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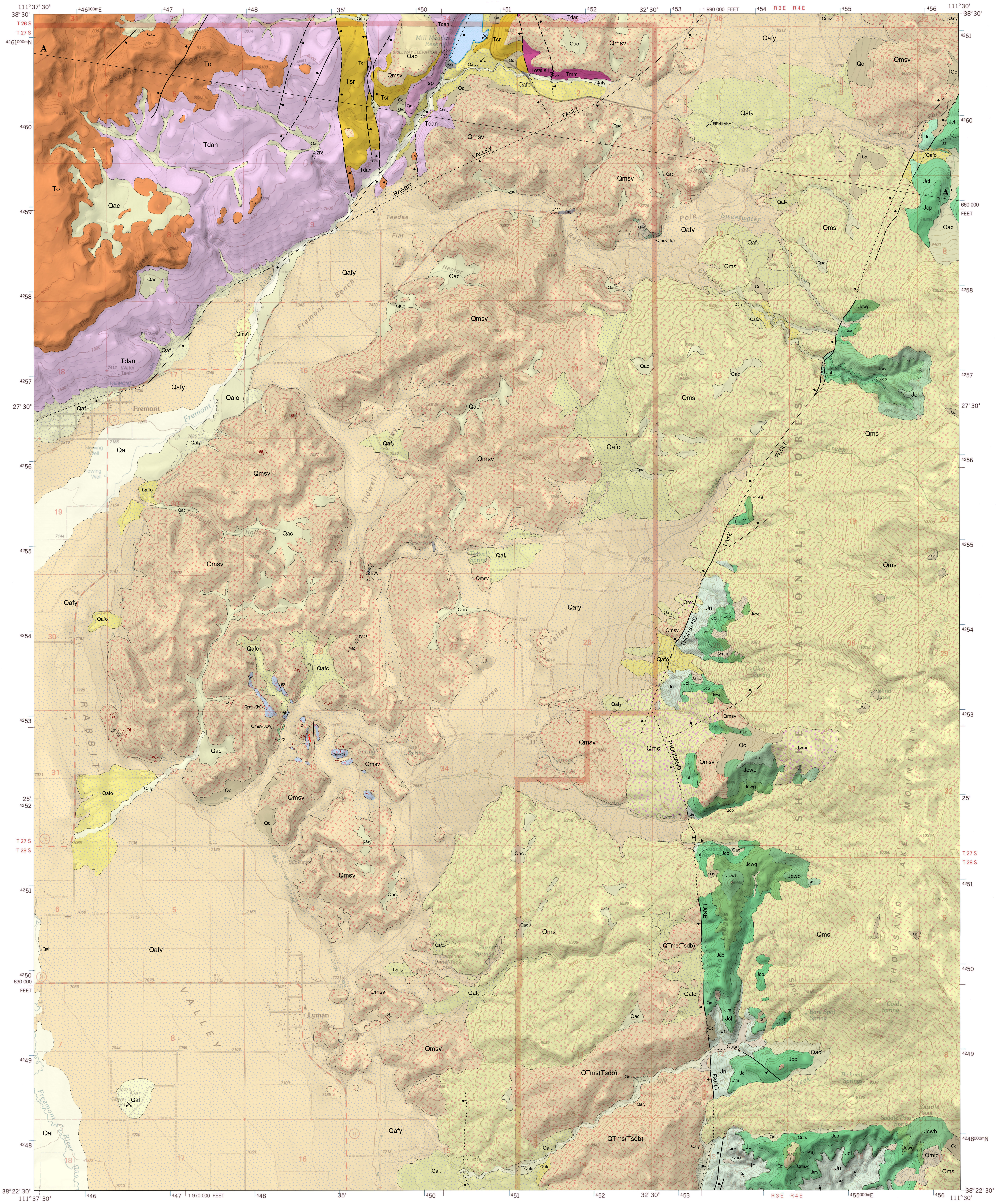
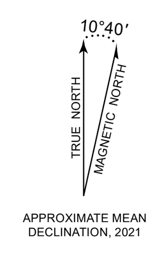




APPROXIMATE MEAN DECLINATION, 2021

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

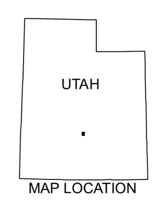
CONTOUR INTERVAL 40 FEET

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]

2021

[1]Utah Geological Survey, Salt Lake City, Utah
[2]College of William and Mary, Department of Geology, Williamsburg, Virginia



MAP LOCATION

Base from USGS Lyman 7.5′ Quadrangle (2001)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1927

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

Utah Geological Survey
1594 West North Temple, Suite 3110
Salt Lake City, UT 84116
(801) 537-3300
https://geology.utah.gov

https://doi.org/10.34191/M-288DM

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

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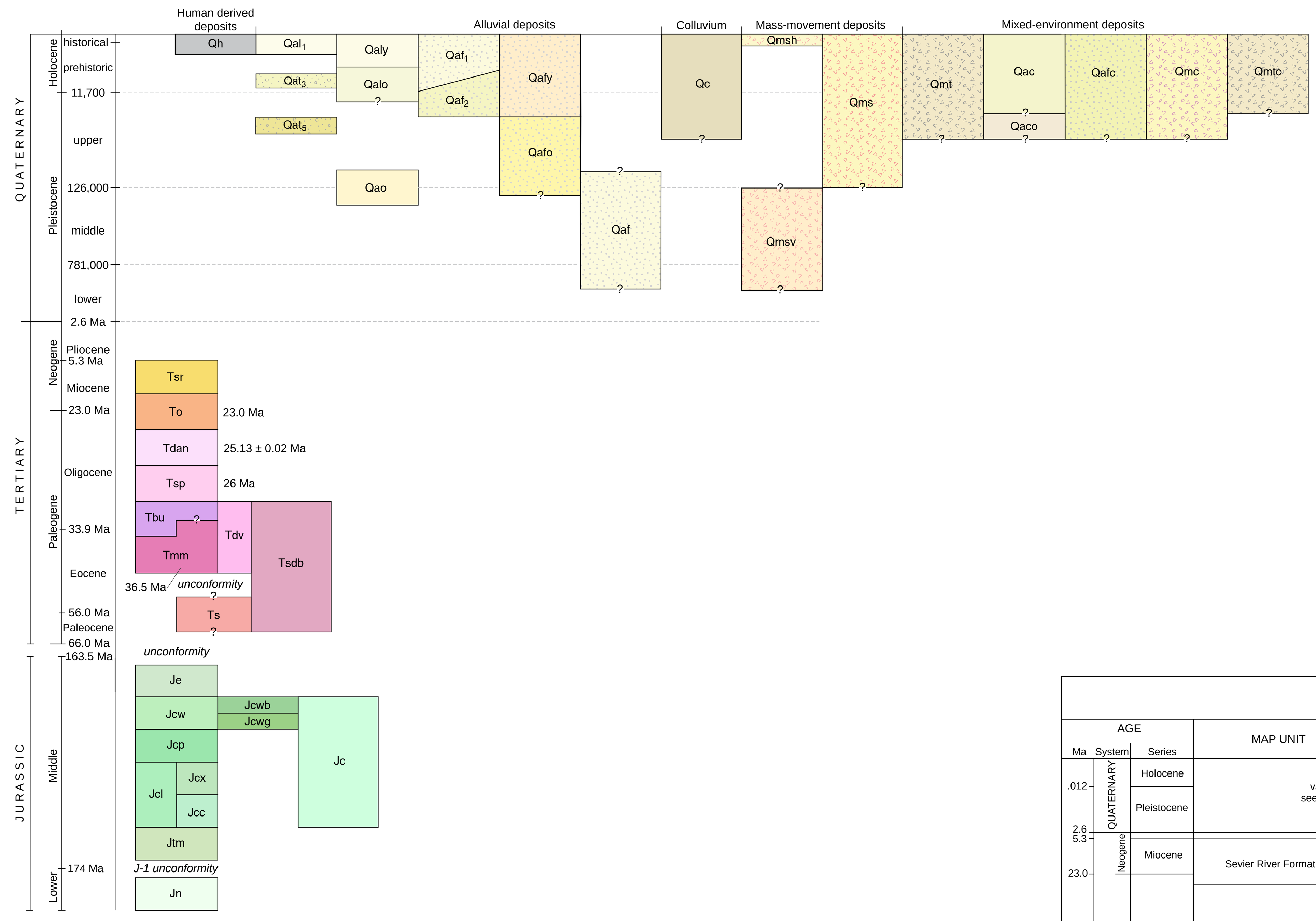
MAP UNITS

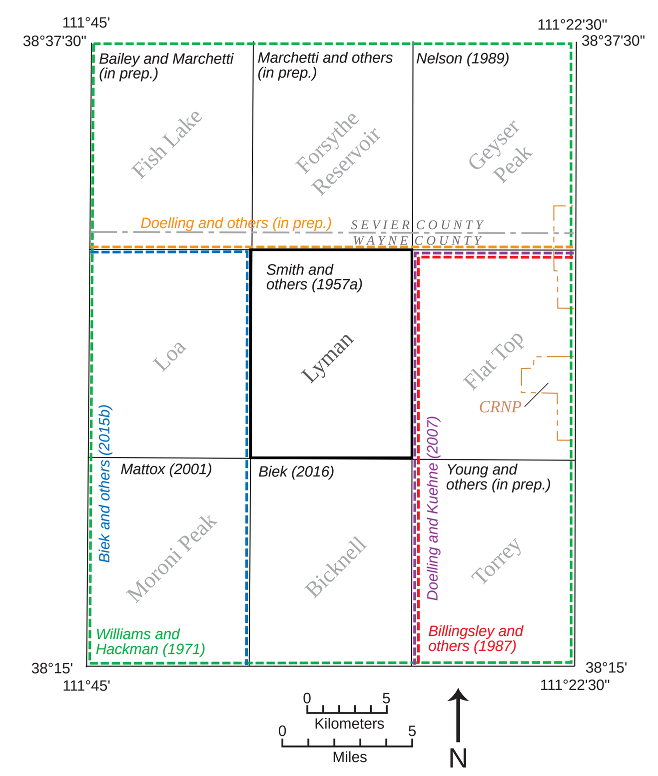
- Qh — Artificial fill
- Qal_1 — Modern stream alluvium
- Qat_3 — Stream-terrace alluvium, level 3
- Qat_5 — Stream-terrace alluvium, level 5
- Qaly — Young stream alluvium
- Qalo — Old stream alluvium
- Qao — Old alluvial deposits
- Qaf_1 — Young fan alluvium
- Qaf_2 — Middle fan alluvium
- Qafy — Young and middle fan alluvium, undivided
- Qafo — Old fan alluvium
- Qaf — Fan alluvium
- Qc — Colluvium
- Qms — Landslides
- Qms? — Landslides?
- Qmsh — Landslides
- Qmsv — Landslide of Rabbit Valley
- Qmsv (Je) — Landslide of Rabbit Valley (Entrada Sandstone component)
- Qmsv (Jcw) — Landslide of Rabbit Valley (Winsor Member of Carmel Formation component)
- Qmsv (ls) — Landslide of Rabbit Valley (limestone component)
- Qmt — Talus
- Qac — Alluvium and colluvium
- Qaco — Older alluvium and colluvium
- Qafc — Fan alluvium and colluvium
- Qmc — Landslides and colluvium
- Qmtc — Talus and colluvium
- QTms (Tsdb) — Older landslide deposits of Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of Bullion Canyon Volcanics
- Tsr — Sevier River Formation
- Tvs — Tertiary volcanic and sedimentary rocks, undivided
- Tvos — Older Tertiary volcanic and sedimentary rocks, undivided
- To — Osiris Tuff
- Tdan — Antimony Tuff Member of Mount Dutton Formation
- Tsp — Volcanic rocks of Signal Peak
- Tbu — Bullion Canyon Volcanics, undivided
- Tmm — Volcanic rocks of Mill Meadow Reservoir
- Tmm? — Volcanic rocks of Mill Meadow Reservoir?
- Tsdb — Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of Bullion Canyon Volcanics, undivided
- Tdv — Dipping Vat Formation
- Ts — Tertiary sedimentary strata
- Je — Entrada Sandstone
- Jc — Carmel Formation, undivided
- Jcw — Winsor Member of Carmel Formation
- Jcwb — Banded subunit of Winsor Member of Carmel Formation
- Jcwg — Gypsiferous subunit of Winsor Member of Carmel Formation
- Jcp — Paria River Member of Carmel Formation
- Jcl — Crystal Creek and Co-op Creek Limestone Members of Carmel Formation, undivided
- Jcx — Crystal Creek Member of Carmel Formation
- Jcc — Co-op Creek Limestone Member of Carmel Formation
- Jtm — Manganese Wash Member of Temple Cap Formation
- Jn — Navajo Sandstone
- Jk — Kayenta Formation
- JŦw — Wingate Sandstone
- Ŧc — Chinle Formation, undivided
- Ŧm — Moenkopi Formation, undivided

CORRELATION OF MAP UNITS

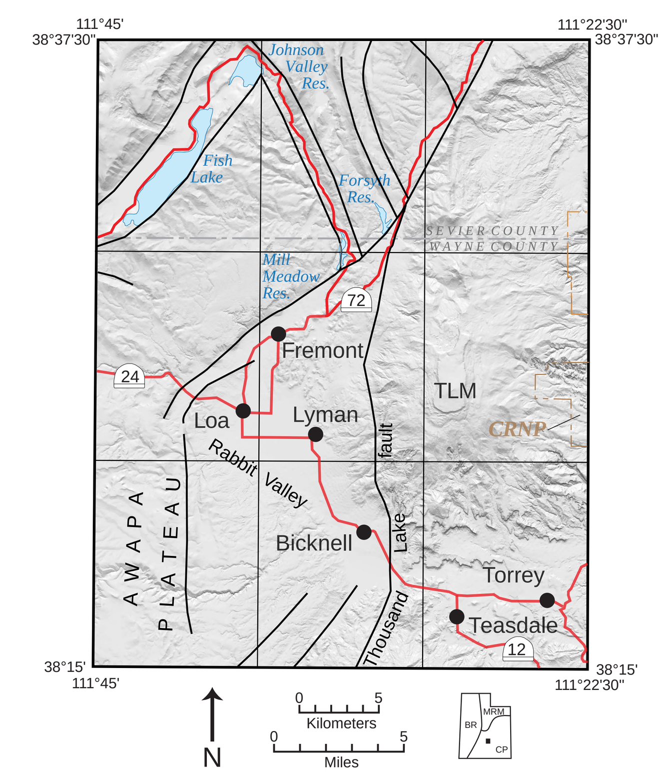


MAP SYMBOLS

- Contact – dashed where approximately located
- Normal fault – dashed where approximately located, dotted where concealed; bar and ball on down-dropped side
- Fault, unknown type – well located
- Clastic dike – well located (Bartram, 2014)
- Strike and dip of bedding; red symbols are from Bartram (2014)
- 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, tephrochronology
- A — A' — Line of cross section



U.S. 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. Heavy black lines are major, potentially active faults. Map of Utah shows physiographic provinces: BR, Basin and Range; MRM, Middle Rocky Mountains; CP, Colorado Plateau.

STRATIGRAPHIC COLUMN

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	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		Pleistocene							unconformity
5.3 – 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	
	TERTIARY, Paleogene	Oligocene	Osiris Tuff	To	300+ (90+)	Calc-alkaline volcanism, development of clustered stratovolcanoes and calderas in southwest Utah from about 37 to 14 Ma; Marysvale volcanic field and intermontane basins	ash-flow tuff from Monroe Peak caldera	densely welded rhyodacite ash-flow tuff	23.0 Ma
			Antimony Tuff Member of the Mount Dutton Formation	Tdan	400+ (120+)		ash-flow tuff from unknown vent	densely welded crystal-poor trachyte ash-flow tuff	25.13 ± 0.02 Ma
			volcanic rocks of Signal Peak	Tsp	200+ (60+)		lava flows from unknown vents	latitic lava flows	26 Ma
			Bullion Canyon Volcanics	Tbu			vent and alluvial facies of stratovolcanoes	lava flows and volcanic mudflow breccia	
33.9		Eocene	volcanic rocks of Mill Meadow Reservoir	Tmm	100+ (30+)				Tdv 29–36 Ma; Tmm 36.5 Ma
			Dipping Vat Formation	Tdv	100+ (30+)		local volcanic sediments deposited in low-relief river and lake basins	volcaniclastic sandstone, siltstone, mudstone and conglomerate	
				Tsdb	900+ (275+)				Tsdb part of large landslides; unconformity
56.0 – 66.0		Paleocene	Tertiary sedimentary strata	Ts	400? (120?)	Foreland basin	intermontane basin	conglomerate, mudstone, limestone	unconformity
163.5	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	
			Carmel Formation, Winsor Mbr., gypsiferous subunit	Jcwg	200 (60)				
			Carmel Formation, Paria River Mbr.	Jcp	150–200 (45–60)		restricted shallow marine	micritic limestone, gypsum, shale	166 Ma
			Carmel Formation, Crystal Creek Mbr.	Jcl; Jcx	200 (60)		coastal sabkha and tidal flat	mudstone, siltstone	167 Ma
			Carmel Formation, 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

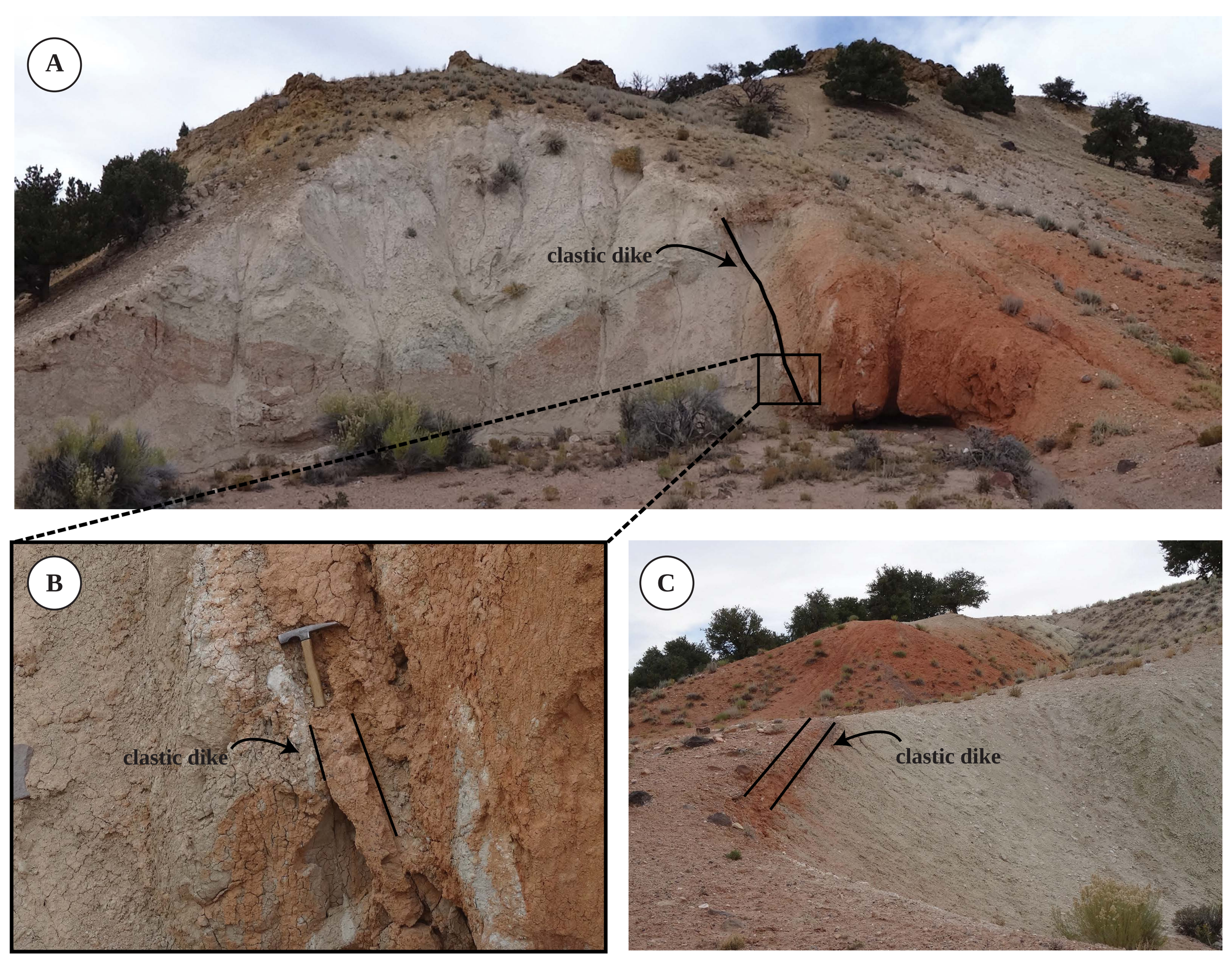
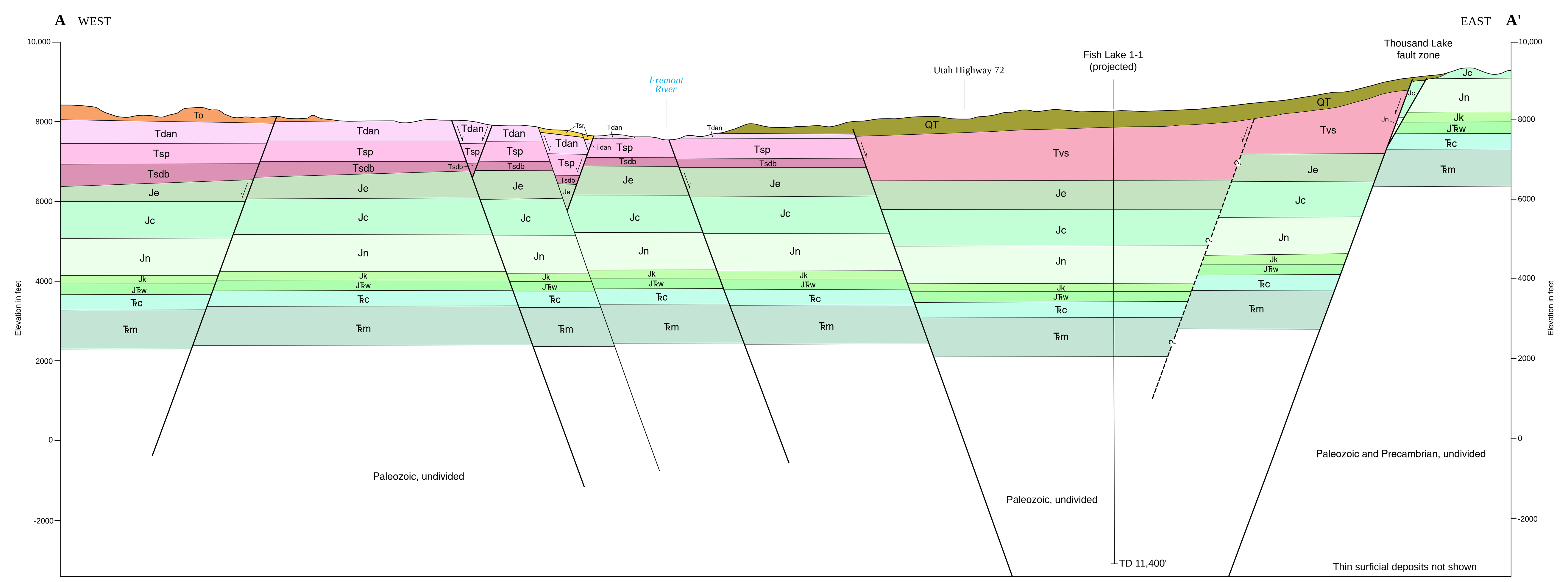


Figure 1. ***A.*** *View north to clastic dike in the north-central part of section 33, T. 27 S., R. 3 E. (UTM NAD83 coordinates 448619E, 4252940N). The dike is about 6 inches (15 cm) wide and consists of subrounded pebbles and granules of the volcanic rocks of Signal Peak and Antimony Tuff Member in a moderately indurated, yellow-brown muddy matrix. It is oriented N15ºW, dips 65ºE, 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. The dike is evidence of overpressured fluids at the base of the landslide of Rabbit Valley (Qmsv).*



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MAP 288DM
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2021

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UTAH GEOLOGICAL SURVEY
contact
1594 W. North Temple, Suite 3110
Salt Lake City, UT 84116
telephone: 801-537-3300
website: geology.utah.gov

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[2]College of William & Mary, Department of Geology, Williamsburg, Virginia

Cover photo: *View southwest across Rabbit Valley and the small town of Loa; Utah Highway 24 traverses the east flank of the Awapa Plateau in the middle distance. Hummocky terrain in the north end of Rabbit Valley is part of an enormous landslide complex about 25 mi² (65 km²) in size shed off the west flank of Thousand Lake Mountain. The landslide is several hundred feet thick and traveled 4 miles (6.5 km) across the valley floor; it may be as young as about 500,000 years old.*

Suggested citation:

Biek, R.F., Bartram, H., Fleming, Z., Wenrich, E., Bailey, C., and Steele, P., 2021, Geologic map of the Lyman quadrangle, Wayne County, Utah: Utah Geological Survey Map 288DM, 15 p., 2 plates, scale 1:24,000, https://doi.org/10.34191/M-288DM.

MAP 288DM
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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 (alluvial deposits of intervening terrace levels Qat_2 and Qat_4 are not present, but are mapped in the adjacent Bicknell quadrangle [Biek, 2016, 2021]); 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 Pleistocene) – 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 3He exposure ages of 520 ± 77 ka and 735 ± 111 ka for pyroxene from two boulders of the volcanic rocks of Signal Peak (their 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 Antimony Tuff Member 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 **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 in Rabbit Valley and other small hills in nearby southern Rabbit Valley; lacks fan morphology and the location of map unit in the 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).

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; Biek and others, in preparation]) 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 readily apparent when viewed in aerial imagery, and they contrast markedly from areas where this stratigraphic interval is unaffected by mass-movement processes. Thus, much of the east part of this quadrangle is here mapped as landslide deposits (Qms, Qmsv). Near the south 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 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 300 feet (90 m) of Thousand Lake Mountain and the uppermost 820 feet (245 m) or more of Boulder Mountain are concealed by mass-movement and local glacial deposits. 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 the Loa 30' x 60' quadrangle (Biek and others, 2015b), and its mostly coeval twin the Dipping Vat Formation is present in fault blocks east of Bicknell. We suspect that such landslide-susceptible strata underlie the resistant caprock of Thousand Lake Mountain. The Winsor Member of the Carmel Formation also likely provides landslide-susceptible material. Interestingly, neither older Carmel strata nor Navajo Sandstone debris is present in these landslide deposits.

Qms, Qmsh, Qms?

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, 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); 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 covered 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 volcanic rocks of Signal Peak, which caps nearby 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 (we map one such "fault" east of the clastic dike and interpret it as a result of landslide movement, not later tectonic faulting) (figure 1 on plate 2), (2) to the west along the high line ditch, where folds and thrust faults are present in white, mostly fine-grained, tuffaceous strata likely of the Dipping Vat Formation, and (3) in road cuts west of Tidwell Reservoir where tilted and faulted, fine-grained tuffaceous strata and quartzite-pebble conglomerate are juxtaposed against shattered volcanic rocks of Signal Peak. Remnants of the landslide of Rabbit Valley are present on the footwall of the Thousand Lake fault near Cedar Creek. The landslide of Rabbit Valley, derived from the west flank of Thousand Lake Mountain, forms the Rabbit Valley salient of Bartram and others (2014).

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.

Qmc **Landslides and colluvium** (Holocene to upper Pleistocene) – Unsorted, locally derived, clay- to boulder-size sediment 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/ 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 between Lyman and 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 mistakenly lumped in with the much younger landslide of Rabbit Valley (Qmsv); the description below is largely based on better exposures in the adjacent Bicknell quadrangle (Biek, 2016, 2021); 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 south of Trail Creek, 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 northeast flank of the Marysvale volcanic field. In the adjacent Bicknell quadrangle, 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 charophytes *Harrisichara tuberculate*, *Sphaerochara aff. Major*, and *Hornichara* also reported from the Brian Head Formation (Jeff Eaton, Weber State University, Emeritus, written communication, May 24, 2016). Coarse-grained facies are pebble-to-boulder sandstone and conglomerate of possible Sevier River Formation affinity (or possibly of the older Bullion Canyon Volcanics).

In the adjacent Bicknell quadrangle, map unit locally contains poorly exposed reddish-brown mudstone, yellowish-brown sandy and micritic limestone, and quartzite- and chert-pebble conglomerate, and medium- to coarse-grained "salt and pepper" sandstone of uncertain age and correlation (Biek, 2021). Such beds 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). 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.

TERTIARY

Tsr **Sevier River Formation** (Miocene) – Moderately to poorly consolidated, light-gray and grayish-brown 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, 1986a); 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, which 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. Biek and others (in preparation) obtained a detrital zircon age of about 20 Ma for their 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 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. 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—basins that bear no relationship to the modern topography.

Tvs **Tertiary volcanic and sedimentary rocks, undivided** (Miocene to Eocene) – Subsurface only.

Tvos **Older Tertiary volcanic and sedimentary rocks, undivided** (upper Oligocene to Eocene) – Subsurface 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; Ball and others, 2009; UGS and NMGRL, 2019; Willis and Doelling, 2019; T. Rivera, written communication, June 18, 2019); forms the uppermost widespread volcanic unit on the Awapa Plateau and is locally overlain by 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).

Tdan **Antimony Tuff Member of Mount Dutton Formation** (upper Oligocene) – Gray, densely welded, phenocryst-poor, trachyte ash-flow tuff with 5% to 15% phenocrysts of plagioclase, subordinate but conspicuous sanidine, and sparse pyroxene 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 inconspicuous and rarely exposed; mapped in the northwest corner of the quadrangle where it disconformably overlies volcanic rocks of Signal Peak and is commonly concealed beneath unmapped colluvium and regolith of variable thickness; 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; see also Mattox, 1991, 2001) and subsequently identified as an ash-flow tuff (Anderson and Rowley [1975], who named it the Antimony Tuff Member; Ball and others [2009] called it the trachyte of Lake Creek); major- and trace-element discrimination diagrams of the Antimony Tuff Member (and of samples identified as trachyte of Lake Creek and tuff of Albinus Canyon elsewhere on the Awapa, Fish Lake, and Sevier Plateaus) cluster remarkably tightly; 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 tuff of Lake Creek (our Antimony Tuff Member) on the Fish Lake Plateau; T. Rivera (written communication, June 18, 2019; see also Holiday and others, 2019) obtained an age of 25.11 ± 0.06 Ma (sanidine) for the Antimony Tuff Member at the east entrance to Kingston Canyon immediately west of Otter Creek Reservoir; 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.

The Antimony Tuff Member was informally called the trachyte of Lake Creek by Bailey and others (2007) in their initial mapping of the Fish Lake Plateau. Concurrent and subsequent mapping by Biek and others (2015b), Kuehne and Doelling (2016), Willis and Doelling (2019), and Doelling and others (in preparation) carried this nomenclature into nearby areas. However, further research suggests that the trachyte of Lake Creek is the same as the Antimony Tuff Member of the Mount Dutton Formation, previously defined as a densely welded ash-flow tuff intertongued within the upper part of the Mount Dutton Formation (Anderson and Rowley, 1975). Given precedence of this earlier name, we abandon the informal name trachyte of Lake Creek in favor of the formally named Antimony Tuff Member.

Rocks petrographically and lithologically like the Antimony Tuff Member are known by a variety of names on the Awapa, Fish Lake, and Sevier Plateaus. The stratigraphic position, age, petrography, and geochemistry of the densely welded, phenocryst-poor trachyte Antimony Tuff Member is similar to that of the tuff of Albinus Canyon in the northern Marysvale field (Steven and others, 1979; Cunningham and others, 1983; Willis and Doelling, 2019), the comparatively thin Kingston Canyon Tuff Member of the Mount Dutton Formation on the Sevier Plateau (Anderson and Rowley, 1975), and to that of the flows of Deer Spring Draw in the northeast part of the Marysvale field (Nelson, 1989). Concerning the tuff of Albinus Canyon and others like it, 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[b]) 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."

The vent or vents of these densely welded, high-temperature, rheomorphic 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). New detrital zircon geochronology further supports a hypothesis that eruption of the Antimony Tuff Member may be temporally linked to emplacement of the Sevier gravity slide (Loffer and others, 2020; see also Biek and others, 2019).

Tsp **Volcanic rocks of Signal Peak** (upper Oligocene) – Gray, weathering to brownish gray, 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 are about 25 to 26 Ma (UGS and NMGRL, 2007, 2009; UGS and NIGL, 2012; Biek and others, in preparation); these rocks overlie newly dated tuff of Albinus Canyon (preliminary weighted mean age of about 25.5 Ma, UGS unpublished data) on the north flank of the Marysvale volcanic field, and underlie the 25.11 Ma Antimony Tuff Member in the east part of the field (Biek and others, in preparation), suggesting that map unit may be older in eastern exposures and span about one million years of time); mapped west of Mill Meadow Reservoir, and also forms the cap of nearby Thousand Lake Mountain; incomplete exposures are at least 200 feet (60 m) thick in this quadrangle; 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; this unit is about 600 feet (200 m) thick along the south flank of Boulder Mountain (Biek and others, in preparation).

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, 2021), Biek and others (2015b, 2017), Kuehne and Doelling (2016), and Willis and Doelling (2019) carried this nomenclature into nearby areas. However, further research suggests that these are the same rocks mapped by Cunningham and others (1983), Rowley and others (1986b, 2002), and Hintze and others (2008) where they were informally named volcanic rocks of Signal Peak and thought to be mostly vent facies (lava flows) 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 any ash-flow tuff 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.

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 (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); 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, 2021).

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 Antimony Tuff Member; 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).

Tsdb **Tertiary sedimentary strata, Dipping Vat Formation, and Three Creeks Tuff Member of 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).

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; 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, 2021); thickness uncertain but probably greater than 100 feet (30 m).

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 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 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 (see, for example, 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 since 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 (UGS, unpublished data). Numerous isotopic ages on the Brian Head Formation show it to be 37 to 30 Ma (Biek and others, 2015a). East of Bicknell, Dipping Vat strata yielded three teeth of *Saltirius utahensis* (stingray) only known from the variegated unit of the Brian Head Formation (Jeff Eaton, written communication, May 24, 2016).

unconformity

Ts **Tertiary sedimentary strata** (middle Eocene? to Paleocene?) – Reddish-brown mudstone, yellowish-brown, 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, 2021); 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; 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); 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 on 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 of Carmel Formation** (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 [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; map patterns indicate a thickness of about 300 feet (90 m); nearly complete 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 of Carmel Formation** (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 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 of Carmel Formation, 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 of Carmel Formation** (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 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); 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 of Carmel Formation** (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 persistent 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 southwestern 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 of Temple Cap Formation** (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 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 southwestern 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 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) – Subsurface only. About 200 feet (60 m) thick on the southwest flank of Thousand Lake Mountain (Biek, 2016, 2021).

JURASSIC-TRIASSIC

JꞦw **Wingate Sandstone** (Lower Jurassic to Upper Triassic) – Subsurface only. About 250 feet (75 m) thick on the southwest flank of Thousand Lake Mountain (Biek, 2016, 2021).

TR-5 unconformity

TRIASSIC

Ꞧc **Chinle Formation, undivided** (Upper Triassic, Norian and Rhaetian) – Subsurface 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 million years during late Middle and early Late Triassic time (e.g., Kirkland and others, 2014).

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

ACKNOWLEDGMENTS

This geologic map is part of an effort to map the west half of the Loa 30' x 60' quadrangle. It revises mapping conducted by undergraduate students (Hanna Bartram, Zachariah Fleming, Erika Wenrich, and Peter Steele) at the College of William & Mary under the direction of Christopher Bailey—thanks to all of them for sharing their unpublished work. Grant Willis (UGS), Hellmut Doelling (UGS, retired), Paul Kuehne (former UGS), Chuck Bailey (College of William & Mary), and Dave Marchetti (Western State Colorado University) shared their knowledge of the geology of the nearby Fish Lake Plateau. Doug Sprinkel (UGS) and Hellmut Doelling (UGS, retired) provided an unpublished measured section of Temple Cap and Carmel strata on Black Ridge, and Doug also reinterpreted selected formation tops for the Fish Lake 1-1 exploration well in the northeast part of the map area. Jeff Eaton (Weber State University, retired) sampled and worked to identify microfossils from fine-grained strata in fault blocks near Bicknell, and north of Loa, just west of this map area, which may shed light on the age of landslide deposits in Rabbit Valley. Colleagues Grant Willis, Stephanie Carney, and Mike Hylland (UGS) reviewed the map and supporting materials, and we are grateful for their collective wisdom. Thanks to Basia Matyjasik (UGS), who created the ArcGIS files, and to Lori Steadman (UGS), who drafted plate 2 figures.

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