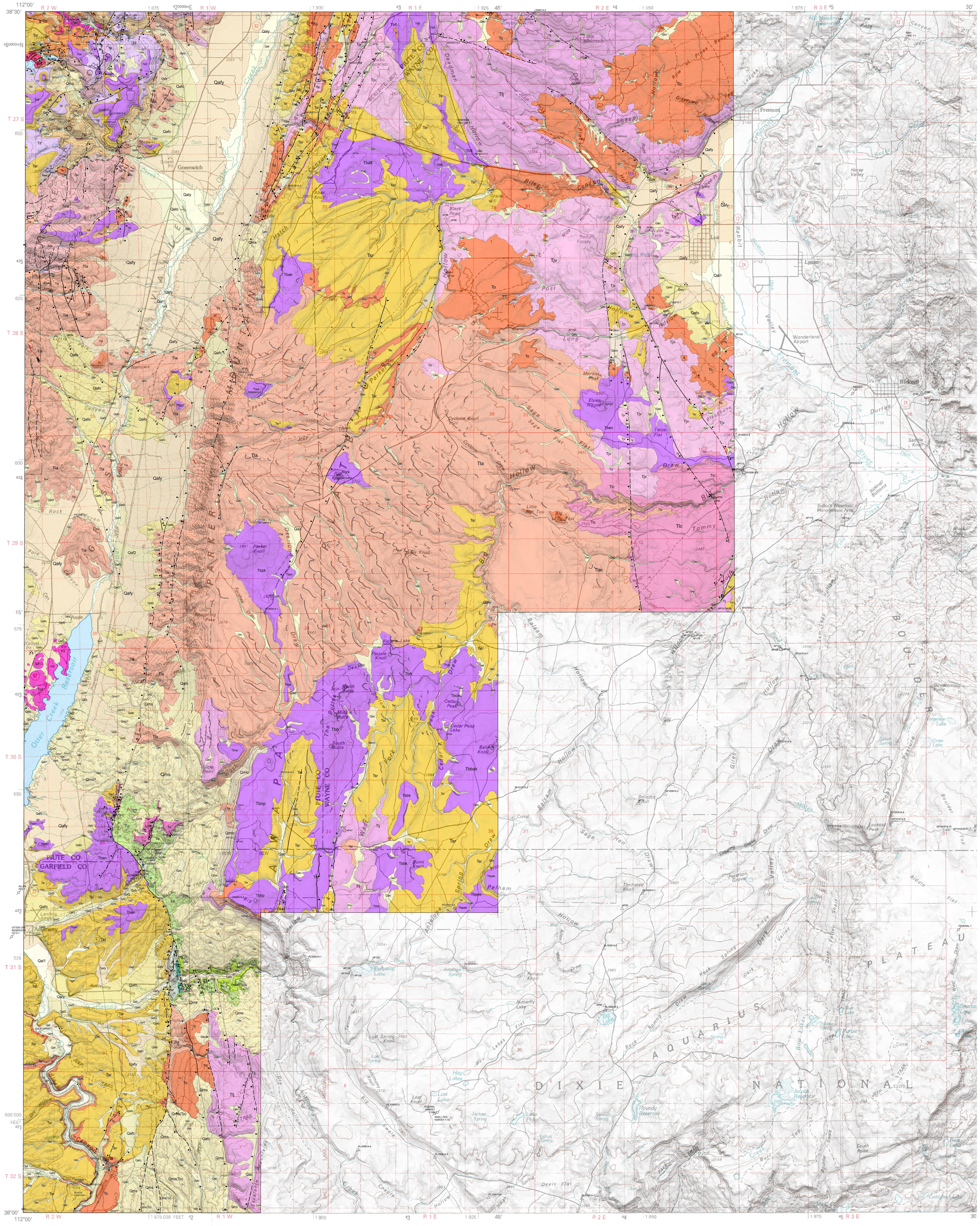

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

INTERIM GEOLOGIC MAP OF THE WESTERN LOA 30' X 60' QUADRANGLE, GARFIELD, PIUTE, AND WAYNE COUNTIES, UTAH (YEAR 2)

2015

by

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SCALE 1:62,500

1 0.5 0 1 2 3 4 MILES

1 0.5 0 1 2 3 4 5 6 KILOMETERS

CONTOUR INTERVAL 20 METERS

UTAH

MAP LOCATION

APPROXIMATE MEAN DECLINATION, 2015

Disclaimer

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This map is a plot of geographic information system (GIS) files created to visually represent the content of the GIS data files. It is not a published map and it contains many features that do not meet UGS cartographic standards, such as automatically generated labels that may overlap other labels and lines.

Base from USGS Loa 30' x 60' Quadrangle (1980)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Project Manager: Paul A. Kuehne

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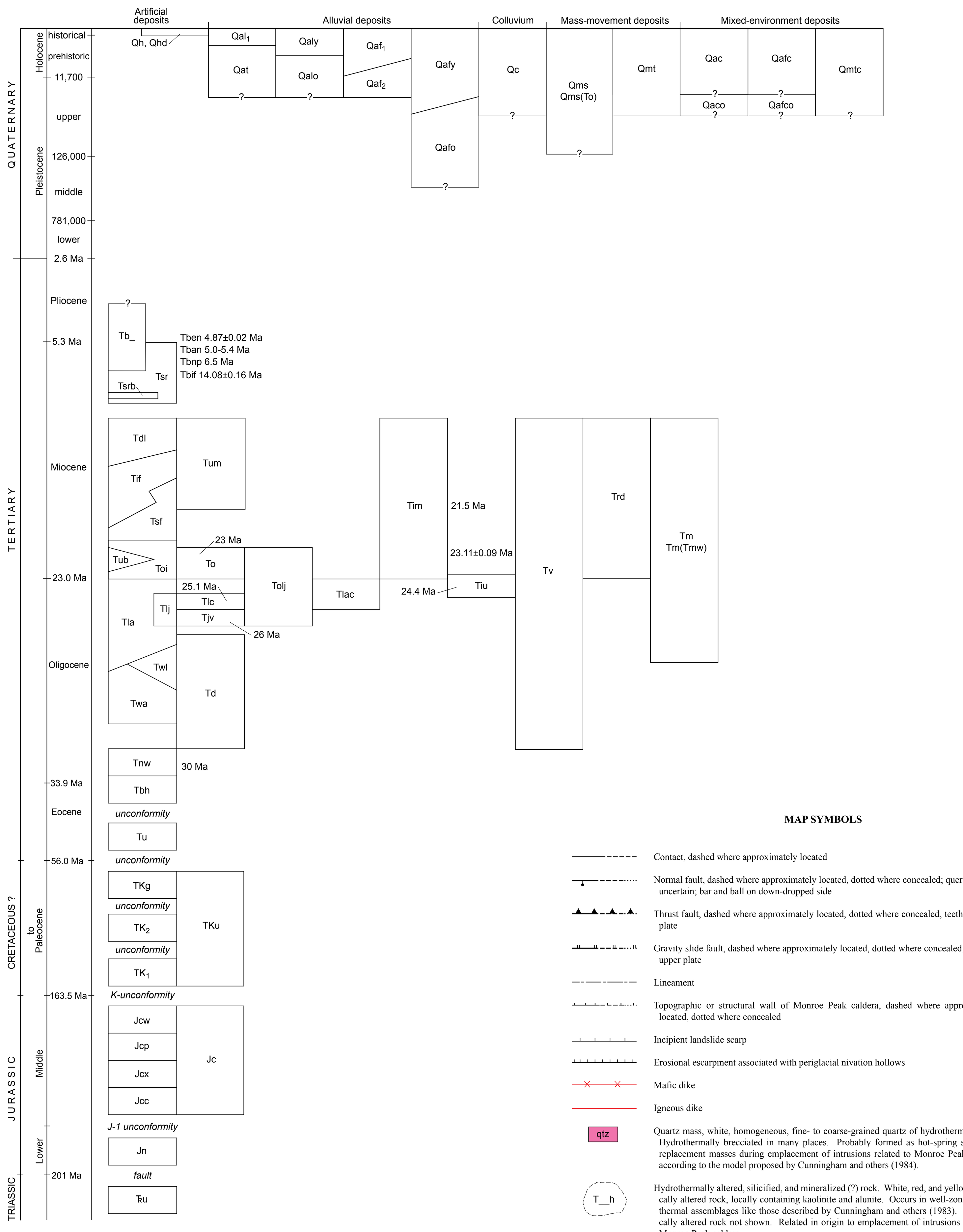
CORRELATION OF MAP UNITS



NOTE: The letter "h" at the end of a map unit symbol in the Greenwich 7.5' quadrangle denotes hydrothermally altered, silicified, and mineralized(?) rock.

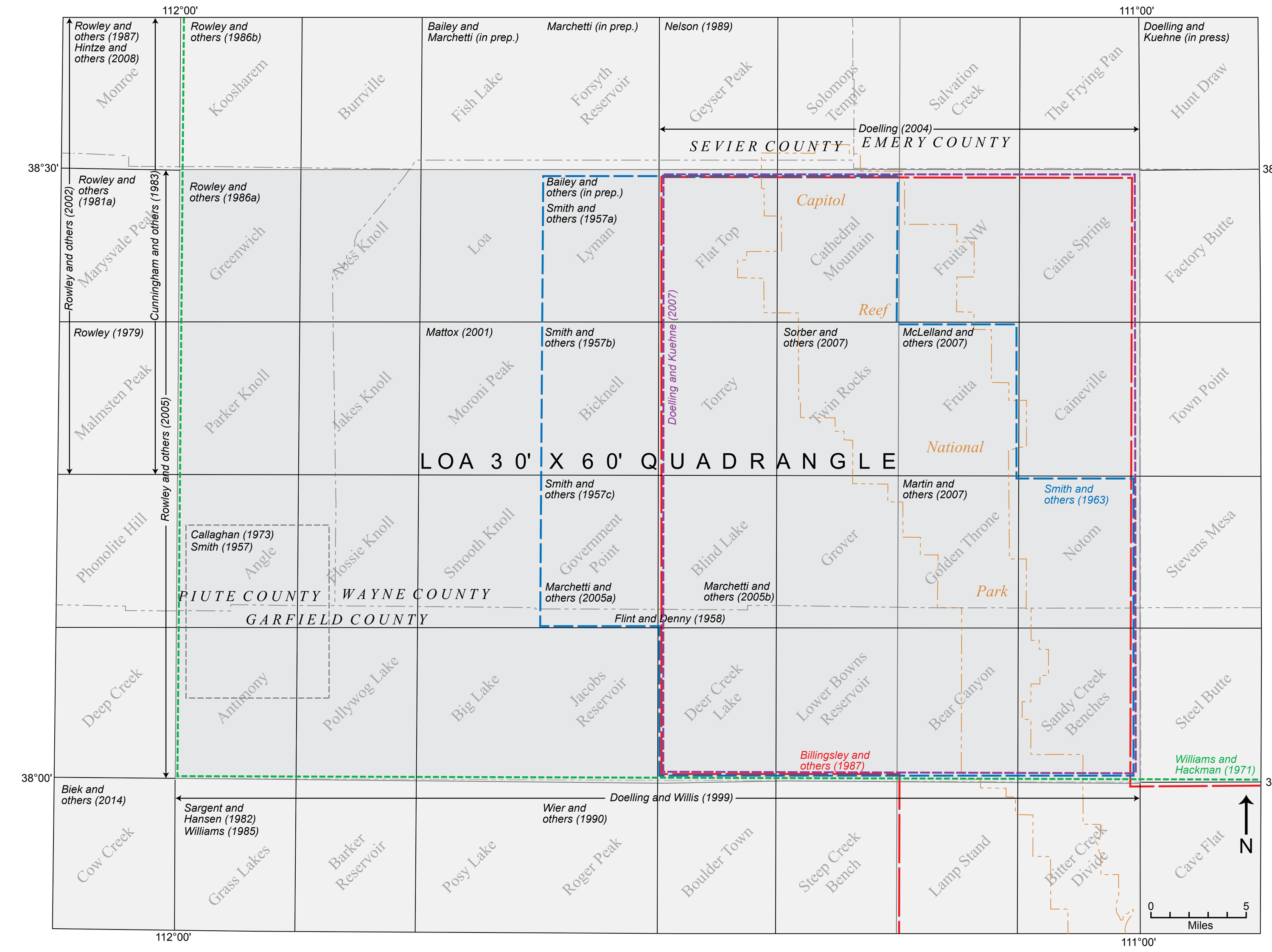
MAP SYMBOLS

- Contact, dashed where approximately located
- Normal fault, dashed where approximately located, dotted where concealed, queried where uncertain; bar and ball on down-dropped side
- Thrust fault, dashed where approximately located, dotted where concealed, teeth on upper plate
- Gravity slide fault, dashed where approximately located, dotted where concealed; barbs on upper plate
- Lineament
- Topographic or structural wall of Monroe Peak caldera, dashed where approximately located, dotted where concealed
- Incipient landslide scarp
- Erosional escarpment associated with periglacial nivation hollows
- Mafic dike
- Igneous dike
- qtz — Quartz mass, white, homogeneous, fine- to coarse-grained quartz of hydrothermal origin. Hydrothermally brecciated in many places. Probably formed as hot-spring sinter and replacement masses during emplacement of intrusions related to Monroe Peak caldera, according to the model proposed by Cunningham and others (1984).
- T__h — Hydrothermally altered, silicified, and mineralized(?) rock. White, red, and yellow, argillically altered rock, locally containing kaolinite and alunite. Occurs in well-zoned hydrothermal assemblages like those described by Cunningham and others (1983). Propylitically altered rock not shown. Related in origin to emplacement of intrusions related to Monroe Peak caldera.
- Strike and dip of bedding
- Horizontal bedding
- Strike and dip of flow foliation
- Strike of vertical flow foliation
- Strike of vertical joint
- Sand and gravel pit
- Quarry
- Prospect, most not shown in Antimony Canyon
- Adit
- Prospect trench
- Volcanic vent
- Spring
- Sample location and number

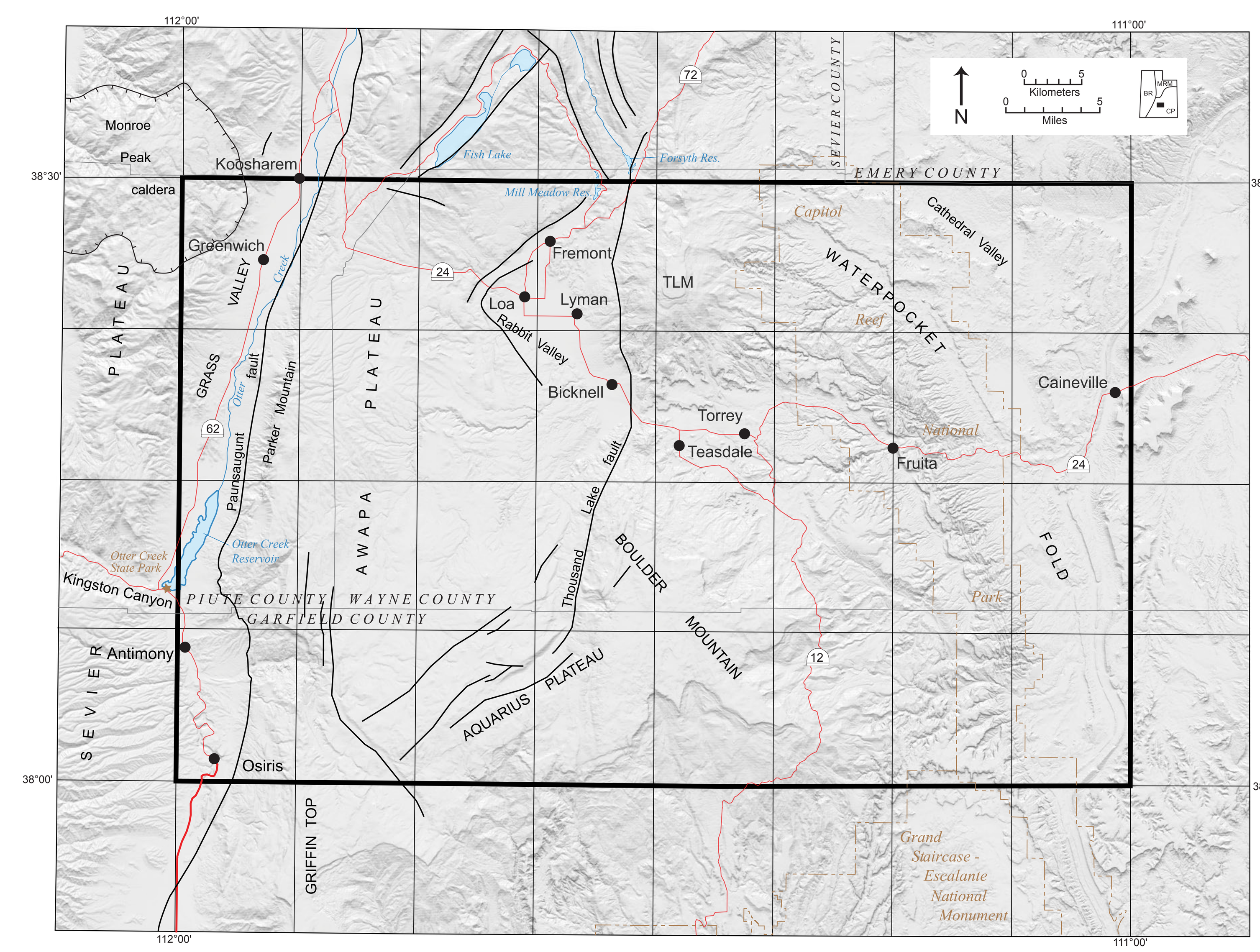
Table 1. Isotopic ages of volcanic rocks, Loa 30' x 60' quadrangle and nearby area.

Lava Flow or Formation	Map Symbol	Sample number	K-Ar age (Ma)	U/Pb (Ma)	$^{40}Ar/^{39}Ar$ age (Ma)	Mineral	7.5' Quadrangle	Easting, NAD83	Northing, NAD83	Lab used	Reference
basaltic lava flows of Antimony	Tban	hpl-5	5.4 ± 0.4			whole rock	Angle	417510	4221629	U.S. Geological Survey	Best and others (1980)
basaltic lava flows of Antimony	Tban	pan-27	5.0 ± 0.3			whole rock	Angle	412509	4223669	U.S. Geological Survey	Best and others (1980)
basaltic andesite	Tba	AP99	23.2 ± 1.5			plagioclase	Abes Knoll	432097	4249485	Geochron Lab., Cambridge	Mattox (1991)
basaltic andesite	Tba	AP47	25.2 ± 1.6			plagioclase	Flossie Knoll	427199	4223601	Geochron Lab., Cambridge	Mattox (1991)
basaltic andesite	Tba	AP126	25.8 ± 1.4			plagioclase	Government Point	447436	4231796	Geochron Lab., Cambridge	Mattox (1991)
basaltic lava flow	Tb	FR072108-1			4.98 ± 0.04*	whole rock	Forsyth Reservoir	453591	4263385	NIGL	UGS & NIGL (2012)
basaltic lava flow	***	AP127	5.9 ± 0.6			whole rock	Government Point	448630	4230401	Geochron Lab., Cambridge	Mattox (1991)
basaltic lava flow	Tbif	G100913-3			14.08 ± 0.16*	groundmass concentrate	Greenwich	416694	4256820	NMGRL	this report
basaltic lava flows of Bluebell Knoll	Tbbuk	BT091106-1			3.38 ± 0.19 Ma	groundmass concentrate	Blind Lake	456194	4223360	NMGRL	UGS & NMGRL (2009)
basaltic lava flows of Elsies Nipple	Tben	B100913-6			4.87 ± 0.02	groundmass concentrate	Bicknell	445809	4239973	NMGRL	this report
basaltic lava flows of Elsies Nipple	Tben	AP173	6.9 ± 0.3			feldspar	Bicknell	445479	4240241	Geochron Lab., Cambridge	Mattox (2001)
fluvial and lacustrine strata of Antimony Canyon	Tf	A072514-1		37.58 ± 3.08		zircon	Angle	417932	4222177	GeoSep Services, Moscow, ID	UGS unpublished data
Forshea Mountain rhyolite	Trf	PH042414-1			7.89 ± 0.12 Ma	sanidine	Phonolite Hill	407826	4229638	NMGRL	UGS unpublished data
latite	Tba	AP119	23.1 ± 1.0			sanidine	Smooth Knoll	443380	4232473	Geochron Lab., Cambridge	Mattox (1991)
latite of Johnson Valley?	Tlb***	BM081605-1			25.11 ± 0.17 Ma	plagioclase	Blind Lake	465154	4223856	NMGRL	UGS & NMGRL (2007)
latite of Johnson Valley?	Tlb***	HL091206-2			26.86 ± 0.53 Ma	hornblende	Deer Creek Lake	459504	4215395	NMGRL	UGS & NMGRL (2009)
latite of Johnson Valley?	Tvh***	HH091406-1			25.55 ± 0.11** Ma	plagioclase	Flat Top	458863	4259751	NMGRL	UGS & NMGRL (2009)
latite of Johnson Valley?	Tlf***	FT081505-1			25.95 ± 0.97 Ma	hornblende	Flat Top	458183	4254859	NMGRL	UGS & NMGRL (2007)
Monroe Peak monzonite porphyry	Tim	G100913-7			23.11 ± 0.09*	groundmass concentrate	Greenwich	414699	4261246	NMGRL	this report
basaltic lava flows of Nicks Point	Tbnp	hpl-4	6.5 ± 0.3			whole rock	Angle	422311	4224675	U.S. Geological Survey	Best and others (1980)
breccia pipe of Pine Canyon	Timbp	83-69X			24.4 ± 1.0 Ma	sanidine	Malmsten Peak			U.S. Geological Survey	Rowley and others (1994)
breccia pipe of Pine Canyon	Timbp	83-69X			23.1 ± 0.1 Ma	biotite	Malmsten Peak			U.S. Geological Survey	Rowley and others (1994)
trachyte tuff of Lake Creek?	Tlb***	BM081605-2			25.13 ± 0.10 Ma	plagioclase	Deer Creek Lake	463805	4216172	NMGRL	UGS & NMGRL (2007)
trachyte tuff of Lake Creek?	Tlf***	FT081505-2			22.8 ± 1.1 Ma	hornblende	Flat Top	458847	4254578	NMGRL	UGS & NMGRL (2007)
volcanic rocks of Mill Meadow Reservoir	Tmm	FR071708-1			36.53 ± 0.14*	biotite	Forsyth Reservoir	451626	4261853	NIGL	UGS & NIGL (2012)
potassium-rich mafic lava flow	***	hpl-3	24.5 ± 0.5			whole rock	Burrville	433303	4261967	U.S. Geological Survey	Best and others (1980)
dacite of Lower Box Creek Reservoir	Tdl				22.48 ± 0.04	sanidine	Greenwich			U.S. Geological Survey	L.W. Snee, unpublished data
Osiris Tuff	To				22.81 ± 0.05	sanidine				U.S. Geological Survey	L.W. Snee, unpublished data
Osiris Tuff	To				22.92 ± 0.04	sanidine				U.S. Geological Survey	L.W. Snee, unpublished data

NOTES:
* denotes isochron age; otherwise 40Ar/39Ar age = weighted mean age
** denotes unreliable age due to low radiogenic yield
*** dentoes symbol used on Doelling and Kuehne (2007) or symbol not yet assigned
age uncertainty = 2 standard deviations
NMGRL = New Mexico Geochronology Research Laboratory
NIGL = Nevada Isotope Geochronology Laboratory



U. S. Geological Survey 7.5' quadrangles and principal sources of geologic mapping used in this compilation.



Shaded-relief image of the Loa 30'x60' quadrangle; TLM = Thousand Lake Mountain.

Table 3. Wildcat exploration drill holes in and near the west half of the Loa 30' x 60' quadrangle.

Map ID Number	API Well Number	Operator	Well Name	Spud Date	Year Abandoned	County	7.5' Quadrangle	Qtr/Qtr	Section	Township-Range	Ft. NS*	NS	Ft. EW*	EW	UTM Eastings	UTM Northings	Latitude	Longitude	TD (feet)	KB (feet)	Ground (feet)	Notes
Drill holes in the west half of the Loa 30' x 60' quadrangle																						
1	4301730124	HARVEY M J JR	ANTIMONY FED 6-1	1984	1984	GARFIELD	Angle	SWNE	6	31S-1W	3140	S	2074	E	417757	4221738	38.13976	-111.93851	600		7032	no logs;"Cretaceous" test
2	4301730083	ARCO OIL & GAS COMPANY	BLACK CANYON 1	1980	1981	GARFIELD	Antimony	NWSE	23	32S-2W	1820	S	1975	E	414510	4206894	38.00569	-111.97378	11972	7175		
3	4301730164	CALIFORNIA OIL CO	CALIFORNIA 1	1964	1964	GARFIELD	Antimony	SWSE	28	31S-2W	660	S	1980	E	412963	4214609	38.07507	-111.99234	2439		6500**	no logs
4	4305530036	ARCO OIL & GAS COMPANY	DEADMAN HOLLOW U 1	1984	1985	WAYNE	Abes Knoll	NENW	23	27S-1E	1050	N	2450	W	432635	4256291	38.45237	-111.77204	7922	8302		Dakota and Entrada test
5	4301730073	SAMEDAN OIL CORPORATION	FEDERAL 1	1977	1978	GARFIELD	Jacobs Reservoir	NENE	18	31S-4E	88	N	1871	W	455473	4218982	38.11757	-111.50797	8718		11120	
6	4301730074	SHELL OIL COMPANY	FEDERAL HARVEY 1-10R	1978	1979	GARFIELD	Pollywog Lake	NWNW	10	32S-1E	1289	N	1089	W	431326	4210752	38.04189	-111.78263	8728	9764		Permian-Mississippian oil and gas test
7	4305530030	MARATHON OIL COMPANY	FISH LAKE 1-1	1981	1996	WAYNE	Lyman	NESW	1	27S-3E	1563	S	2214	W	453393	4260135	38.48834	-111.53441	11400	8209		CO2 producer but no market
8	4301730069	SHELL OIL COMPANY	SHELL FED HARVEY 1-10	1975	1982	GARFIELD	Pollywog Lake	SWNW	10	32S-1E	1476	N	633	W	431187	4210695	38.04137	-111.78421	5140		9747	no logs
9	4305530038	BEARD OIL COMPANY	TANNER 1-27	1990	1999	WAYNE	Bicknell	SESE	27	28S-3E	660	S	660	E	450801	4243793	38.34093	-111.56298	7100	7004		CO2 test
Drill holes near the west half of the Loa 30' x 60' quadrangle																						
	4301730118	ARCO OIL & GAS COMPANY	ALLEN FEE 1	1983	1983	GARFIELD	Phonolite Hill	SWSW	3	31S-2W	725	S	505	W	412060	4221069	38.1332	-112.00343	7050		6380	Mississippian oil and gas test
	4303111227	ARCO OIL & GAS COMPANY	ANTIMONY CANYON 1	1965	1966	PIUTE	Phonolite Hill	SENE	30	30S-2W	1590	N	553	E	408471	4225171	38.1698	-112.0449	7296		6351	
	4304130008	MAY PETROLEUM INC	CEDARLESS FLAT 1	1975	1976	SEVIER	Forsyth Reservoir	NESW	28	26S-3E	1592	S	1953	W	448486	4263394	38.51744	-111.59091	unknown		8039	no logs; Mississippian test
	4301730120	RICHARDSON OPERATING CO	CHARGER 1	1983	shut-in	GARFIELD	Roger Peak	SESW	29	32S-3E	720	S	2410	W	447508	4204807	37.9894	-111.59779	3443	8361		CO2 test
	4301730121	RICHARDSON OPERATING CO	CHARGER 2	1984	shut-in	GARFIELD	Roger Peak	NWSW	33	32S-3E	1851	S	318	W	448478	4203568	37.97828	-111.58665	3035	8046		CO2 test
	4301710903	PHILLIPS PETROLEUM CO	ESCALANTE ANTICLINE 1	1960	1960	GARFIELD	Roger Peak	SWNW	32	32S-3E	2224	N	549	W	446932	4203909	37.98127	-111.60428	3384		9232	no logs
	4301730127	ARCO OIL & GAS COMPANY	FOREST CREEK DIVIDE U 1	1984	1984	GARFIELD	Deep Creek	NENW	28	31S-2W	130	N	2435	W	411114	4215981	38.08725	-112.01359	3680		7085	Navajo oil and gas test
	4301710189	CALIFORNIA OIL CO	OTTER CRK RESERVOIR CO 2-1	1964	1964	GARFIELD	Deep Creek	NENE	16	31S-2W	600	N	570	E	411726	4219036	38.11484	-112.00699	3144		6391	
	4304120083	MOUNTAIN FUEL SUPPLY CO	RED CLIFFS U 1	1966	1966	SEVIER	Forsyth Reservoir	SENW	15	26S-4E	2028	N	2606	W	459678	4267065	38.5511	-111.46275	6485		8181	

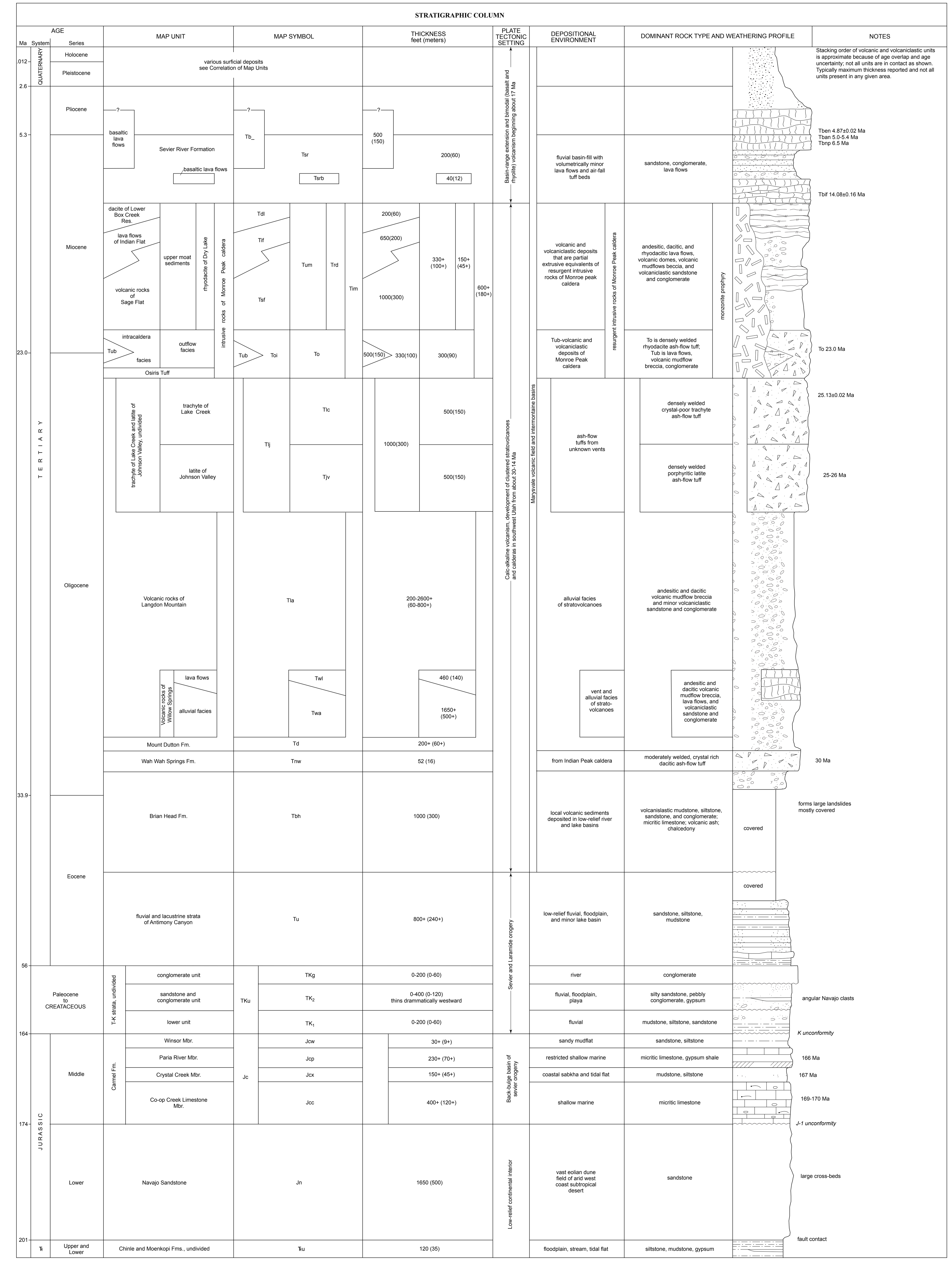
Source: Utah Division of Oil, Gas, and Mining; http://oilgas.ogm.utah.gov/Data_Center/LiveData_Search/well_data_lookup.cfm; accessed April 15, 2015.
* denotes feet north, south, east, or west from section boundary
** approximate elevation
Location data NAD83

Table 2. Palynological data for the Loa 30' x 60' quadrangle.

Sample Number	Map symbol	7.5' quadrangle	Easting, NAD83	Northing, NAD83	Age determination
A070914-2a	Tu	Antimony	420850	4216332	Indeterminate
A072514-2	Tu	Angle	418441	4222676	latest Mississippian to early Pennsylvanian*
JGE 7-10-14-1	Tu	Angle	418286	4223056	latest Mississippian to early Pennsylvanian*
A050615-1	Tu	Angle	417871	4222383	early to middle Eocene
A050615-2	Tu	Angle	417871	4222383	early to middle Eocene

Note: Identifications by Gerald Waanders.
* denotes clearly reworked from unknown sources in the thrust belt

STRATIGRAPHIC COLUMN



Interim Geologic Map of the Western Loa 30′ x 60′ Quadrangle, Garfield, Piute, and Wayne Counties, Utah (Year 2)

by

Robert F. Biek[1], Jeffrey G. Eaton[2], Peter D. Rowley[3], and Stephen R. Mattox[4]

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UTAH GEOLOGICAL SURVEY
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2015

MAP UNIT DESCRIPTIONS

QUATERNARY

Human-Derived Deposits

Qh **Artificial fill** (Historical) – Engineered fill used along highways SR-24 and SR-62; fill of variable thickness and composition should be anticipated in all developed or disturbed areas; typically less than 20 feet (6 m) thick.

Qhd **Disturbed land** (Historical) – Disturbed areas (landfill, sand and gravel pits) in the northeast part of the Moroni Peak quadrangle.

Alluvial Deposits

Qal_1 **Modern stream alluvium** (Holocene) − Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in active, main-stem stream channels and floodplains of Otter Creek and East Fork Sevier River; locally includes minor stream-terrace alluvium as much as about 10 feet (3 m) above current stream level; typically incised into older alluvial and fan deposits; probably less than 20 feet (6 m) thick.

Qat **Stream-terrace alluvium** (Holocene to upper Pleistocene) − Moderately sorted sand, silt, and pebble to boulder gravel that forms gently sloping terraces above, and incised by, active streams and washes; deposited in a stream-channel environment, but locally includes colluvium and small alluvial fans; includes several terrace levels that are typically at elevations of about 10 to 20 feet (3-6 m) above active streams but are not subdivided here due to limitations of map scale; typically less than 20 feet (6 m) thick.

Qaly **Young stream alluvium** (Holocene) − Combined stream alluvium (Qal_1) and the youngest (lowest elevation) part of stream-terrace alluvium (Qat), but undivided here due to limitations of map scale; mapped along major drainages as well as in upland drainages where it may include small alluvial-fan deposits from tributary drainages and colluvium from adjacent slopes; deposits along all but the largest drainages commonly grade downslope into alluvial fans; locally includes historical debris-flow and debris-flood deposits derived from tributary drainages; typically less than 20 feet (6 m) thick, but deposits in major stream valleys may locally exceed 30 feet (9 m) thick.

Qalo **Old stream alluvium** (Holocene to upper Pleistocene) – Similar to young stream alluvium (Qaly), but forms incised deposits along Box Creek, south of Greenwich, that are of slightly higher elevation; underlain by fan alluvium of Grass Valley; probably less than 20 feet (6 m) thick.

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

Qaf_2 **Middle fan alluvium** (Holocene to upper Pleistocene) − Similar in composition and morphology to young fan alluvium (Qaf_1), but forms inactive surfaces incised by younger stream and fan deposits; equivalent to the older, lower part of young and middle fan alluvium (Qafy); present throughout Grass Valley likely due to base-level adjustments following movement of the Paunsaugunt fault zone; 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 inactive surfaces incised by small streams (Qaf_2 equivalent) that are undivided here; deposited principally as debris flows and debris floods, but colluvium locally constitutes a significant part adjacent to range fronts; small, isolated deposits are typically less than a few tens of feet thick, but large, coalesced deposits in Grass Valley and Rabbit Valley are much thicker and form the upper part of basin-fill deposits.

Qafo **Older fan alluvium** (upper to middle Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment with moderately developed calcic soils (caliche); forms broad, gently sloping, incised surfaces in Grass Valley, Rabbit Valley, and around Antimony Bench; deposited principally as debris flows and debris floods; exposed thickness as much as several tens of feet.

Colluvial Deposits

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

Glacial Deposits

Glacial deposits are present immediately east of the map area at Boulder Mountain (Marchetti and others, 2005, 2007) and to the north on the Fishlake Plateau (Weaver and others, 2006; Marchetti, 2007; Marchetti and others, 2011), although none are known on the Awapa Plateau. However, periglacial features known as nivation hollows appear to be widely present on the west-central Awapa Plateau at elevations as low as about 8350 feet (2550 m). These features are best developed on relatively non-resistant volcaniclastic strata of the volcanic rocks of Langdon Mountain (Tla) where they form northwest-trending scalloped escarpments with their eroded, steeper sides facing northeast. These escarpments are shown on the map. Thin, gravelly, silty sand deposits are present at the base of some of these escarpments, but are not mapped due to limitations of scale and poor morphological expression. Nivation hollows form through repeated freeze-thaw cycles at the margins of long-lasting but slowly melting snow patches. Freeze-thaw cycles work to break and loosen rock at the margin of the snow patch, which is then washed downslope by meltwater. As the snow patch recedes in size, excavation of material continues inward, ultimately forming a scalloped slope. On the Awapa Plateau, nivation hollows are presumed to be related to the Pinedale alpine glacial advance, which is roughly coeval with the late Wisconsin glaciation, Last Glacial Maximum (LGM), and Marine Oxygen Isotope Stage 2 (MIS 2). The main Pinedale advance on nearby Boulder Mountain and Fishlake Plateau occurred about 21.1 ka based on cosmogenic exposure ages of boulders (Marchetti, 2006; Weaver and others, 2006; Marchetti and others, 2005, 2007, 2011).

Mass-Movement Deposits

Qms, Qms(To)
Landslides (Historical? to upper? Pleistocene) − Very poorly sorted, locally derived material deposited by rotational and translational movement; composed of clay- to boulder-size debris as well as large, partly intact, bedrock blocks; characterized by hummocky topography, numerous internal scarps, chaotic bedding attitudes, and common small ponds, marshy depressions, and meadows; query indicates areas of unusual morphology that may be due to landsliding; thickness highly variable, but typically several tens of feet or more thick; large deposits along the western margin of the Awapa Plateau, east of Otter Creek Reservoir, and in the upper reaches of Antimony Canyon doubtless locally exceed 200 feet (60 m) thick; the western flank of the Escalante Mountains, part of the west-dipping Escalante monocline in the southwest corner of the map area, displays large, mostly intact, rotated blocks of Osiris Tuff mapped separately as Qms(To), although the degree of displacement due to landsliding versus offset by strands of the Paunsaugunt fault zone is uncertain; undivided as to inferred age because even landslides that have subdued morphology (suggesting that they are older, weathered, and have not experienced recent, large-scale movement) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003).

Vegetation and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as LiDAR may show that many slopes host surficial deposits that reveal evidence of creep or shallow landsliding. Understanding the location, age, and stability of landslides, and of slopes that may host as-yet unrecognized landslides, requires detailed geotechnical investigations.

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

Mixed-Environment Deposits

Qac **Alluvium and colluvium** (Holocene to upper Pleistocene) − Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales and small drainages by fluvial, slope-wash, and creep processes; generally less than 20 feet (6 m) thick.

Qaco **Older alluvium and colluvium** (upper? Pleistocene) − Similar to mixed alluvium and colluvium (Qac), but forms incised, isolated remnants, typically along the upper reaches of streams; probably about 20 to 30 feet (6-9 m) thick.

Qafc **Fan alluvium and colluvium** (Holocene to upper? Pleistocene) − Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows, debris floods, and slope wash at the mouths of active drainages and the base of steep slopes; locally reworked by small, ephemeral streams; forms coalesced apron of fan alluvium and colluvium impractical to map separately at this scale; includes fan alluvium along the margins of Grass Valley that exhibits a steeper slope than the larger, coalesced fan deposits that emanate from major drainages; typically 10 to 40 feet (3-12 m) thick.

Qafco **Older fan alluvium and colluvium** (upper? Pleistocene) − Similar to mixed fan alluvium and colluvium (Qafc), but forms incised, isolated remnants, typically along the upper reaches of streams; probably about 20 to 30 feet (6-9 m) thick.

Qmtc **Talus and colluvium** (Holocene to upper Pleistocene) – Poorly sorted, angular to subangular, cobble- to boulder-size and finer-grained interstitial sediment deposited principally by rockfall and slope wash on steep slopes throughout the quadrangle; includes minor alluvial sediment at the bottom of washes; talus and colluvium are common on steep slopes across the map area, but are mapped only where they conceal contacts or form broad aprons below cliffs of resistant bedrock units; commonly grades downslope into colluvium; generally less than 30 feet (9 m) thick.

Stacked-Unit Deposits

Stacked-unit deposits comprise a discontinuous veneer of Quaternary deposits that mostly conceal underlying bedrock units. Although most bedrock in the quadrangle is partly covered by colluvium or other surficial deposits, we use stacked units to indicate those areas where bedrock is almost wholly obscured by thin surficial deposits that are derived from more than just residual weathering of underlying bedrock.

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

Qac/Tjv **Mixed alluvium and colluvium over the latite of Johnson Valley** (Holocene/upper Oligocene) – Mapped west of Loa where an apron of alluvium, fan alluvium, and colluvium mostly conceals latite of Johnson Valley.

TERTIARY

Upper Tertiary basaltic lava flows

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

The following descriptions of individual basaltic lava flows are brief because of widespread petrographic and geochemical similarity among flows, because of their typically poorly exposed and deeply weathered outcrops, and because of limited geochemical and age data. Except where noted, all lava flows are dark gray and fine grained and contain small olivine phenocrysts (commonly altered to iddingsite) and abundant small plagioclase and clinopyroxene phenocrysts. Basaltic lava flows typically have a rubbly base and a dense, jointed middle part; the vesicular upper part of the lava flows is typically eroded away. Cinder cones are absent and remnant scoria is missing or rare, showing that vent areas are deeply eroded. Lava flows are typically 20 to 30 feet (6-9 m) thick and commonly consist of multiple thin sheets separated by thin rubbly zones. Where it fills paleotopography, a single massive flow can exceed 200 feet (60 m) thick. Additional geochemical correlation and radiometric ages of several basaltic lava flows, including those of Abes Knoll, Pine Peaks, and several flows at the southwest margin of the Awapa Plateau east of Otter Creek Reservoir and Antimony, may ultimately prove useful to understand the long-term slip history of the Paunsaugunt fault.

Basaltic magmas are partial melts derived from the compositionally heterogeneous lithospheric mantle, which, coupled with fractional crystallization, may account for most of the geochemical variability between individual lava flows (Lowder, 1973; Best and Brimhall, 1974; Mattox, 1991; Nelson and Tingey, 1997; Johnson and others, 2010). Nb/La ratios for virtually all samples of basaltic and andesitic lava flows from the map area are less than 1.0, thus suggesting a lithospheric mantle source (Fitton and others, 1991). Rock names follow LeBas and others (1986) based on limited geochemistry; virtually all flows are classified as basalt, potassic trachybasalt, or less commonly basaltic trachyandesite. Major- and trace-element data for volcanic rocks in the western half of the Loa 30' x 60' quadrangle will be published separately at the end of this project. Until chemical analyses and radiometric dating are completed, basaltic map units are arranged alphabetically below.

Tb **Basaltic lava flows, undivided** (Pliocene to Miocene) – Used where differentiation of basaltic lava flows is unclear due to lack of distinctive morphology and inadequate geochemical and age data. Also used for basaltic lava flow near Browns Canyon southwest of Greenwich.

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

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

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

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

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

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

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

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

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

Tbfl **Basaltic lava flows of Fish Lake** (Pliocene to Miocene) – Potassic trachybasalt to shoshonite that probably erupted from a vent in the Burrville quadrangle north of this map area; distinction of this flow from the lithologically similar Abes Knoll flow near highway SR-24 is poorly defined; locally covered by volcaniclastic gravels here assigned to the Sevier River Formation; maximum exposed thickness is about 30 feet (9 m).

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

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

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

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

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

Tbpek **Basaltic lava flows of Pelham Knoll** (Pliocene to Miocene) – Basaltic flow that forms poorly exposed sage-covered surface of apparent similar age to other nearby basaltic lava flows on the southern Awapa Plateau.

Tbpp **Basaltic lava flows of Pine Peaks** (Pliocene to Miocene) – Latite named after possible vent area at Pine Peaks at the west edge of the Awapa Plateau; query indicates that the correlation is uncertain west of the Paunsaugunt fault zone; as much as 200 feet (60 m) thick at Pine Peaks.

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

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

Tsr **Sevier River Formation** (Miocene) – Moderately to poorly consolidated, light-gray and grayish-brown volcaniclastic conglomerate, pebbly sandstone, sandstone, and minor siltstone; locally contains interbedded basaltic lava flows, most of which are mapped separately as Tsrb; 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 of the Mount Belknap Volcanics (Rowley and others, 1986a); forms poorly exposed, planar and gently sloping, sagebrush-covered surfaces on the Awapa Plateau where it overlies the Osiris Tuff; on the Sevier Plateau in the west-central part of the Greenwich quadrangle, map unit is lithologically similar to, but unconformably overlies, upper moat sediments (Tum; along the inside southern edge of the Monroe Peak caldera); the Sevier River Formation is similar to the volcanic rocks of Langdon Mountain, but can be distinguished by stratigraphic position (above the Osiris Tuff) and the local presence of subrounded clasts of Osiris Tuff and olivine basalt; at least 500 feet (150 m) thick in the Beaver 30' x 60' quadrangle to the west (Rowley and others, 2005), but maximum thickness on the Awapa Plateau is about 400 feet (120 m).

The Sevier River Formation was named by Callaghan (1938) for partly consolidated basin-fill deposits near Sevier, Utah, on the north side of the Marysvale volcanic field. The name was formerly applied to all basin-fill deposits in and near Sevier and Grass Valleys, but, because most of its exposures are in adjacent ranges, it was later recognized to have been deposited in basins that formed generally prior to the main episode of basin-range extension, which created the present topography (Rowley and others, 1981b, 1998, 2002; Rowley, 1998). In and near its type area near the town of Sevier, the Sevier River Formation contains air-fall tuffs and basaltic lava flows 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). In this map area on the Sevier Plateau, the Sevier River Formation is overlain by the 14 Ma basaltic lava flows of Indian Flat on the Sevier Plateau northwest of Greenwich; its age on the Awapa Plateau is poorly constrained, but 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.

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

Trd **Rhyodacite of Dry Lake** (Miocene) – Resistant, light-gray, pinkish-gray, and brownish-gray, flow-foliated, locally spherulitic, moderately crystal-rich rhyodacite lava flows with 10-30% phenocrysts of plagioclase, subordinate hornblende, and minor biotite, quartz, and Fe-Ti oxides; named for exposures near Dry Lake immediately west of Forshea Mountain west of this map area; poorly exposed in rounded hills west of Otter Creek Reservoir where it is as much as about 150 feet (45 m) thick.

Tm, Tm(Tnw)
Megabreccia of Dry Wash (Miocene to Oligocene) – A remnant of a gravity slide mass northeast of Antimony; basal 30 feet (9 m) is a ledge of intensely fractured and sheared, gray and greenish-gray volcanic mudflow breccia and minor apparent Wah Wah Springs Formation with common grayish-brown to grayish-red clastic dikes of ultracataclasite in multiple orientations (but mostly subvertical) and as much as 1 foot (0.3 m) wide and tens of feet long; upper part of unit is white to light-gray volcaniclastic conglomerate and sandstone that lacks quartzite clasts, and thin interbedded volcanic mud-

flow breccia, all locally cut by ultracataclasite dikes; basal shear plane is horizontal and well exposed along the west edge of section 32, T. 30 S., R. 1 W., with grooves and striations oriented N12ºW although the absolute direction of movement is unclear; age unknown, but unit overlies a ledge-forming volcanic mudflow breccia that contains angular Spry-like clasts similar to those in the volcanic rocks of Bull Rush Peak (late Oligocene), which in turn overlies volcaniclastic conglomerate and sandstone containing sparse, rounded quartzite clasts (all mapped as Tv, although the volcaniclastic part may belong to the Brian Head Formation); includes a fault-bounded, near-vertical, intensely fractured and sheared panel of apparent Wah Wah Springs strata, mapped as Tm(Tnw), caught between splays of the Paunsaugunt fault zone about 1 mile (3 km) northwest of the Dry Wash block; as much as about 260 feet (80 m) thick.

Tv **Volcanic rocks of Dry Wash** (Miocene to Oligocene) – Slope-forming, gray and brownish-gray andesitic porphyry with abundant plagioclase phenocrysts, and a grayish-brown to grayish-red, flow-foliated, crystal-poor rhyolitic lava flow with 5-10% phenocrysts of plagioclase, subordinate hornblende, and minor biotite; principal exposure in Dry Wash overlies a 3-foot-thick (1 m) travertine which in turns overlies ledge-forming Wah Wah Springs Formation; where it underlies the megabreccia of Dry Wash, unit consists of volcaniclastic conglomerate and sandstone containing sparse, rounded quartzite clasts and overlying, ledge-forming volcanic mudflow breccia with angular Spry-like clasts similar to the volcanic rocks of Bull Rush Peak; about 2 miles (3 km) to the northwest of the main exposure in Dry Wash, consists only of a steeply west-dipping, deeply altered, intensely fractured rhyolitic flow about 40 feet (12 m) thick caught between splays of the Paunsaugunt fault zone; rhyolitic flow may be related to the rhyodacite of Dry Lake exposed west of Otter Creek Reservoir; as much as about 300 feet (90 m) thick in Dry Canyon.

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

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

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

Tif, Tifh

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

Tsf, Tsfh

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

Toi, Toih

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

Tub, Tubh

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

Tolj **Osiris Tuff, trachyte tuff of Lake Creek, and latite of Johnson Valley, undivided** (lower Miocene to upper Oligocene) – Mapped south of Antimony Canyon on the southwestern Awapa Plateau pending additional fieldwork.

To **Osiris Tuff, outflow facies** (lower Miocene to upper Oligocene) – Resistant, light-gray and grayish-brown, densely welded, moderately crystal-rich, trachyte ash-flow tuff (petrographically a rhyodacite); contains about 20 to 25% phenocrysts of plagioclase, subordinate sanidine and biotite, and minor pyroxene and Fe-Ti oxides (Anderson and Rowley, 1975; Mattox, 2001); forms a simple cooling unit, which in some places includes an upper, light-gray vapor-phase zone and a basal black vitrophyre as much as 10 feet (3 m) thick; commonly weathers to large rounded boulders; contains drawn-out pumice lenticles; upper part and margins of unit along paleovalleys (such as those of modern-day Riley Canyon and Dog Flat Hollow west and northwest of Loa) locally exhibit steeply dipping flow foliations, rheomorphic features caused by secondary flowage of rock during the last few tens of meters of movement; the preferred age of the Osiris is about 23 Ma (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; typically about 100 to 150 feet (30-45 m) thick, but as much as about 300 feet (90 m) thick where it fills paleovalleys west of Loa.

The Osiris Tuff erupted from the Monroe Peak caldera, the southeast corner of which is in the northwestern corner of the map area. This caldera is 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 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.

Tlac **Trachyte tuff of Lake Creek and volcanic rocks of Langdon Mountain, undivided** (upper Oligocene) – Undivided in the southwestern part of the Moroni Peak quadrangle due to poor outcrop and geomorphic expression.

Tlj **Trachyte tuff of Lake Creek and latite of Johnson Valley, undivided** (upper Oligocene) – Previous geologic mapping of the Awapa Plateau (Williams and Hackman, 1971; Mattox, 1991, 2001) and Fish Lake Plateau (Bailey and Marchetti, in prep.; Marchetti and others, 2013) showed the widespread presence of two petrographically and chemically distinct pre-Osiris Tuff units originally interpreted as lava flows and subsequently identified as ash-flow tuffs (Ball and others, 2009). These are informally named the crystal-rich latite of Johnson Valley and the overlying crystal-poor trachyte tuff of Lake Creek after Ball and others (2009). Only the Lake Creek unit is obviously an ash-flow tuff; we remain uncertain as to the ash-flow tuff versus lava flow nature of the latite of Johnson Valley as described below. Though quite different in hand sample, these units are of similar isotopic age and are difficult to separate during reconnaissance-scale geologic mapping and so have been locally lumped here pending additional work.

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 is 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 names "latite of Johnson Valley" and "trachyte tuff of Lake Creek" with earlier established nomenclature.

Tlc **Trachyte of Lake Creek** (upper Oligocene) – Gray, densely welded, phenocryst-poor trachyte ash-flow tuff with 5-15% 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; unit likely consists of several cooling units but prominent vitrophyres are lacking; best exposed in Graveyard Hollow north of Loa where it is at least 450 feet (135 m) thick and underlies the Osiris Tuff; commonly weathers to poorly exposed, regolith-covered slopes that, from a distance, are difficult to distinguish from those developed on the volcanic rocks of Langdon Mountain or the Sevier River Formation; 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); includes "latite lava flows" of Mattox (2001), given their similar stratigraphic position, petrology, and chemistry; major- and trace-element discrimination diagrams (UGS unpublished data) show that samples identified as trachyte tuff of Lake Creek cluster remarkably tightly, further suggesting that these widely scattered samples support interpretation of the unit as an ash-flow tuff rather than multiple lava flows erupted from multiple sources as inferred by previous workers; Mattox (1991, 2001) showed that his "latite" is interbedded with the volcanic rocks of Langdon Mountain on the Awapa Plateau; on the northern Awapa Plateau and Fish Lake Plateau, typically overlies the latite of Johnson Valley, but southward it overlies lahars of the volcanic rocks of Langdon Mountain; based on major- and trace-element chemistry, appears to cap Hens Hole Peak immediately east of the map area; ongoing work will further assess the possibility that given their similar stratigraphic position, petrology, age, and chemistry, the trachyte tuff of Lake Creek may be the tuff of Albinus Canyon, Kingston Canyon Tuff Member, or the Antimony Tuff Member; Mattox (1991) reported a K-Ar age of 23.1 ± 1.0 Ma for his sample AP119 (here mapped as trachyte tuff of Lake Creek) in Wildcat Canyon on the east-central Awapa Plateau, considerably younger than the tuff of Albinus Canyon, which yielded a K-Ar age on plagioclase of 25.3 ± 1.3 Ma (Rowley and others, 1994); however, Bailey and Marchetti (in prep.; 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 on the Fish Lake Plateau; as much as about 500 feet (150 m) thick on the Awapa Plateau, and about 500 feet (150 m) thick at Fish Lake Hightop (Bailey and Marchetti, in prep.), north of this map area.

Tjv **Latite of Johnson Valley** (upper Oligocene) – Gray, weathering to brownish gray, densely welded, porphyritic trachyandesite (latite) with 25-35% 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; interpreted by Ball and others (2009) as an ash-flow tuff likely consisting of several cooling units but prominent vitrophyres are lacking; Smith and others (1963) recognized three units at Boulder Mountain immediately east of this map area; includes potassium-rich mafic lava flows of Mattox (2001) given their similar stratigraphic position, petrology, and chemistry; weathers to rough, dark-colored, bouldery outcrops that on aerial photographs look similar to younger, blocky lava flows; major- and trace-element discrimination diagrams show that samples identified as latite of Johnson Valley 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); further, similar geochemistry (UGS unpublished data) suggests that these widely scattered samples support interpretation of the unit as an ash-flow tuff rather than having erupted as multiple lava flows, yet we remain uncertain whether the unit represents one or more ash-flow tuffs or lava flows; table 1 shows several $^{40}Ar/^{39}Ar$ ages for this unit of about 25 to 26 Ma; because this unit clearly underlies the trachyte tuff of Lake Creek, our preferred age for the latite of Johnson Valley is 26 Ma; forms the cap of Boulder Mountain and Thousand Lake Mountain immediately east of the map area; generally thins southward from the Fish Lake Plateau; also mapped at the north edge of the Greenwich quadrangle, where it was previously mapped as the vent facies of the volcanic rocks of Langdon Mountain by Rowley and others (1986a); as much as 500 feet (150 m) thick at Big Hollow on the central Awapa Plateau (Mattox (1991, 2001); incomplete exposures near Fish Lake are at least 800 feet (245 m) thick (Bailey and Marchetti, in prep.) and Marchetti and others (2013) reported that the unit is locally in excess of 1000 feet (300 m) thick on the plateau to the northeast; Smith and others (1963) reported this unit to be 475 feet (145 m) thick at Boulder Mountain.

Tla, Tlah

Volcanic rocks of Langdon Mountain, alluvial facies (Oligocene) – Poorly to moderately resistant, andesitic to dacitic volcanic mudflow breccia (lahars) and subordinate volcaniclastic sandstone and conglomerate; letter "h" indicates areas that are hydrothermally altered, silicified, and possibly mineralized in the vicinity of the Monroe Peak caldera on the Sevier Plateau; hydrothermally altered rock is also present but not mapped separately east of Otter Creek Reservoir at the base of the west-central Awapa Plateau; may locally include volumetrically minor, thin andesitic and dacitic lava flows on the Awapa Plateau, but on the Sevier Plateau includes volumetrically significant lava flows, commonly hydrothermally altered, here not mapped separately due to poor exposure; also on the Sevier Plateau, in the western part of the Parker Knoll quadrangle, includes petrographically similar lava flows and lahars assigned by Rowley and others (2005) to an intertonguing unit, the volcanic rocks of Little Table, but not separated here due to poor exposure and apparent limited extent; southward in the Parker Knoll quadrangle, south of Rock Canyon in sections 13, 14, 23, and 24, T. 29 S., R. 2 W., unit includes basaltic andesite lava flows with pyroxene phenocrysts as much as 0.75 inch (2 cm) long; in Dry Valley northwest of Loa, includes non-resistant, light-yellowish-brown and reddish-brown, fine-grained volcaniclastic sandstone and siltstone; unit is well exposed along the western escarpment of the Awapa Plateau, but typically weathers to regolith-covered low rounded hills elsewhere; locally interbedded with trachyte tuff of Lake Creek (Tlc) in Big Hollow on the central Awapa Plateau ("latite lava flows" of Mattox, 2001); on the central and southern Awapa Plateau, typically overlain by the Osiris Tuff (To), whereas to the north overlain by latite of Johnson Valley (Tlj); deposited principally as lahars sourced from one or more stratovolcanoes in the central Sevier Plateau at or near Langdon Mountain, which lies immediately west of the map area (Rowley, 1979; Rowley and others, 1979, 1981a; Mattox, 1991); Mattox (2001) reported that the unit is in excess of 2600 feet (800 m) thick at Parker Mountain on the west-central flank of the Awapa Plateau; map patterns show that it thins dramatically southward to about 200 feet (60 m) thick south of Big Point on the southwestern flank of the plateau.

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

Volcanic Rocks of Willow Spring

A stratovolcano sequence of pyroxene-bearing rocks exposed in the Sevier Plateau south of the Monroe Peak caldera. Consists largely of an alluvial facies, but also includes overlying, sparse, thin, lithologically similar lava flows. Map unit description modified from Rowley and others (1986a).

Twl **Lava flow facies** (upper Oligocene) – Moderately resistant, pinkish-gray and gray, basaltic to andesitic lava flows and subordinate volcanic mudflow breccia; contains sparse to moderately abundant phenocrysts of pyroxene, subordinate Fe-Ti oxides, local hornblende, and minor plagioclase and olivine; maximum thickness about 460 feet (140 m).

Twa **Alluvial facies** (upper Oligocene) – Poorly to moderately resistant, pinkish-gray, gray, and brownish-gray, andesitic volcanic mudflow breccia and subordinate lava flows and volcaniclastic sandstone and conglomerate; clasts are generally glassy with phenocrysts of plagioclase, pyroxene, and minor Fe-Ti oxides; maximum thickness at least 1650 feet (500 m).

Td **Mount Dutton Formation, alluvial facies** (upper Oligocene) – Light- to dark-gray and brown, crystal-poor, andesitic to dacitic volcanic mudflow breccia and lesser interbedded volcaniclastic conglomerate; in Black Canyon, along highway SR-22 in section 11, T. 32 S., R. 2 W., also contains a resistant ledge of lithic ash-flow tuff about 15 feet (5 m) thick; the Mount Dutton Formation is poorly and incompletely exposed in Black Canyon where it is as much as about 200 feet (60 m) thick.

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

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

Tnw **Wah Wah Springs Formation** (lower Oligocene) – Pale-red to grayish-orange-pink, moderately welded, crystal-rich, dacitic ash-flow tuff; phenocrysts of plagioclase, hornblende, and biotite (plus minor quartz, Fe-Ti oxides, and sanidine) constitute about 40% of the rock; contains pebble-size lithic fragments of mostly brown, fine-grained volcanic rock that weather out to leave cavities in the rock; basal surge deposits and vitrophyre locally present; mapped only along the middle reaches of Dry Wash east of Otter Creek Reservoir where it forms a prominent ledge on the northern side of the canyon; the abundance of hornblende over biotite is unique among Great Basin ash-flow tuffs; derived from the Indian Peak caldera of the 27 to 32 Ma Indian Peak caldera complex that straddles the Utah-Nevada border (Best and others, 1989a, 1989b, 2013); today, the Wah Wah Springs covers at least 8500 square miles (22,000 km^2) with an estimated volume of as much as about 720 cubic miles (3000 km^3) (Best and others, 1989a); about 30 Ma on the basis of many K-Ar and $^{40}Ar/^{39}Ar$ age determinations (Best and Grant, 1987; Best and others, 1989a, 1989b; Rowley and others, 1994); Best and others (2013) reported a thickness of 52 feet (16 m) in Dry Wash; because of its unusual stratigraphic position, unconformable over strata mapped as fluvial and lacustrine strata of Antimony Canyon, its identification is uncertain and may instead be the petrographically and chemically similar 27 Ma Three Creeks Tuff.

Tbh **Brian Head Formation** (lower Oligocene to upper Eocene) – Mapped in one small exposure below Big Point at the southwest flank of the Awapa Plateau where it consists of poorly to moderately cemented, heterolithic volcanic mudflow breccia with a light-gray ashy and sandy matrix; andesitic to dacitic clasts to boulder size are subangular to subrounded and matrix supported; lacks quartzite clasts; also exposed but not mapped separately at the base of the Dry Wash megabreccia (Tm, Tm[Tnw]) where it consists of volcaniclastic conglomerate and white to light-gray tuffaceous mudstone and sandstone; large rotated blocks of volcaniclastic mudstone and tuffaceous fine-grained sandstone with thin chalcedony beds, typical of Brian Head strata present on the southern Sevier Plateau, are present but not mapped separately in landslide complexes below the rim of the plateau east and south of Otter Creek Reservoir; as in areas to the southwest (Biek and others, 2015), Brian Head strata are interpreted to be the causal agent of these landslide complexes along the plateau's southwestern margin; south of Big Point, unit overlain by cliff-forming latitic flows and volcanic mudflow breccia and northward by volcanic rocks of Langdon Mountain; numerous isotopic ages on the formation in the Panguitch 30' x 60' quadrangle to the southwest show it to be 37 to 30 Ma (Biek and others, 2015); thickness unknown because lower contact with fluvial and lacustrine strata of Antimony Canyon is covered by landslides, but given outcrop constraints, must be no more than about 1000 feet (300 m) in the upper reaches of Antimony Canyon; just 2 miles (3 km) to the north, west of Big Point, map patterns there suggest it is no more than about 400 feet (120 m) thick; Biek and others (2015) reported the formation to be about 1000 feet (300 m) thick on the southern Sevier Plateau southwest of this map area.

Pre-volcanic strata of Antimony Canyon

Near the heart of the Marysvale volcanic field, below its immense thickness of volcanic rocks, Antimony Canyon and Dry Wash expose an enigmatic section of fluvial, floodplain, and minor lacustrine strata more than 1000 feet (300 m) thick that bear little resemblance to strata that occupy this interval immediately north and south of the volcanic field. Smith

(1957) assigned the name Flagstaff(?) Formation to these beds and discussed interpretations of earlier workers who variously assigned them to multiple Late Jurassic to Paleocene formations. Pending further stratigraphic studies and the search for datable materials, we prefer to use informal names for this interval.

We divide this interval into four informal units and recognize that we have little age control on the lower three units. In ascending order, these units are: (1) a lower dark-reddish-brown silty sandstone and pebbly sandstone interval (TK_1); (2) a yellowish-brown, westward-thinning wedge of silty, fine- to medium-grained sandstone and local conglomerate with subangular to subrounded Navajo Sandstone pebbles to boulders (TK_2); (3) a prominent ledge-forming conglomerate interval (TKg) with rounded quartzite and limestone pebbles and cobbles; and (4) a thick, upper, "salt and pepper" sandstone and siltstone interval with several thin limestone beds (Tu). Stratigraphic studies by co-author Eaton and his students, now ongoing, have further constrained the age and provenance of these strata, but much remains unknown. Sand of the lower three units is almost entirely well-rounded quartz recycled from Mesozoic eolianites, probably the Navajo Sandstone. Sand of the upper unit, however, contains conspicuous black chert grains and is less mineralogically mature than that of the lower two units. Limestone and calcareous sandstone beds near the base of the upper unit yielded sparse early to middle Eocene gastropods, and mudstone there yielded sparse early to middle Eocene palynomorphs, but the age of the basal three units remains poorly constrained. The lower two units (TK_1 and TK_2) pinch out westward against the Antimony anticline and the third unit (TKg) is folded over the crest of the anticline; overlying, early to middle Eocene fluvial and lacustrine strata (Tu) are steeply tilted immediately adjacent to the east flank of the anticline. The lithology and structural position of the lower three units—in increasingly progressive angular unconformity over older units—is similar to North Horn strata exposed at the north edge of the volcanic field near Glenwood (Doelling and Kuehne, in prep.) and farther north in Salina Canyon (Willis, 1986) and at the south end of the San Pitch Mountains (Weiss, 1994). Collectively, the Antimony Canyon and Dry Wash strata record progressive unconformities associated with late-stage movement of the Antimony anticline.

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

Tu **Fluvial and lacustrine strata of Antimony Canyon** (middle to lower Eocene) – Yellowish-brown to white, commonly silty, fine- to medium-grained calcareous sandstone, minor siltstone and mudstone; a thin, ledge- and cliff-forming, light-gray silty limestone is present at and near the base in Antimony Canyon, whereas northward in Dry Wash, several thin similar limestone beds as much as about 2 feet (0.5 m) thick are present throughout the section; thin- to thick-bedded, weathering to steep, ledgy slopes; includes minor thin gypsum beds and veins typically less than 1 inch (3 cm) thick; sandstone contains conspicuous black chert grains giving a "salt and pepper" appearance to many beds; extensively bleached with local Fe-rich Liesegang banding; mudstones are locally organic-rich and dark brown to brownish black—of five palynomorph samples, one was barren, two yielded only latest Mississippian to Early Pennsylvanian spores and pollen, and two yielded abundant latest Mississippian to Early Pennsylvanian and rare early to middle Eocene pollen—the older Paleozoic pollen is clearly reworked from unknown sources in the thrust belt (table 2; UGS unpublished data); upper contact everywhere covered by landslide deposits, but map unit appears to be overlain by fine-grained volcaniclastic strata of the Brian Head Formation; deposited in fluvial, floodplain, and minor lacustrine environments; sparse gastropods indicate an early to middle Eocene age for the basal part of the Tu map unit (Joseph Hartman, University of North Dakota, written communication, February 9, 2015), as do rare palynomorphs; a U-Pb detrital zircon analysis of sample A072514-1, from the base of the section in Dry Wash, yielded a single 37.58 ± 3.08 Ma grain and a prominent middle Cretaceous peak (UGS unpublished data); maximum exposed thickness about 800 feet (240 m).

TKu **Cretaceous-Tertiary strata, undivided** (lower Eocene to Upper Jurassic) – Map units TK_1, TK_2, and TKg undivided on the south side of Dry Wash due to map scale.

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

TK_2 **Sandstone and conglomerate unit** (lower Eocene to Upper Cretaceous) – Yellowish-brown, typically medium- to thick-bedded, calcareous, fine- to medium-grained silty sandstone and conglomerate; conglomerate is comprised of subangular to subrounded pebbles to boulders of locally derived Navajo Sandstone and minor rounded chert pebbles; this conglomerate forms the base of the unit in eastern exposures, as well as several overlying thin beds typically 3 to 5 feet (1-2 m) thick throughout the remainder of the unit, but is locally missing westward towards the Antimony anticline; includes minor thin gypsum beds and veins typically less than 1 inch (3 cm) thick; sand is almost entirely rounded quartz, probably recycled from the Navajo Sandstone; extensively bleached with common Fe-rich Liesegang banding in sandstone beds; weathers to ledgy slopes; upper contact corresponds to the base of the overlying cliff-forming quartzite conglomerate; deposited in fluvial and floodplain environments; as much as about 400 feet (120 m) thick in eastern Antimony Canyon, but thins dramatically westward towards the Antimony anticline where it is no more than a few tens of feet thick and where it is absent over the crest of the anticline.

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

JURASSIC

Jc **Carmel Formation** (Middle Jurassic) – The Carmel Formation is exposed only in a structurally attenuated section in Antimony Canyon on the vertical east limb of a Sevier-age anticline, the west limb of which is truncated and buried on the hanging wall of the Paunsaugunt fault zone. Nomenclature follows that of Sprinkel and others (2011a) and Doelling and others (2013). The Carmel Formation was deposited in a shallow inland sea of a back-bulge basin, and together with the underlying Temple Cap Formation, provides the first clear record of the effects of the Sevier orogeny in southwestern Utah (Sprinkel and others, 2011a). A Middle Jurassic age is from Imlay (1980) and Sprinkel and others (2011a). 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) – Non-resistant, light-reddish-brown or locally greenish-gray, laminated shale, siltstone, and fine- to medium-grained sandstone, all with thin gypsum beds and cross-cutting veins; poorly cemented and so weathers to vegetated slopes; upper, unconformable contact is at the base of a dark-reddish-brown pebbly sandstone and conglomerate of uncertain but likely Late Cretaceous to early Eocene age (TK_1); deposited on a broad, sandy mud flat (Imlay, 1980; Blakey and others, 1983); incomplete, overturned section is a few tens of feet thick in Antimony Canyon.

Jcp **Paria River Member** (Middle Jurassic, Bathonian) – Resistant, light- and yellowish-gray micritic and argillaceous limestone and calcareous mudstone laminated in very thick beds, minor reddish-brown and greenish-gray shale, and, at the base of the member, a thick gypsum bed; upper contact not exposed; deposited in shallow-marine and coastal-sabkha environments (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; incomplete section as much as 230 feet (70 m) thick in Antimony Canyon, but section may be structurally attenuated.

Jcx **Crystal Creek Member** (Middle Jurassic, Bathonian) – Non-resistant, thin- to medium-bedded, reddish-brown siltstone, mudstone, and fine- to medium-grained sandstone; commonly gypsiferous and contains local contorted pods of gypsum; upper contact corresponds to the base of the thick 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 within the member near Gunlock that were likely derived from a magmatic arc in what is now southern California and western Nevada; deposited in coastal-sabkha and tidal-flat environments (Imlay, 1980; Blakey and others, 1983); incomplete section as much as 150 feet (45 m) thick in Antimony Canyon, but section may be structurally attenuated.

Jcc **Co-op Creek Limestone Member** (Middle Jurassic, Bajocian) – Resistant, thin- to medium-bedded, light-gray micritic limestone and calcareous shale; locally contains *Isocrinus* sp. crinoid columnals, pelecypods, and gastropods; upper contact corresponds to the base of slope-forming reddish-brown siltstone; differs considerably from the lower Carmel southwest of Bicknell, exposed on the northern Waterpocket Fold, in its lack of interbedded sandstone and siltstone (thus it resembles basal Carmel exposures of southwest Utah rather than the time-equivalent Judd Hollow Member of the Henry Mountains basin); 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 (Imlay, 1980; Blakey and others, 1983); as much as about 400 feet (120 m) thick in Antimony Canyon, but section may be structurally attenuated.

Temple Cap Formation (Middle to Lower Jurassic) – Temple Cap strata are not present 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 an early Middle Jurassic paleohigh (Doelling and others, 2013) or possibly due to attenuation associated with folding in the core of the anticline; see Sprinkel and others (2011a) an Doelling and others (2013) for a description of this formation in southern Utah.

Unconformity (J-1) The J-1 unconformity of 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 or white sandstone that consists of well-rounded, fine- to medium-grained, frosted quartz sand; upper, unconformable contact is poorly exposed but regionally is sharp and planar, corresponding to a prominent break in slope, with cliff-forming, cross-bedded sandstone below and reddish-brown mudstone of the Sinawava Member of the Temple Cap Formation above; forms prominent ridge at the entrance to Antimony Canyon, eroded from the vertical east limb of a Sevier-age anticline; deposited in a vast coastal and inland dune field with prevailing winds principally from the north (Blakey, 1994; Peterson, 1994), part of one of the world's largest coastal and inland paleodune fields (Milligan, 2012); correlative in part with the Nugget Sandstone of northern Utah and Wyoming and the Aztec Sandstone of southern Nevada and adjacent areas (see, for example, Kocurek and Dott, 1983; Riggs and others, 1993; Sprinkel and others, 2011b); much of the sand may originally have been transported to areas north and northwest of Utah via a transcontinental river system that tapped Grenvillian-age (about 1.0 to 1.3 Ga) crust involved in Appalachian orogenesis of eastern North America (Dickinson and Gehrels, 2003, 2009a, 2009b; Rahl and others, 2003; Reiners and others, 2005); Smith (1957) reported 1650 feet (500 m) of Navajo Sandstone in Antimony Canyon, but map patterns there suggest an incomplete thickness of about 1150 feet (350 m).

TRIASSIC

TRu **Chinle and Moenkopi Formations, undivided** (Upper and Lower Triassic) – Reddish-brown siltstone with thin gypsum beds and veinlets and greenish-gray smectitic mudstone; incomplete, fault-bounded section is as much as about 120 feet (35 m) thick.

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