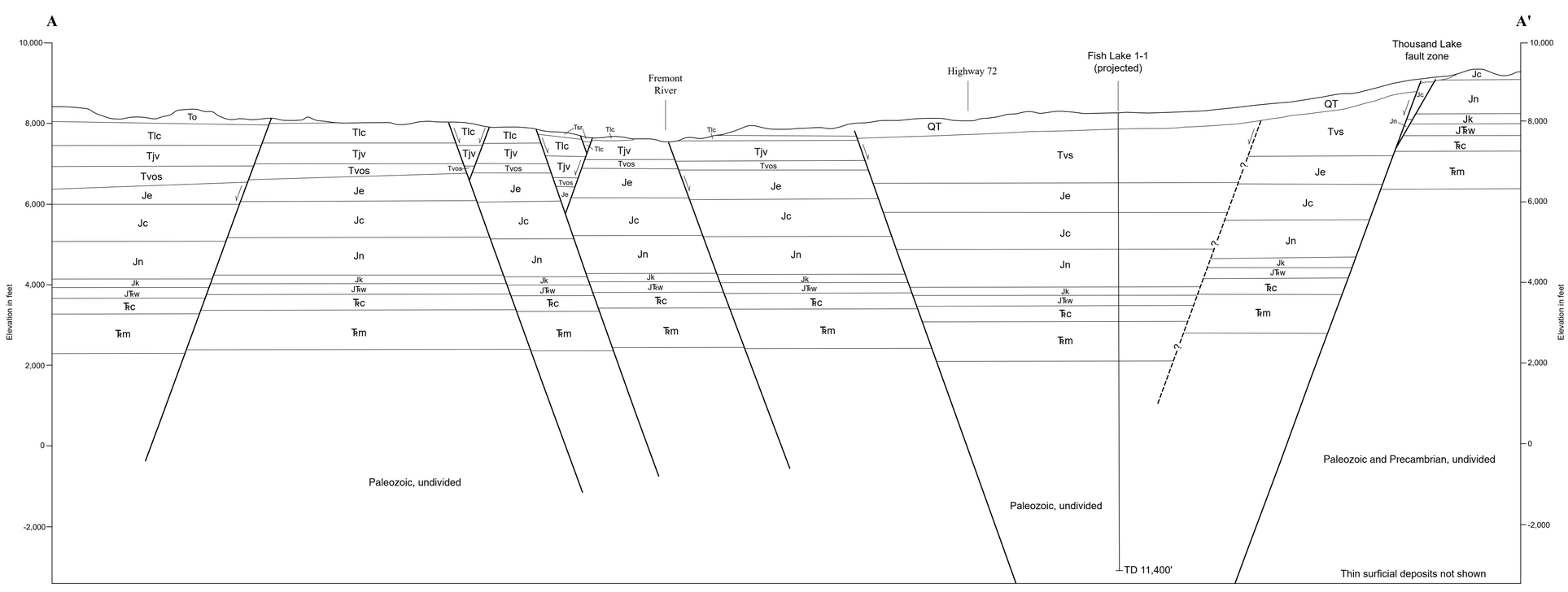


Figure 1. A. *View north to clastic dike in the north-central part of section 33, T. 27 S., R. 3 E. (UTM NAD83 coordinates 448619E, 4252940N). The dike is about 6 inches (15 cm) wide and consists of subrounded pebbles and granules of latite of Johnson Valley and trachyte of Lake Creek in a moderately indurated, yellow-brown muddy matrix. It is oriented N15°W, dips 65°E, and was injected along a fault that juxtaposes moderately northwest-dipping, light-gray and pale-red, tuffaceous, muddy siltstone and fine-grained sandstone of uncertain affinity on the west against moderate-red to moderate-reddish-brown, indistinctly bedded but likely subhorizontal, fine-grained sandstone and silty sandstone, likely Winsor strata, but possibly Entrada.* ***B.*** *Close-up of dike.* ***C.*** *View southward to dike.*



Interim Geologic Map of the Lyman Quadrangle, Wayne County, Utah

by

Robert F. Biek [1], Hanna Bartram [2], Zachariah Fleming [2], Erika Wenrich [2], Christopher Bailey [2], and Peter Steele [2]

[1] Utah Geological Survey
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2017

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MAP UNIT DESCRIPTIONS

QUATERNARY

Human-derived deposits

Qh **Artificial fill** (Historical) − Engineered fill and general borrow material used for the Mill Meadow Reservoir dam, Utah Highway 72 Red Canyon crossing, and small stock ponds; fill of variable thickness and composition should be anticipated in all developed or disturbed areas; mapped only where fill is typically 6 feet (2 m) or more thick.

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 the Fremont River; locally includes minor stream-terrace alluvium as much as about 10 feet (3 m) above current stream level; probably less than 20 feet (6 m) thick.

Qat_3, Qat_5

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, the Fremont River; deposited in a stream-channel environment, but locally includes colluvium and small alluvial fans; mapped below the Mill Meadow Reservoir dam where the river cuts through resistant volcanic rocks; each terrace represents the elevation of stream base level prior to being incised; subscript denotes relative age and height above adjacent drainage; a single Qat_3 terrace is about 30 feet (9 m) above the river level, whereas Qat_5 terraces ranges from about 50 to 60 feet (15–18 m) above the river (alluvium of intervening terrace levels Qat_2 and Qat_4 is not present, but is mapped in the adjacent Bicknell quadrangle [Biek, 2016]); as much as about 50 feet (15 m) thick.

Qaly **Young stream alluvium** (Holocene) − Combined stream alluvium (Qal_1) and the youngest (lowest elevation) part of stream-terrace alluvium (Qat_2), but undivided here due to limitations of map scale; mapped along ephemeral streams where it locally includes small alluvial-fan deposits from tributary drainages and colluvium from adjacent slopes; deposits commonly grade downslope into alluvial fans; locally includes historical debris-flow and debris-flood deposits; typically less than 20 feet (6 m) thick.

Qalo **Old stream alluvium** (Holocene to upper Pleistocene) – Similar to young stream alluvium (Qaly), but forms incised deposits along Trail Creek in the southeast corner of the quadrangle; probably less than 20 feet (6 m) thick.

Qao **Old alluvial deposits** (middle to lower Quaternary) – Moderately sorted sand, silt, and pebble to boulder gravel that forms a southward sloping surface high above the Fremont River; 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 the latite of Johnson Valley map unit 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 Forsythe Reservoir quadrangle.

Northward in the Forsythe 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 volcaniclastic strata of the Sevier River Formation. The "Airport terrace," however, is cut across the resistant trachyte 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, our old landslide deposits (Qmsv) 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 young and middle fan alluvium (Qafy), but differentiated because Qaf_1 typically forms smaller fans with a steeper longitudinal profile; 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 mostly inactive surfaces incised by younger stream and fan deposits; equivalent to the older, lower part of young and middle fan alluvium (Qafy); 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 (Qaf_2 equivalent) incised by small streams that are undifferentiated here; deposited principally as debris flows and debris floods, but adjacent to range fronts colluvium locally constitutes a significant part; small, isolated deposits are typically less than a few tens of feet thick, but large, coalesced deposits in Rabbit Valley are much thicker and form the upper part of basin-fill deposits; Anderson and Reuter (2011) reported that unconsolidated basin fill is about 350 feet (107 m) thick in the Fish Lake 1-1 exploration well, the upper part of which is this young and middle fan alluvium (basin geometry suggests that these sediments are somewhat thicker in the southwest part of the map area).

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 gently sloping, deeply incised surfaces along the margins of Rabbit Valley and along the Thousand Lake fault zone; deposited principally as debris flows and debris floods; exposed thickness as much as several tens of feet.

Qaf **Oldest fan alluvium** (Quaternary) – Similar to old fan alluvium (Qafo) but forms isolated, boulder-covered hill at the Lyman cemetery in Rabbit Valley; maximum exposed thickness about 30 feet (9 m).

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; common on most slopes, but mapped only where it conceals contacts or mantles broad areas and shallow depressions; typically less than 20 feet (6 m) thick.

Mass-movement deposits

The flanks of Thousand Lake Mountain (and Boulder Mountain to the south [Doelling and Kuehne, 2007]) are nearly completely covered by rotational slumps, translational landslides, and earthflows 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 (2005, 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 volcaniclastic 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 unusual topography are apparent when viewed in Google Earth imagery, and they contrast markedly from areas where this stratigraphic interval is unaffected by mass-movement processes. Thus, much of the eastern part of this quadrangle is here mapped as landslide deposits (Qms, Qmsv), whereas near the southern quadrangle boundary, in the hanging wall of the Thousand Lake fault, the range front is eroded from apparently older landslide deposits that include or conceal Tertiary strata (QTms/Tsdb).

It is unclear what stratigraphic horizon serves as the principal slip surface for these large landslide complexes because the uppermost 300 feet (90 m) of Thousand Lake Mountain is concealed by mass-movement deposits below its resistant volcanic caprock. 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 southern 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). 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 the Loa 30′ x 60′ quadrangle (Biek and others, 2015b), and its coeval twin, the Dipping Vat Formation, is present in fault blocks east of Bicknell (Biek, 2016). We suspect that such landslide-susceptible strata underlie the resistant caprock of Thousand Lake Mountain. The Winsor Member of the Carmel Formation also likely serves as a major slip surface. Interestingly, neither older Carmel strata nor Navajo Sandstone debris is present in these landslide deposits.

Qms, Qmsh

Landslides (Historical to lower? Pleistocene) − Very poorly sorted clay- to boulder-size debris and large, intact bedrock blocks deposited by rotational, translational, and earth-flow movement; characterized by hummocky topography, numerous internal scarps, chaotic bedding attitudes, and small ponds, marshy depressions, and meadows; at several locations, landslide deposits spill across the Thousand Lake fault zone and the older parts of these deposits exhibit fault scarps; query indicates area of suspected lateral spread morphology along the Fremont River northeast of Fremont; see discussion of landslides of Rabbit Valley (Qmsv) for relationship between Qms and Qmsv; Qmsh denotes small historical landslide in lower Carmel strata above Cedar Creek spring; thickness highly variable, but map patterns suggest that larger deposits on the west flank of Thousand Lake Mountain locally exceed several hundred feet thick; deposits mapped as Qms are not divided by 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 landslides. Understanding the location, age, and stability of landslides, and of slopes that may host as-yet unrecognized landslides, requires detailed geotechnical investigations.

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 earthflow movement; characterized by large-scale hummocky topography that is more subdued than deposits mapped simply as landslides (Qms); mostly buried by boulder veneer, but individual blocks of displaced bedrock are locally mapped as Qmsv(ls), Qmsv(Je), Qmsv(Jcw), described below; 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 latite of Johnson Valley, 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 sec. 33, T. 27 S., R. 3 E.), where tilted and faulted blocks of brecciated limestone of uncertain affinity and a clastic dike are present (figure 1), (2) to the west along the high line ditch, where folds and thrust faults are present in white, tuffaceous, mostly fine-grained volcaniclastic strata likely of the Dipping Vat Formation, and (3) in road cuts west of Tidwell Reservoir where tilted and faulted, fine-grained volcaniclastic strata and quartzite-pebble conglomerate are juxtaposed against shattered latite of Johnson Valley. Based on their subdued morphology and stranded position in the landscape, remnants of the landslide of Rabbit Valley are present on the footwall of the Thousand Lake fault. The landslide of Rabbit Valley forms the Rabbit Valley salient of Bartram and others (2014), 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 map area; 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 the 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 meringue-like 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.

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; although talus is common at the base of steep slopes across the map area, it is mapped only in Red Canyon where it conceals and stands in stark contrast to underlying Entrada strata now part of old landslide deposits; talus that is part of landslide complexes is not mapped separately; 3 to 10 feet (1–3 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 small perennial and ephemeral streams, 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 remnants; on the footwall of the Thousand Lake fault a remnant along Sweetwater Creek is offset, while a remnant along Trail Creek is apparently unfaulted; about 20 to 30 feet (6–9 m) thick.

Qafc **Fan alluvium and colluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, weakly to non-stratified, clay- to boulder-size sediment deposited principally by debris flows and debris floods at the mouths of active drainages and as colluvium shed from adjacent slopes; varies locally from mostly fan alluvium to mostly colluvium but is combined here due to map scale and typically poor geomorphic contrast; probably less than 40 feet (12 m) thick.

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 is locally in excess of 100 feet (30 m) thick, but most deposits are only a few feet to several tens of feet thick.

Qmtc **Talus and colluvium** (Holocene to upper? Pleistocene) – Poorly sorted, cobble- to boulder-size angular debris and finer-grained interstitial sediment deposited principally by rockfall and slope wash on steep slopes throughout the quadrangle; 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.

QUATERNARY and TERTIARY

QTms(Tsdb)

Older landslide deposits over Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of the 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 latite of Johnson Valley; limited exposures reveal fine- and coarse-grained volcaniclastic, and locally non-volcaniclastic, strata of widely varying attitudes that may be fault-bounded bedrock blocks or rotated blocks that are part of a deeply eroded landslide; the description below is largely based on better exposures in the adjacent Bicknell quadrangle (Biek, 2016); the distribution and thickness of individual units is highly variable, but map patterns suggest that the combined package is in excess of 900 feet (275 m) thick.

Fine-grained volcaniclastic 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 of McGookey (1960) exposed on the northeastern 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 southeastern flank of the volcanic field (Jeff Eaton, written communication, May 24, 2016); they also yielded charophytes *Harrisichara tuberculate*, *Sphaerochara aff. Major*, and *Hornichara* also reported from the Brian Head Formation (Jeff Eaton, written communication, June 21, 2017). Coarse-grained volcaniclastic facies consist of 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 adjacent 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, and quartzite- and chert-pebble conglomerate, and medium- to coarse-grained "salt and pepper" sandstone comprise 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 non-volcaniclastic strata appear similar to strata in Lime Kill Hollow, 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). These non-volcaniclastic strata appear in a similar stratigraphic position as the Crazy Hollow Formation and the formation of Aurora (see Willis, 1988) on the northeastern 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 southeastern flank of the volcanic field.

TERTIARY

Tsr **Sevier River Formation** (Miocene) – Moderately to poorly consolidated, light-gray and grayish-brown volcaniclastic conglomerate, pebbly sandstone, sandstone, and minor siltstone; clasts are subrounded to rounded intermediate-composition volcanic rocks; locally contains thin, white, air-fall ash beds, some of which may belong to the Joe Lott Tuff Member (about 19 Ma) of the Mount Belknap Volcanics (Rowley and others, 1986); preserved east of Mill Creek Reservoir at the south end of the Fremont River graben and well exposed in road cuts in a smaller graben to the west; maximum thickness in this quadrangle is about 200 feet (60 m), but regionally is as much as about 400 feet (120 m) thick on the Awapa Plateau (Biek and others, 2015b).

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 that created the present topography (Rowley and others, 1981, 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 that have fission-track and K-Ar ages of 14 and 7 Ma and basaltic lava flows that have K-Ar ages of 9 and 5.6 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 western 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 (Biek and others, 2015b). The Sevier River Formation thus spans much of the Miocene and was deposited in basins of different ages across this part of south-central Utah, most of which bear little relationship to the modern topography.

Tvs Tertiary volcanic and sedimentary rocks, undivided (Miocene to Eocene) – Shown on cross section only.

Tvos Older Tertiary volcanic and sedimentary rocks, undivided (upper Oligocene to Eocene) – Shown on cross section only, west of the Rabbit Valley fault.

To **Osiris Tuff** (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 that typically includes an upper, light-gray vapor-phase zone and a basal black vitrophyre as much as 10 feet (3 m) thick; commonly weathers to large rounded boulders, as, for example, at The Ledges in the northwest corner of the quadrangle; contains drawn-out pumice lenticles; the preferred age of the Osiris is about 23 Ma (Rowley and others, 1994); forms the uppermost widespread volcanic unit on the Awapa Plateau and is only locally overlain by volcaniclastic gravels of the Sevier River Formation and younger middle Miocene to Pliocene basaltic lava flows; nearly complete section at The Ledges is about 300 feet (90 m) thick.

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). Fleck and others (1975) reported K-Ar ages for the Osiris Tuff (corrected according to Dalrymple, 1979) on biotite of 23.4 ± 0.4 Ma (sample R3) from the southern Sevier Plateau and 22.7 ± 0.4 Ma (sample R12) from the southern Tushar Mountains. Cunningham and others (2007) reported that the tuff erupted between 22.92 and 22.81 Ma based on preliminary unpublished $^{40}Ar/^{39}Ar$ ages by L.W. Snee, and Ball and others (2009) reported that several $^{40}Ar/^{39}Ar$ ages on sanidine average 23.03 ± 0.08 Ma.

Tlc **Trachyte tuff of Lake Creek** (upper Oligocene) (temporary name, see note below) – Gray, densely welded, phenocryst-poor, trachyte ash-flow tuff with 5 to 15% phenocrysts of plagioclase, pyroxene, hornblende, and Fe-Ti oxides commonly in a glassy matrix; typically exhibits pronounced platy compaction foliation and lighter-colored "lenticules" interpreted to be flattened gas-rich zones; basal vitrophyre typically inconspicuous and poorly exposed; mapped in the northwest corner of the quadrangle where it commonly weathers to mostly poorly exposed, regolith-covered slopes; on the Awapa Plateau, Williams and Hackman (1971) called this unit a latite, but Mattox (1991, 2001), although he retained the name latite, correctly noted that it is a trachyte according to the classification scheme of LeBas and others (1986); originally interpreted as lava flows (Williams and Hackman, 1971; Mattox, 1991, 2001) and subsequently identified as an ash-flow tuff (Ball and others, 2009); major- and trace-element discrimination diagrams (UGS unpublished data) show that samples identified as trachyte tuff of Lake Creek cluster remarkably tightly, except, possibly, on the west flank of the Fish Lake Plateau (Willis and Doelling, in preparation); on the northern Awapa Plateau and Fish Lake Plateau, map unit typically overlies the latite of Johnson Valley, but southward it overlies lahars of the volcanic rocks of Langdon Mountain (Biek and others, 2015b); Bailey and Marchetti (in preparation; see also UGS and NIGL, 2012) reported $^{40}Ar/^{39}Ar$ ages of 25.68 ± 0.19 Ma (groundmass concentrate) and, our preferred age, 25.13 ± 0.02 Ma (sanidine) for their trachyte tuff of Lake Creek on the Fish Lake Plateau; incomplete section is at least 400 feet (120 m) thick near Fremont; incomplete exposures near Fish Lake may be 800 feet (245 m) (Bailey and Marchetti, in preparation) to 1000 feet (300 m) (Marchetti and others, 2013) thick.

Rocks apparently equivalent to the trachyte tuff of Lake Creek are known by a variety of names on the Sevier Plateau and nearby areas. The stratigraphic position, age, petrography, and chemistry of the densely welded, phenocryst-poor trachyte tuff of Lake Creek are similar to that of the comparatively thin Kingston Canyon and Antimony Tuff Members of the Mount Dutton Formation (Anderson and Rowley, 1975), the tuff of Albinus Canyon (Steven and others, 1979; Cunningham and others, 1983), and the flows of Deer Spring Draw (Nelson, 1989). It is possible that the trachyte tuff of Lake Creek correlates with one or more of these units. Rowley and others (1994, p. 15) noted that

> The tuff of Albinus Canyon is considered a proximal accumulation from a nearby source [possibly buried under southernmost Sevier Valley] that also erupted the Kingston Canyon and Antimony Tuff Members. The similarity in composition, appearance, and age of the tuff of Albinus Canyon and the Kingston Canyon and Antimony Tuff Members with the units of the Isom Formation and other units from sources in Nevada is a regional petrologic problem about which we and others currently are perplexed. Best, Christiansen, and others (1989) have discussed the Isom compositional type of tuff [densely welded, phenocryst-poor trachyte] and other compositional types and have suggested that they represent magmas in different areas that had similar origins and crystallization histories.

That the vent or vents of these densely welded rheomorphic ash-flow tuffs is not apparent may indicate that their magma source was deep in the crust and thus never expressed by typical collapse caldera (Ekren and others, 1984).

One difficulty with possible equivalency of these units is that the trachyte tuff of Lake Creek is the thickest among them, typically an order-of-magnitude thicker than the Kingston Canyon and Antimony Tuff Members even though it is far from the inferred source in southernmost Sevier Valley. Possibly this is due to accumulation on the flanks of the Marysvale volcanic complex; that is, these units are relatively thin on the volcanic pile itself, yet thicken eastward where they accumulated in paleovalleys that radiated away from the center of the pile. Ongoing research on regional correlation of these units may allow us to replace the temporary, informal name "trachyte tuff of Lake Creek" with earlier established nomenclature.

Tjv **Latite of Johnson Valley** (upper Oligocene) (temporary name, see note below) – Gray, weathering to brownish-gray, porphyritic trachyandesite (latite) lava flows 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 that on aerial photographs look like typical blocky lava flows; major- and trace-element discrimination diagrams (UGS unpublished data) show that samples identified as latite of Johnson Valley (Biek and others, 2015b) cluster remarkably tightly with few exceptions, notably the large-ion lithophile elements Ba and Sr, which are enriched in the northern Awapa Plateau as also noted by Mattox (1991); however, mapping by Willis and Doelling (in preparation) on the west flank of the Fish Lake Plateau shows a more diverse chemistry for rocks they tentatively map as equivalent to the latite of Johnson Valley; interpreted by Ball and others (2009) as an ash-flow tuff likely consisting of several cooling units, but they found no vitrophyres, nor did Biek and others (2015b) in exposures on the Awapa Plateau; thin sections show no glass shards, so we now interpret this unit as consisting of multiple latitic lava flows present over much of the eastern part of the Marysvale volcanic field, including the caprock at Boulder Mountain and Thousand Lake Mountain; Smith and others (1963) recognized three units at Boulder Mountain southeast of this map area; includes potassium-rich mafic lava flows of Mattox (2001) given their similar stratigraphic position, petrology, and chemistry; several $^{40}Ar/^{39}Ar$ ages for this unit are about 25 to 26 Ma (UGS and NMGRL, 2007, 2009; UGS and NIGL, 2012; UGS unpublished data), but because it clearly underlies the trachyte tuff of Lake Creek, our preferred age for the latite of Johnson Valley is 26 Ma; incomplete section is about 200 feet (60 m) thick in this quadrangle, but is as much as 500 feet (150 m) thick at Big Hollow southwest of Loa (Mattox, 1991, 2001); incomplete exposures near Fish Lake may be 800 feet (245 m) thick (Bailey and Marchetti, in preparation) and Marchetti and others (2013) reported that the unit is locally in excess of 1000 feet (300 m) thick on the Fishlake Plateau, but these thicknesses are suspect due to widespread colluvial cover and possible duplication by normal faults; Smith and others (1963) reported this unit to be 475 feet (145 m) thick at Boulder Mountain.

The stratigraphic position, age, petrography, and chemistry of the latite of Johnson Valley is similar to that of the volcanic rocks of Signal Peak, vent and lesser alluvial facies rocks derived from a shield volcano complex in the northern Marysvale volcanic field (Rowley and others, 1981; Willis and Doelling, in preparation). Ongoing research on regional correlation of these units may allow us to replace the temporary, informal name "latite of Johnson Valley" with earlier established nomenclature.

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 latite of Johnson Valley; includes ledge-forming, 10- to 15-foot-thick, reddish-brown lithic ash-flow tuff with a glassy matrix (sample L062015-1); biotite from an ash layer yielded an isochron age of 36.53 ± 0.14 (sample FR071708-1 of Marchetti and others, 2013; UGS and NIGL, 2012); incomplete thickness is about 100 feet (30 m).

Ongoing regional study of the volcanic rocks of the eastern Marysvale volcanic field suggests that these rocks 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 volcaniclastics 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; Steven and others, 1979; Cunningham and others, 1984; Rowley and others, 1994; and Rowley and others, 2002).

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

Tbu **Bullion Canyon Volcanics, undivided** (Oligocene to upper Eocene?) – Gray to reddish-brown volcanic mudflow breccia, lava flows, ash-flow tuff, and volcaniclastic conglomerate and sandstone of mostly dacitic and andesitic composition; erupted and eroded from several clustered stratovolcanoes in the northern Marysvale volcanic field (see, for example, Rowley and others, 1994); may form parts of poorly exposed and apparently chaotic blocks within map unit QTms(Tsdb), as it does in the adjacent Bicknell quadrangle to the south (Biek, 2016).

Tdv **Dipping Vat Formation** (lower Oligocene to upper Eocene) – Light-gray to white, thin- to medium-bedded, fine- to medium-grained, locally coarse-grained, sandstone, siltstone, and mudstone; may form parts of poorly exposed and apparently chaotic blocks within map unit QTms(Tsdb), as it does in the adjacent Bicknell quadrangle to the south (Biek, 2016).

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. We tentatively assign these beds to the Dipping Vat Formation, defined from exposures on the northern flank of the Marysvale volcanic field (McGookey, 1960), but realize similar strata on the southern flank of the field are known as the Brian Head Formation (see, for example, Biek and others 2015a, 2015b).

unconformity

Ts **Tertiary sedimentary strata** (middle Eocene? to Paleocene?) – Pale-yellowish-brown and reddish-brown mudstone, medium- to coarse-grained "salt and pepper" sandstone, pebble conglomerate, and minor yellowish-brown sandy and micritic limestone; clasts are rounded, pebble- to small-cobble-size quartzite of mostly tan, gray, and white hues, with uncommon red quartzite and rare black chert and Paleozoic limestone pebbles; typically poorly cemented and non-resistant; may form parts of poorly exposed and apparently chaotic blocks within map unit QTms(Tsdb), as it does in the adjacent Bicknell quadrangle to the south (Biek, 2016); pebbles are locally common as a 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; likely related to middle Eocene (Duchesnean Land Mammal Stage, 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); thickness unknown, but may exceed 400 feet (120 m) thick on nearby Thousand Lake Mountain (Doelling and Kuehne, 2007).

unconformity

JURASSIC

Je **Entrada Sandstone** (Middle Jurassic) – Pale- to light-brown to pale-reddish-brown, fine-grained sandstone and silty sandstone that weathers to steep ledgy slopes; typically very thick and 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 is about 200 feet (60 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, undivided** (Middle Jurassic) – Undivided in fault blocks along the Thousand Lake fault zone, and also used on cross section. The Lyman quadrangle lies near the northern end of a region of extensive sand influx during the Middle Jurassic 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 Formation and Page Sandstone (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 back-bulge basin and, together with the underlying Temple Cap Formation, provides the first clear record of the effects of the Sevier orogeny in southwestern 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 at Black Ridge in the adjacent Bicknell quadrangle 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).

Jcw **Winsor Member** (Middle Jurassic, Callovian to Bathonian) – Undivided in Red Canyon where subunits appear less distinctive, containing less gypsum and less sand than exposures to the south, where it is divided into a lower gypsiferous subunit and a thicker upper banded subunit; deposited on a broad, sandy mud flat during the second major regression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983).

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 [3 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; map patterns indicate a thickness of about 300 feet (90 m); an incomplete section 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 the uppermost thick limestone bed, light-gray, laminated, aphanitic 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; map patterns indicate a thickness of about 200 feet (60 m); 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, aphanatic to finely crystalline, chippy-weathering limestone, and numerous thick white alabaster gypsum beds including a 30-foot-thick (9 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; map patterns indicate a thickness of about 150 to 200 feet (45–60 m); 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.

Jcl **Crystal Creek and Co-op Creek Limestone Members, undivided** (Middle Jurassic, Bathonian to Bajocian) – Combined unit due to map scale limitations; combined unit is about 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; distinctive reddish-brown beds locally missing; upper contact typically corresponds to the base of a thick, white, nodular Paria River gypsum bed; 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 in southwestern 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 coeval Thousand Pockets Member in southcentral 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); ranges from a few feet to about 20 feet (6 m) thick; 30 feet (9 m) thick on Black Ridge (Douglas Sprinkel, written communication, May 14, 2015).

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, and calcareous shale; locally fossiliferous with *Isocrinus* sp. crinoid columnals, pelecypods, and gastropods, including a laterally persistant 1- to 2-foot-thick (0.1–0.2 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, typically reddish-brown siltstone; 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 southwestern Utah; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1980; Blakey and others, 1983); map patterns indicate a thickness of about 180 to 200 feet (55–60 m); 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).

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 three-foot-thick (1 m) ledge of yellowish-brown, fine-grained sandy limestone; based on $^{40}Ar/^{39}Ar$ ages of sanidine and biotite, and 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); about 3 to 10 feet (1–3 m) thick, but is not mapped north of Yellow Ledges due to thinness and typically poor exposure; 43 feet (13 m) thick on Black Ridge (Douglas Sprinkel, written communication, May 14, 2015).

The Lyman 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, light-gray to white sandstone that consists of well-rounded, fine- to medium-grained, frosted quartz sand; lack of typical light-reddish-orange color is 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 slopes 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 (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); incomplete section is about 600 feet (180 m) thick; map patterns show that the Navajo is about 800 feet (245 m) thick on the southwest flank of Thousand Lake Mountain; 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.

Jk Kayenta Formation (Lower Jurassic) – Shown on cross section only. About 200 feet (60 m) thick on the southwest flank of Thousand Lake Mountain (Biek, 2016).

JURASSIC-TRIASSIC

JTRw Wingate Sandstone (Lower Jurassic to Upper Triassic) – Shown on cross section only. About 250 feet (75 m) thick on the southwest flank of Thousand Lake Mountain (Biek, 2016).

TR-5 unconformity

TRIASSIC

TRc Chinle Formation, undivided (Upper Triassic, Norian and Rhaetian) – Shown on cross section only. About 400 feet (120 m) thick on the south flank of Thousand Lake Mountain (Kirkland and others, 2014).

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).

TRm Moenkopi Formation, undivided (Lower to Middle Triassic) – Shown on cross section only; about 1000 feet (300 m) thick on the southern flank of Thousand Lake Mountain (Doelling and Kuehne, 2007).

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REFERENCES

Anderson, P.B., and Reuter, J., 2011, Oil and gas potential of the Awapa Plateau area, Piute, Wayne, and Garfield Counties, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 233–259.

Anderson, J.J., and Rowley, P.D., 1975, Cenozoic stratigraphy of southwestern high plateaus of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern high plateaus of Utah: Geological Society of America Special Paper 160, p. 1–51.

Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey Special Study 105, 49 p.

Bailey, C.M., and Marchetti, D.W., in preparation, Geologic map of the Fish Lake quadrangle, Sevier and Wayne Counties, Utah: Utah Geological Survey Miscellaneous Publication, scale 1:24,000.

Ball, J.L., Bailey, C., and Kunk, M.J., 2009, Volcanism on the Fish Lake Plateau, central Utah: Geological Society of America Abstracts with Programs, v. 41, no. 6, p. 17.

Bartram, H.C., Bailey, C., Fleming, Z.D., and Marchetti, D.W., 2014, The Thousand Lake fault—normal faulting and landscape evolution at the Colorado Plateau margin, Utah: Geological Society of America Abstracts with Programs, v. 46, no. 6, p. 593.

Beitler, B., Parry, W.T., and Chan, M.A., 2003, Bleaching of Jurassic Navajo Sandstone on Colorado Plateau Laramide highs—evidence of exhumed hydrocarbon supergiants?: Geology, v. 31, p. 1041–1044.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1035–1050.

Biek, R.F., 2016, Interim geologic map of the Bicknell quadrangle, Wayne County, Utah: Utah Geological Survey Open-File Report 654, 18 p., 2 plates, scale 1:24,000.

Biek, R.F., Eaton, J.G., Rowley, P.D., and Mattox, S.R., 2015b, Interim geologic map of the western Loa 30′ x 60′ quadrangle, Garfield, Piute, and Wayne Counties, Utah: Utah Geological Survey Open-File Report 648, 20 p., 2 plates, scale 1:62,500.

Biek, R.F., Rowley, P.D., Anderson, J.J., Maldonado, F., Moore, D.W., Hacker, D.B., Eaton, J.G., Hereford, R., Filkorn, H.F., and Matyjasik, B., 2015a, Geologic map of the Panguitch 30′ x 60′ quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Map 270DM, 162 p., 3 plates, scale 1:62,500.

Billingsley, G.H., Jr., Huntoon, P.W., and Breed, W.J., 1987, Geologic map of Capitol Reef National Park and vicinity, Utah: Utah Geological and Mineral Survey Map 87, 4 plates, scale 1:62,500.

Blakey, R.C., 1994, Paleogeographic and tectonic controls on some Lower and Middle Jurassic erg deposits, Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 273–298.

Blakey, R.C., Peterson, F., Caputo, M.V., Geesman, R.C., and Voorhees, B.J., 1983, Paleogeography of Middle Jurassic continental, shoreline, and shallow marine sedimentation, southern Utah, *in* Reynolds, M.W., and Dolley, E.D., editors, Mesozoic paleogeography of west-central United States: Denver, Colorado, Rocky Mountain Section of Society of Economic Paleontologists and Mineralogists, p. 77–100.

Callaghan, E., 1938, Preliminary report on the alunite deposits of the Marysvale region, Utah: U.S. Geological Survey Bulletin 886-D, p. 91–134.

Chan, M.A., Parry, W.T., and Bowman, J.R., 2000, Diagenetic hematite and manganese oxides and fault-related fluid flow in Jurassic sandstones, southeastern Utah: American Association of Petroleum Geologists Bulletin, v. 84, p. 1281–1310.

Cunningham, C.G., Rowley, P.D., Steven, T.A., and 2007, Geologic evolution and mineral resources of the Marysvale volcanic field, west-central Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 143–161.

Cunningham, C.G., Steven, T.A., Campbell, D.L., Naeser, C.W., Pitkin, J.A., and Duval, J.S., 1984, Multiple episodes of igneous activity, mineralization, and alteration in the western Tushar Mountains, Marysvale volcanic field, west-central Utah, *in* Steven, T.A., editor, Igneous activity and related ore deposits in the western and southern Tushar Mountains, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Professional Paper 1299-A, 22 p.

Cunningham, C.G., Steven, T.A., Rowley, P.D., Glassgold, L.B., and Anderson, J.J., 1983, Geologic map of the Tushar Mountains and adjacent areas, Marysvale volcanic field, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1430-A, 1 plate, scale 1:50,000.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558–560.

DeBlieux, D.D., 2006, New discoveries of fossil mammals are providing important information about Utah's geologic past: Utah Geological Survey, Survey Notes, v. 38, no. 2, p. 8–9.

Dickinson, W.R., and Gehrels, G.E., 2003, U-Pb ages of detrital zircons from Permian and Jurassic eolian sandstones of the Colorado Plateau, USA—paleogeographic implications: Sedimentary Geology, v. 163, issues 1–2, p. 29–66.

Dickinson, W.R., and Gehrels, G.E., 2009a, U-Pb ages of detrital zircons in Jurassic eolian and associated sandstones of the Colorado Plateau—evidence for transcontinental dispersal and intraregional recycling of sediment: Geological Society of America Bulletin, v. 121, nos. 3 and 4, p. 408–433.

Dickinson, W.R., and Gehrels, G.E., 2009b, Insights into North American paleogeography and paleotectonics from U-Pb ages of detrital zircons in Mesozoic strata of the Colorado Plateau USA: International Journal Earth Science, DOI 10.1007/s00531-009-0462-0, 19 p.

Doelling, H.H., and Kuehne, P.A., 2007, Interim geologic map of the east half of the Loa 30′ x 60′ quadrangle, Wayne, Garfield, and Emery Counties, Utah: Utah Geological Survey Open-File Report 489, 28 p., 1 plate, scale 1:100,000.

Doelling, H.H., Sprinkel, D.A., and Kuehne, P.A., 2013, Temple Cap and Carmel Formations in the Henry Mountains Basin, Wayne and Garfield Counties, Utah, *in* Morris, T.H., and Ressetar, R., editors, The San Rafael Swell and Henry Mountains basin—geologic centerpiece of Utah: Utah Geological Association Publication 42, p. 279–318, with appendices.

Ekren, E.B., McIntyre, D.H., and Bennett, E.H., 1984, High-temperature, large-volume, lava-like ash-flow tuffs without calderas in southwestern Idaho: U.S. Geological Survey Professional Paper 1272, 76 p.

Fleck, R.J., Anderson, J.J., and Rowley, P.D., 1975, Chronology of mid-Tertiary volcanism in High Plateaus region of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 53–61.

Flint, R.F., and Denny, C.S., 1958, Quaternary geology of Boulder Mountain, Aquarius Plateau, Utah: U.S. Geological Survey Bulletin 1061-D, p. 103–164, 6 plates, scale 1:63,360.

Huth, T.E., Young, B.W., Marchetti, D.W., Chan, M.A., and Cerling, T.E., in preparation, Geologic map of the Torrey quadrangle, Wayne County, Utah: Utah Geological Survey Miscellaneous Publication, scale 1:24,000.

Imlay, R.W., 1980, Jurassic paleobiogeography of the conterminous United States in its continental setting: U.S. Geological Survey Professional Paper 1062, 134 p.

Kirkland, J.I., Martz, J.W., DeBlieux, D.D., Santucci, V.L., Madsen, S.K., Wood, J.R., and Payne, N.M., 2014, Paleontological resource inventory & monitoring, Chinle and Cedar Mountain Formations, Capitol Reef National Park, Utah: Utah Geological Survey Contract Report to the National Park Service prepared under cooperative agreement #P13AC00601 Task #P13AC01248, 128 p., plus appendices.

Kocurek, G., and Dott, R.H., Jr., 1983, Jurassic paleogeography and paleoclimate of the central and southern Rocky Mountains region, *in* Reynolds, M.W., and Dolley, E.D., editors, Mesozoic paleogeography of the west-central United States: Denver, Colorado, Rocky Mountain Section Society of Economic Paleontologists and Mineralogists, p. 101–116.

Kowallis, B.J., Christiansen, E.H., Deino, A.L., Zhang, C., and Everitt, B.H., 2001, The record of Middle Jurassic volcanism in the Carmel and Temple Cap Formations of southwestern Utah: Geological Society of America Bulletin, v. 113, no. 3, p. 373–387.

LeBas, M.J., LeMaitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745–750.

Marchetti, D.W., in preparation, Interim geologic map of the Forsyth Reservoir 7.5′ quadrangle, Sevier County, Utah: Utah Geological Survey Open-File Report.

Marchetti, D.W., 2007, Pleistocene glaciations in central Utah—a review, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.J., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 197–203.

Marchetti, D.W., Bailey, C., Parks, R., Mikos, M., and Bowles, C.J., 2013, Preliminary geologic map of the Forsyth Reservoir 7.5′ quadrangle, Sevier County, Utah: Geological Society of America Abstracts with Programs, v. 45, no. 7, p. 376.

Marchetti, D.W., Cerling, T.E., Dohrenwend, J.C., and Gallin, W., 2007, Ages and significance of glacial and mass movement deposits on the west side of Boulder Mountain, Utah, USA: Palaeogeography, Palaeoclimatology, and Palaeoecology, v. 252, p. 503–513.

Marchetti, D.W., Cerling, T.E., and Lips, E.W., 2005, A glacial chronology for the Fish Creek drainage of Boulder Mountain, Utah, USA: Quaternary Research, v. 64, p. 263–271.

Mattox, S.R., 1991, Petrology, age, geochemistry, and correlation of the Tertiary volcanic rocks of the Awapa Plateau, Garfield, Piute, and Wayne Counties, Utah: Utah Geological Survey Miscellaneous Publication 91-5, 46 p., 1 plate, scale 1:100,000.

Mattox, S.R., 2001, Geologic map of the Moroni Peak quadrangle, Wayne County, Utah: Utah Geological Survey Miscellaneous Publication 01-5, 14 p., 2 plates, scale 1:24,000.

McGookey, D.P., 1960, Early Tertiary stratigraphy of part of central Utah: American Association of Petroleum Geologists Bulletin, v. 44, no. 5, p. 589–615.

Milligan, M., 2012, Sizing up titans—Navajo erg vs. Sahara ergs, which was the larger sand box?: Utah Geological Survey, Survey Notes, v. 44, no. 3, p. 8–9.

Nelson, S.T., 1989, Geologic map of the Geyser Peak quadrangle, Wayne and Sevier Counties, Utah: Utah Geological and Mineralogical Survey Map 114, 2 plates, scale 1:24,000.

Peterson, F., 1988, Stratigraphy and nomenclature of Middle and Upper Jurassic rocks, western Colorado Plateau, Utah and Arizona: U.S. Geological Survey Bulletin 1633-B, p. B13–B56.

Peterson, F., 1994, Sand dunes, sabkhas, streams, and shallow seas—Jurassic paleogeography in the southern part of the Western Interior basin, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 233–272.

Phillips, S.P., and Morris, T.H., 2013, Identification of an extensive paleotopographic high on the Navajo Sandstone by surface to subsurface correlation of the Temple Cap Formation and time-equivalent portions of the Page Sandstone, *in* Morris, T.H., and Ressetar, R., editors, The San Rafael Swell and Henry Mountains Basin—geologic centerpiece of Utah: Utah Geological Association Publication 42, p. 261–278.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—a preliminary survey: U.S. Geological Survey Professional Paper 1035-A, 29 p.

Potter, S.L., and Chan, M.A., 2011, Joint controlled fluid flow patterns and iron mass transfer in Jurassic Navajo Sandstone, southern Utah, USA: Geofluids, v. 11, p. 184–198.

Rahl, J.M., Reiners, P.W., Campbell, I.H., Nicolescu, S., and Allen, C.M., 2003, Combined single-grain (U-Th)/He and U-Pb dating of detrital zircons from the Navajo Sandstone, Utah: Geology, v. 31, no. 9, p. 761–764.

Reiners, P.W., Campbell, I.H., Nicolescu, S., Allen, C.M., Hourigan, J.K., Garver, J.I., Mattinson, J.M., and Cowan, D.S., 2005, (U-Th)/(He-Pb) double-dating of detrital zircons: American Journal of Science, v. 305, p. 259–311.

Riggs, N.R., Mattinson, J.M., and Busby, C.J., 1993, Correlation of Jurassic eolian strata between the magmatic arc and the Colorado Plateau—new U-Pb geochronologic data from southern Arizona: Geological Society of America Bulletin, v. 105, p. 1231–1246.

Rowley, P.D., 1998, Cenozoic transverse zones and igneous belts in the Great Basin, western United States—their tectonic and economic implications, *in* Faulds, J.E., and Stewart, J.H., editors, Accommodation zones and transfer zones—the regional segmentation of the Basin and Range Province: Geological Society of America Special Paper 323, p. 195–228.

Rowley, P.D., Cunningham, C.G., and Kaplan, A.M., 1981, Geologic map of the Monroe SE quadrangle, Sevier and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1331, 1 plate, scale 1:24,000.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1998, Cenozoic igneous and tectonic setting of the Marysvale volcanic field, and its relation to other igneous centers in Utah and Nevada, *in* Friedman, J.D., and Huffman, A.C., Jr., coordinators, Laccolith complexes of southeastern Utah—time of emplacement and tectonic setting—workshop proceedings: U.S. Geological Survey Bulletin 2158, p. 167–202.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Workman, J.B., Anderson, J.J., and Theissen, K.M., 2002, Geologic map of the central Marysvale volcanic field, southwestern Utah: U.S. Geological Survey Geologic Investigations Series Map I-2645-A, scale 1:100,000.

Rowley, P.D., Mehnert, H.H., Naeser, C.W., Snee, L.W., Cunningham, C.G., Steven, T.A., Anderson, J.J., Sable, E.G., and Anderson, R.E., 1994, Isotopic ages and stratigraphy of Cenozoic rocks of the Marysvale volcanic field and adjacent areas, west-central Utah: U.S. Geological Survey Bulletin 2071, 35 p.

Rowley, P.D., Steven, T.A., Anderson, J.J., and Cunningham, C.G., 1979, Cenozoic stratigraphic and structural framework of southwestern Utah: U.S. Geological Survey Professional Paper 1149, 22 p.

Rowley, P.D., Steven, T.A., and Mehnert, H.H., 1981, Origin and structural implications of upper Miocene rhyolites in Kingston Canyon, Piute County, Utah: Geological Society of America Bulletin, Part I, v. 92, p. 590-602.

Rowley, P.D., Williams, P.L., and Kaplan, A.M., 1986, Geologic map of the Greenwich quadrangle, Piute County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1589, 1 plate, scale 1:24,000.

Smith, T.L., Huff, L.C., Hinrichs, E.N., and Luedke, R.G., 1957a, Preliminary geologic map of the Loa 1 NE [Lyman] quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Field Studies Map MF-100, 1 plate, scale 1:24,000.

Smith, T.L., Huff, L.C., Hinrichs, E.N., and Luedke, R.G., 1957b, Preliminary geologic map of the Loa 1 SE [Bicknell] quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Field Studies Map MF-101, 1 plate, scale 1:24,000.

Smith, T.L., Huff, L.C., Hinrichs, E.N., and Luedke, R.G., 1957c, Preliminary geologic map of the Loa 4 NE [Government Point] quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Field Studies Map MF-102, 1 plate, scale 1:24,000.

Smith, T.L., Huff, L.C., Hinrichs, E.N., and Luedke, R.G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geological Survey Professional Paper 363, 102 p., 1 plate, scale 1:62,500.

Sprinkel, D.A., Doelling, H.H., Kowallis, B.J., Waanders, G., and Kuehne, P.A., 2011a, Early results of a study of Middle Jurassic strata in the Sevier fold and thrust belt, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 151–172.

Sprinkel, D.A., Kowallis, B.J., and Jensen, P.H., 2011b, Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 131–149.

Steven, T.A., Cunningham, C.G., Naeser, C.W., and Mehnert, H.H., 1979, Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S. Geological Survey Bulletin 1469, 40 p.

Steven, T.A., Rowley, P.D., and Cunningham, C.G., 1984, Calderas of the Marysvale volcanic field, west-central Utah: Journal of Geophysical Research, v. 89, no. B10, p. 8751–8764.

Utah Geological Survey and Nevada Isotope Geochronology Laboratory, 2012, $^{40}Ar/^{39}Ar$ geochronology results for the Forsyth Reservoir, Hilgard Mountain, and Mount Terrill quadrangles, Utah: Utah Geological Survey Open-File Report 594, variously paginated: Online, https://ugspub.nr.utah.gov/publications/open_file_reports/ofr-594.pdf.

Utah Geological Survey and New Mexico Geochronology Research Laboratory, 2007, $^{40}Ar/^{39}Ar$ geochronology results for the Soldiers Pass, Granite Peak, Granite Peak SE, Camels Back Ridge NE, Flat Top, Blind Lake, and Deer Creek Lake quadrangles, Utah: Utah Geological Survey Open-File Report 504, variously paginated: Online, https://ugspub.nr.utah.gov/publications/open_file_reports/ofr-504.pdf.

Utah Geological Survey and New Mexico Geochronology Research Laboratory, 2009, $^{40}Ar/^{39}Ar$ geochronology results for the Blind Lake, Deer Creek Lake, Flat Top, Henrie Knolls, Tabbys Peak, Tabbys Peak SW, Wig Mountain, and Wig Mountain NE quadrangles, Utah: Utah Geological Survey Open-File Report 547, variously paginated: Online, https://ugspub.nr.utah.gov/publications/open_file_reports/OFR-547.pdf.

Williams, P.L., and Hackman, R.J., 1971, Geology, structure, and uranium deposits of the Salina quadrangle, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-591, 2 plates, scale 1:250,000.

Willis, G.C., 1988, Geologic map of the Aurora quadrangle, Sevier County, Utah: Utah Geological and Mineral Survey Map 112, 20 p., scale 1:24,000.

Willis, G.C., and Doelling, H.H., in preparation, Interim geologic map of the Burrville quadrangle, Sevier County, Utah: Utah Geological Survey Open-File Report, scale 1:24,000.