UTAH GEOLOGICAL SURVEY
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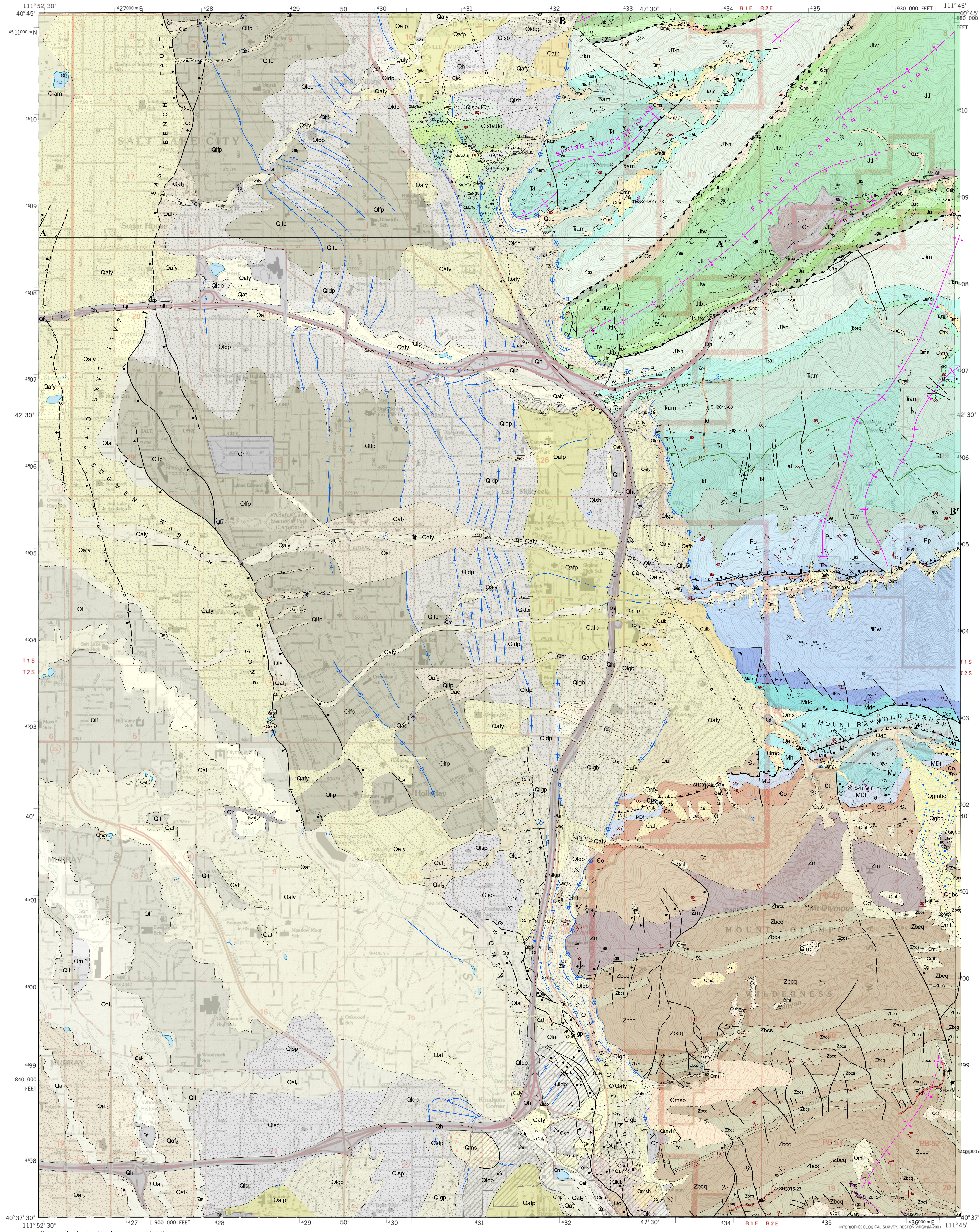

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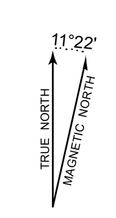
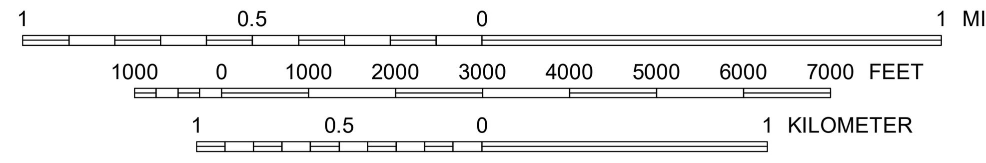


APPROXIMATE MEAN DECLINATION, 2018

SCALE 1:24,000

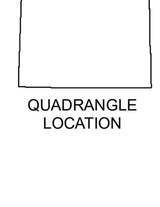


CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 10 FEET

INTERIM GEOLOGIC MAP OF THE SUGAR HOUSE QUADRANGLE, SALT LAKE COUNTY, UTAH

by
Adam P. McKean

2018



QUADRANGLE LOCATION

Base from USGS Sugar House 7.5' Quadrangle (1998). Projection and datum for base map are UTM NAD 27 and GIS data are UTM NAD 83. To conform to adjoining geologic maps, the geology is mapped to the 7.5' boundary of older UTM NAD 27 basemaps to the west and newer UTM NAD 83 basemaps to the east; this explains the visible difference in the boundaries of the geology and the base map. The geology is accurately shown relative to cultural and topographic features on the base map.

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GIS and Cartography: Adam P. McKean and Martha L. Jensen

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1	2	3
4		5
6	7	8

1. Salt Lake City North
2. Fort Douglas
3. Mountain Dell
4. Salt Lake City South
5. Mount Aire
6. Midvale
7. Draper
8. Dromedary Peak

ADJOINING 7.5' QUADRANGLE NAMES

GEOLOGIC SYMBOLS

- Contact – Dashed where approximately located; dotted where concealed; queried where uncertain
- Scratch contact – Known extent of shallow bedrock, probably extends farther, see booklet
- Fault – Sense of offset not known or complex; dashed where approximately located, dotted where concealed
- 40 — Normal fault – Dashed where approximately located, dotted where concealed; bar and ball on downthrown side; queried where existence uncertain; arrows on cross section indicate direction of relative movement; red symbols and dips are from Crittenden (1965d)
- Thrust fault – Dashed where approximately located, dotted where concealed; sawteeth on upper plate; bar and ball on downthrown side indicates a reversal of fault slip due to uplift of the Cottonwood arch
- Detachment fault– Dashed where approximately located, dotted where concealed; roundteeth on upper plate
- Lacustrine shorelines – Major shorelines of Lake Bonneville; mapped at the top of wave-cut bench for erosional shorelines and at the top of constructional bars and barrier beaches; may coincide with geologic contacts
- S — Stansbury shoreline
- B — Bonneville shoreline (highstand) – Dashed where approximately located
- t — Transgressive shorelines (present above the Provo shoreline and below the Bonneville shoreline) – Dashed where approximately located
- P — Provo shoreline – Dashed where approximately located, dotted where concealed
- r — Regressive shorelines (present below the Provo shoreline) – Dashed where approximately located, dotted where concealed
- Alluvial terrace scarp – Dashed where approximately located
- Glacial moraine crest, asymmetrical, tick marks are on the steep side
- Glacial moraine crest, symmetry uncertain
- Landslide scarp – Hachures on downdropped side
- Base of medial massive limestone (T̵Rtl) of the Thaynes Formation
- A——A' Line of cross section
- Hinge zone trace of anticline – Dashed where approximately located
- Hinge zone trace of syncline – Dashed where approximately located
- Outline of aggregate sand and gravel pit operations, contact based on 2012 orthophotography (Utah Automated Geographic Reference Center, 2012)
- Natural surficial deposits are mapped in areas disturbed by sand and gravel operations in attempt to show the pre-mining geology (based on 1937 aerial photographs) and cross-cutting relationships
- Structural measurements – red symbols and dips are from Crittenden (1965d)
- 65 65 — Strike and dip of inclined bedding
- 85 85 — Strike and dip of overturned bedding
- Vertical bedding
- 65 — Strike and dip of cleavage
- Spring
- Water well (selected)
- Quarry
- Adit
- Prospect
- Shaft
- Sand and gravel pit
- SH2015-9 — Rock sample location and number, see McKean (2017c) for geochemical data
- Qldp/Jtc — Stacked unit – Denotes thin cover of first unit overlying second unit, mapped only near and east of Foothill Drive where shallow bedrock is concealed by surficial units

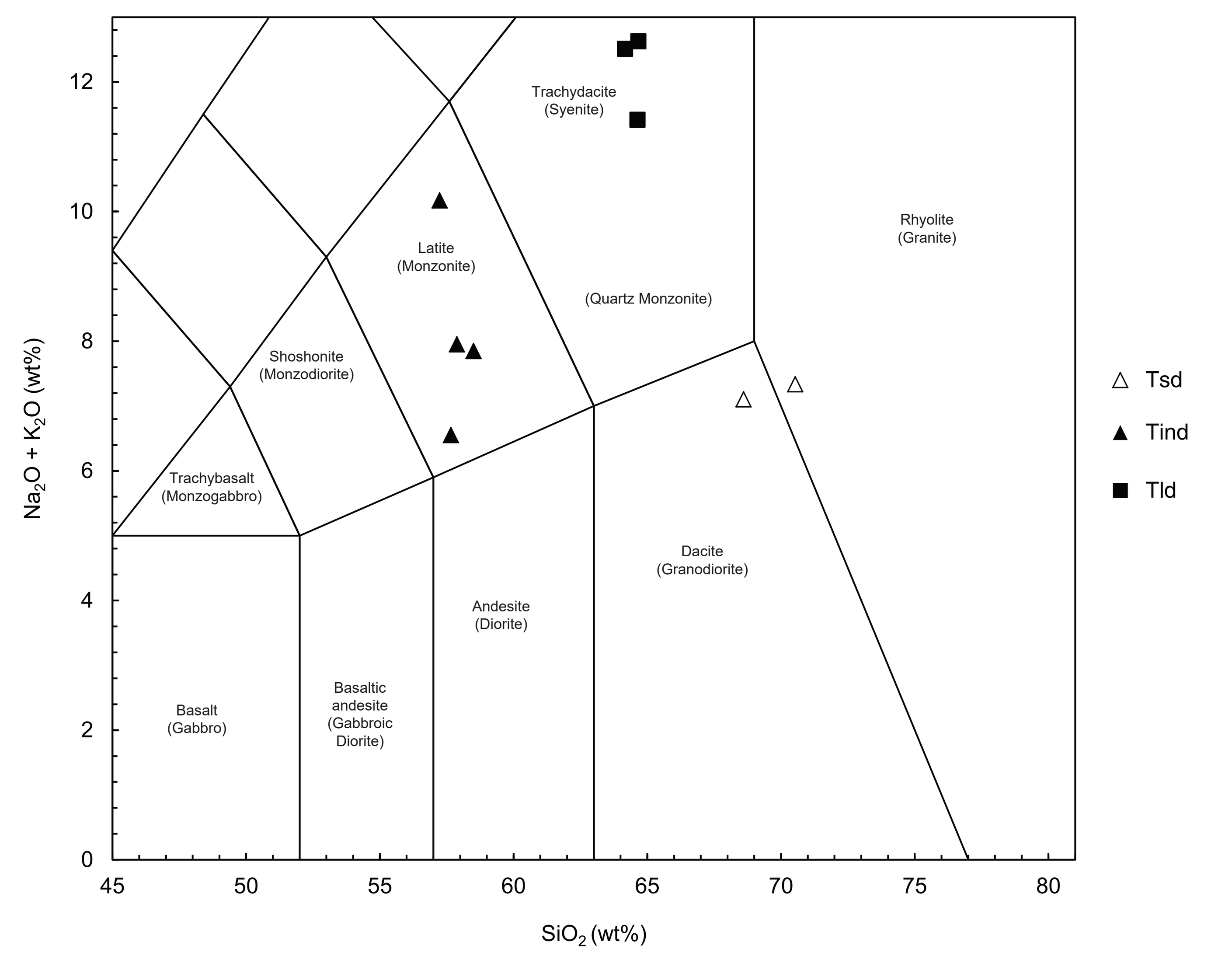
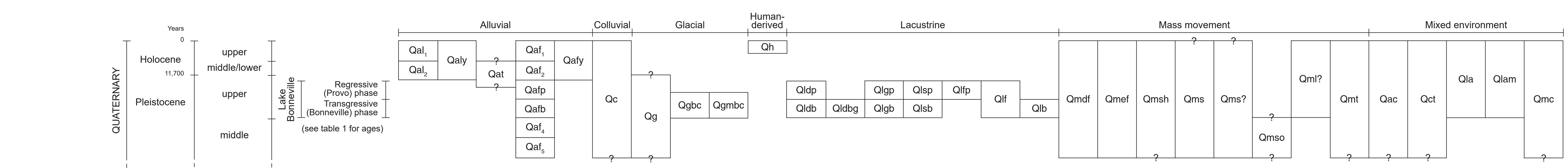
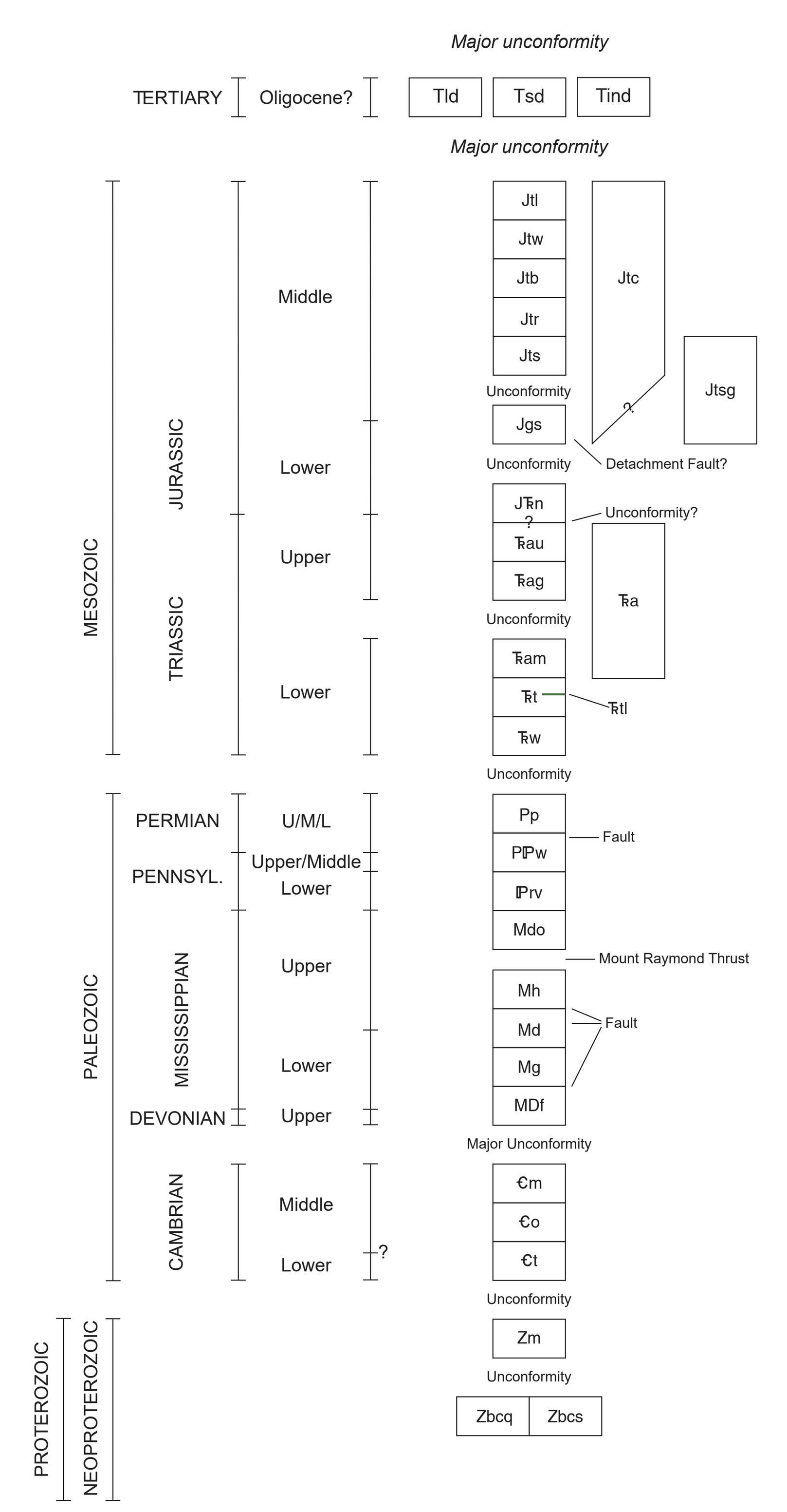


Figure 2. *Total alkali-silica classification for igneous rocks of the Sugar House 7.5-minute quadrangle (values have been normalized to 100% on a volatile-free basis). Classification diagram from Le Bas and others (1986), with plutonic (holocrystalline) names from Middlemost (1994) in parentheses; see McKean (2017c) for whole-rock geochemical data; silicic dikes (*Tsd*), intermediate dikes and sills (*Tind*), and lamprophyric dikes and sill (*Tld*).*

CORRELATION OF GEOLOGIC UNITS





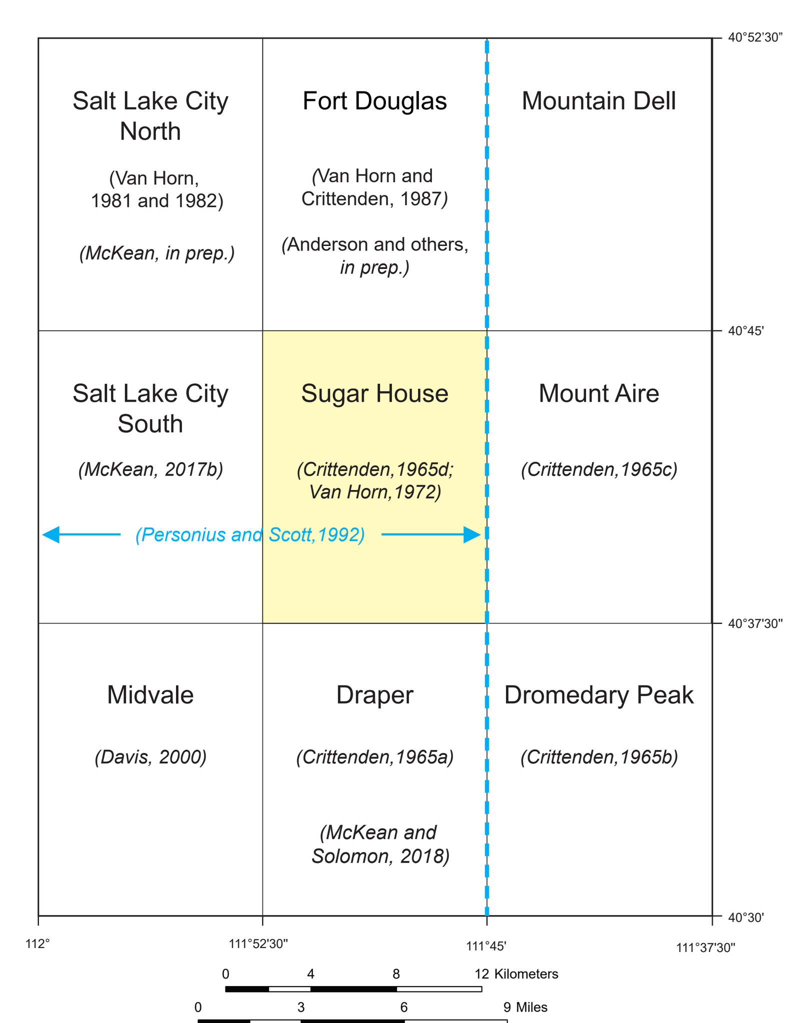
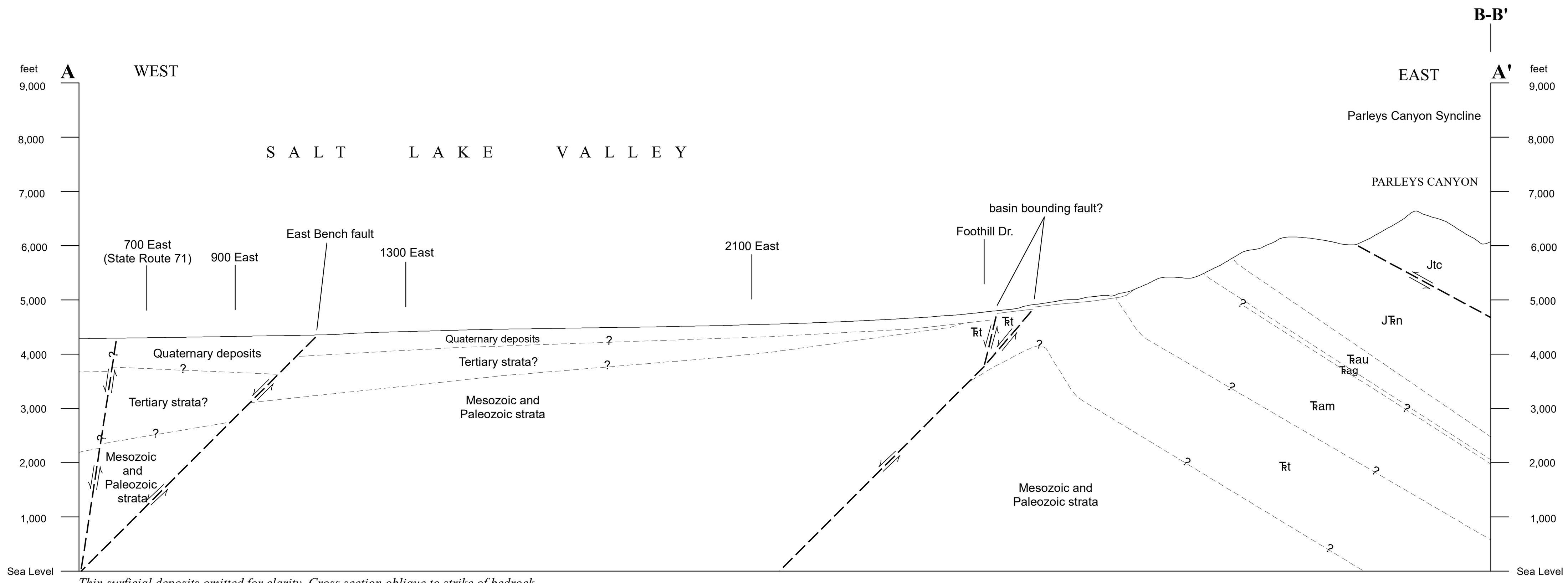
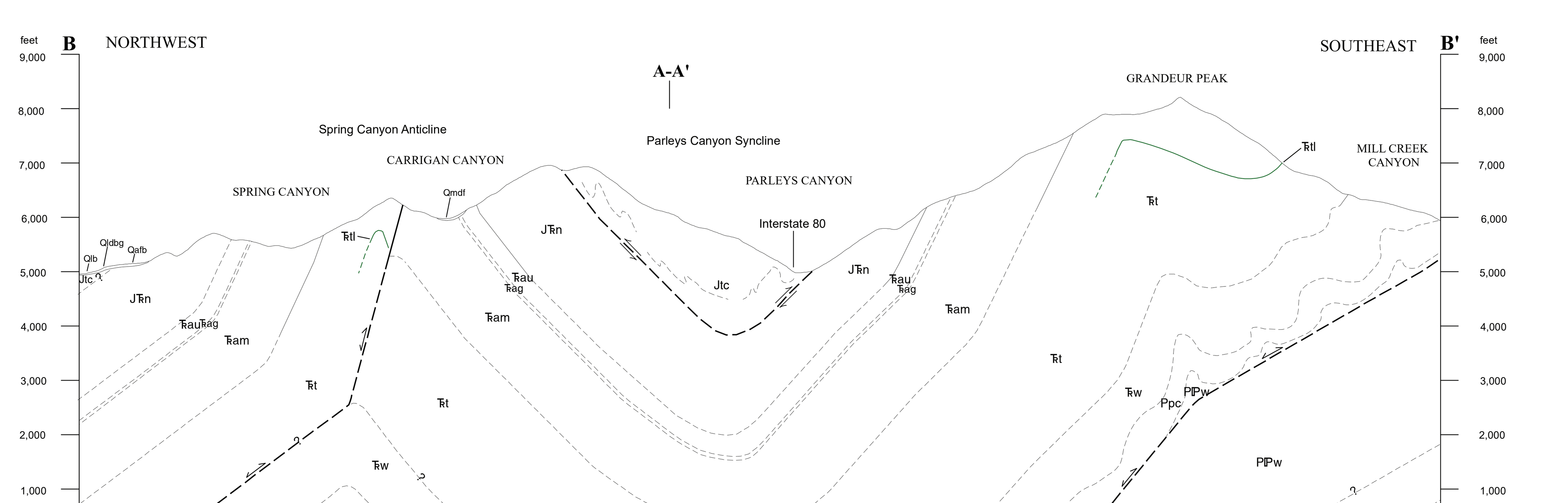


Figure 1. Index map showing selected geologic maps available for the Sugar House and surrounding 7.5' quadrangles.



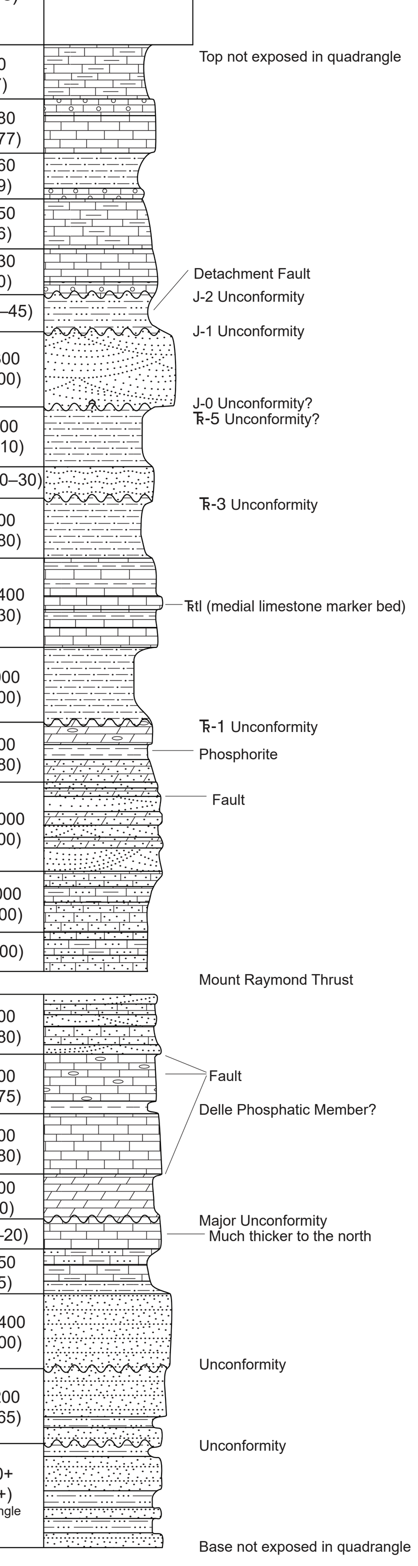
Thin surficial deposits omitted for clarity. Cross section oblique to strike of bedrock.
Created using data from Cook and Berg (1961), Arnow and others (1970), Mattick (1970), Meiiji Resource Consultants (1983), Zoback (1983), Crone and Harding (1984), and Case (1985).



Thin surficial deposits omitted for clarity.
Schematic folds shown in Twin Creek Limestone (Jtc), Woodside Shale (T̵Rw), Park City Formation (Ppc), and Weber Quartzite (PIPw).

LITHOLOGIC COLUMN

AGE		FORMATION		MAP UNIT SYMBOL		THICKNESS Feet (Meters)	LITHOLOGY
JURASSIC	MIDDLE	Twin Creek Limestone	Leeds Creek Member	Jtc	Jtl	>1500 (>457)	
			Watton Canyon Member		Jtw	420–580 (128–177)	
			Boundary Ridge Member		Jtb	120–160 (36–49)	
			Rich Member		Jtr	220–250 (67–76)	
			Sliderock Member	Jtsg	Jts	120–130 (37–40)	
	? LOWER	Gypsum Spring Formation			? Jgs	0–150 (0–45)	
?	?	Nugget Sandstone		JT̵Rn		800–1300 (244–400)	
TRIASSIC	UPPER	Ankareh Formation	upper member	T̵Ra	T̵Rau	500–700 (150–210)	
			Gartra Grit Member		T̵Rag	70–100 (20–30)	
	LOWER		Mahogany Member		T̵Ram	800–900 (245–280)	
		Thaynes Formation		T̵Rt		1800–2400 (550–730)	
		Woodside Shale		T̵Rw		400–1000 (120–300)	
PERMIAN	LOWER	Park City and Phosphoria Formations		Pp		700–900 (210–280)	
PENNS.	U M	Weber Sandstone		PIPw		1200–3000 (365–900)	
	L	Round Valley Limestone		IPrv		500–1000 (120–300)	
MISSISSIPPIAN	UPPER	Doughnut Formation		Mdo		1000 (300)	
		Humbug Formation		Mh		700–900 (210–280)	
	LOWER	Deseret Limestone		Md		500–900 (150–275)	
		Gardison Limestone		Mg		350–600 (100–180)	
D	U	Fitchville Formation		MDf		150–200 (50–60)	
CAMBRIAN	MID	Maxfield Limestone		Ꞓm		0–60 (0–20)	
		Ophir Formation		Ꞓo		170–250 (50–75)	
	LOWER	Tintic Quartzite		Ꞓt		1000–1400 (300–400)	
PROTEROZOIC	NEOPROTEROZOIC	Mutual Formation		Zm		800–1200 (250–365)	
		Big Cottonwood Formation		Zbcq Zbcs		12,000+ (3800+) in quadrangle	



Not to scale

INTERIM GEOLOGIC MAP OF THE SUGAR HOUSE QUADRANGLE, SALT LAKE COUNTY, UTAH

by

Adam P. McKean

Disclaimer

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UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 687DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2018

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INTRODUCTION

Location and Geographic Setting

The Sugar House 7.5-minute quadrangle is located within Salt Lake County on the eastern margin of Salt Lake Valley and includes the mountain front of the Wasatch Range. A number of creeks flow from the Wasatch Range into the valley, including Red Butte, Emigration, Parleys, Mill, Big and Little Cottonwood Creeks, and smaller creeks. The urbanized valley floor part of the quadrangle includes the cities of Salt Lake City in the northern part, with Holladay, Millcreek Township, South Salt Lake City in the central part; Murray, Midvale, and Cottonwood Heights in the southern part; and areas of unincorporated Salt Lake County. In the Wasatch Range the quadrangle contains the Mount Olympus Wilderness area and recreation areas in Mill Creek and Neffs Canyons, and other parts of the Wasatch National Forest. The Sugar House quadrangle was mapped to provide the basis for identifying and delimiting potential geologic hazards for derivative Utah Geological Survey (UGS) geologic hazard maps of urban and rapidly developing areas being prepared by the UGS Geologic Hazards Mapping Initiative.

GEOLOGY

Bedrock Stratigraphy and Geologic Structure

Bedrock exposed in the Wasatch Range covers an expansive geologic history from Precambrian to Tertiary with significant breaks in the Cambrian to Devonian and Cretaceous to early Tertiary. The oldest rock unit exposed in the quadrangle is the Neoproterozoic Big Cottonwood Formation, which was deposited in a rift basin (Crittenden, 1977; Dehler and others, 2010). In Big Cottonwood Canyon southeast of the quadrangle, the Neoproterozoic Mutual Formation and underlying Mineral Fork Formation unconformably overlie the Big Cottonwood Formation (Crittenden, 1977). In this quadrangle the Mineral Fork Formation is missing at the unconformity. An unconformity is also present below the Cambrian Tintic Quartzite, which overlies the Mutual Formation. The Ophir Formation conformably overlies the Tintic and the lower part of the Maxfield Limestone conformably overlies the Ophir. Most of the Maxfield Limestone and other Cambrian, Ordovician, Silurian, and most Devonian strata are missing in the quadrangle due to the erosion and non-deposition during Ordovician Tooele arch (Hintze, 1959) and the Devonian Stansbury uplift (Rigby, 1959; Morris and Lovering, 1961). Carbonate and clastic rocks (limestone, dolomite, shale and sandstone) were deposited over the uplift; in the map area these rocks are in the Late Devonian to Early Mississippian Fitchville Formation. Overlying the Fitchville Formation are the Mississippian Gardison Limestone, Deseret Limestone, and Humbug Formation. The Late Mississippian Doughnut Formation is in fault contact (Mount Raymond thrust) with the Humbug and the Deseret. The lower Doughnut, seen in nearby areas, is missing and may have been faulted out. The overlying Early Pennsylvanian Round Valley Limestone is also different (more carbonate and fossiliferous) than in nearby areas. The Middle Pennsylvanian to Early Permian Weber Sandstone overlies the Round Valley and has a detachment fault in the upper part near the contact with the overlying Early Permian Park City Formation. Shale or saline rocks of the Weber Sandstone seen in other areas are not recognized here due to the detachment fault. The Park City Formation is a mixed unit divided into two parts, with the lower part overlain by the intervening Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation. The Meade Peak is overlain by a map unit that includes upper members of the Phosphoria and Park City Formations. The Early Triassic marine Woodside Shale and Thaynes Formation overlie the upper Park City Formation and Phosphoria unit. The TR-1 unconformity may separate the Woodside Shale from the Park City Formation unit (Pipiringos and O'Sullivan, 1978), as a thin part of the Dinwoody Formation is mapped at the base of the Woodside Shale, or the Dinwoody Formation may just be thin. The Mahogany Member of the Ankareh Formation conformably overlies the Thaynes Formation. Fluvial and lacustrine deposits of the Gartra Grit Member and upper member of the Ankareh Formation overlie the Mahogany Member. The TR-3 unconformity is likely present at the base of the Gartra Grit on the north side of the Uinta Mountains and Cottonwood Arch (Pipiringos and O'Sullivan, 1978). The Early Jurassic Nugget Sandstone is separated from the underlying Ankareh by the J-0 unconformity (Pipiringos and O'Sullivan, 1978; Imlay, 1980); however, others have interpreted the Nugget-Ankareh contact as conformable (Sprinkel and others, 2011; Irmis and others, 2015) with the TR-5 unconformity in the upper Ankareh (Lucas, 1993). The contact between the Nugget Sandstone and Gypsum Spring Formation is the J-1 unconformity (Pipiringos and O'Sullivan, 1978; Sprinkel and others, 2011) but in this quadrangle is a detachment fault. The uppermost pre-thrust unit exposed in the quadrangle is the Middle Jurassic Twin Creek Limestone, which is separated from the Gypsum Spring Formation by the J-2 unconformity (Imlay, 1967, 1980; Pipiringos and O'Sullivan, 1978; Sprinkel and others, 2011).

During the Jurassic to early Tertiary, contractional folding and faulting deformed bedrock units of the region (see for example Willis, 1999; DeCelles, 2006), leading to numerous unconformities, and as a part of this deformation, synorogenic deposits. The Late Cretaceous Mount Raymond thrust system developed with east-southeast directed slip and associated folding (see for example Bradley and Bruhn, 1988; Yonkee and Weil, 2011). Later, these thrusts and folds were tilted northward and folded by the Cottonwood arch. The Cottonwood arch is a broad, domal, east-plunging antiform in the central Wasatch Range (see Eardley, 1968, 1969; Crittenden, 1977). In the Sugar House quadrangle, uplift of the Cottonwood arch caused Neoproterozoic rocks of the Big Cottonwood Formation and Mutual Formation and overlying units to dip northward into the Parleys Canyon syncline. The timing of the Cottonwood arch is a subject of continued debate; to the east the possibly related Uinta Mountain uplift is Late Cretaceous to Eocene (Bradley and Bruhn, 1988; Yonkee and Weil, 2011). The arch is coeval with intrusion of the Oligocene Little Cottonwood stock (John and others, 1997; Vogel and others, 2001), and possibly continues into the middle-Miocene with movement on the Wasatch fault zone (Parry and Bruhn, 1986). Movement on both the Mount Raymond thrust system and a Mill Creek Canyon thrust fault are apparently down to the north normal and consistent with a reversal of fault slip due to uplift of the Cottonwood arch.

Normal faults in the bedrock in the quadrangle may be evidence for Eocene extension, “collapse” of the orogenic belt, or these faults maybe related to late Miocene and younger basin and range faulting. Oligocene magmatism related to intrusions in the Cottonwood canyons (Constenius, 1996; Vogel and others, 1997, 2001; McKean, 2017c), is likely the source for a number of small intrusive dikes and sills (Tld, Tsd, and Tind) in the Sugar House quadrangle. The dikes and sills lack specific age control but are assumed to be Oligocene, the same age as the Cottonwood Canyons intrusions. Late Miocene to recent (ca. 18-0 Ma) extensional basin and range faulting (see Parry and Bruhn, 1986) on Wasatch fault zone is expressed in the area as the Salt Lake City segment of the Wasatch fault zone (see Personius and Scott, 1992), which separates the Salt Lake Valley from the Wasatch Range.

Surficial Geology

Surficial geologic deposits within the quadrangle consist of alluvial, colluvial, glacial, lacustrine and deltaic, marsh, and mass-movement deposits. They are unconsolidated deposits of Quaternary age that overlie the bedrock in the valleys and mountains and are dominated by deposits of late Pleistocene Lake Bonneville. Lake Bonneville was a large lake that covered much of northwestern Utah and adjacent parts of Idaho and Nevada in the Bonneville basin between 30,000 and 13,000 years ago (all ages in this section are in calibrated years, see table 1) and can be divided into transgressive, overflowing, and regressive phases (Oviatt and others, 1992; Godsey and others, 2005, 2011; Oviatt, 2015; see table 1). Along the range front these lacustrine deposits interfinger with alluvial deposits that form alluvial fans and fan-deltas. Table 1 provides time constraints and elevations for many geologic features and map units in the quadrangle.

The oldest surficial deposits exposed in the quadrangle are alluvial-fan deposits (Qaf_4, Qaf_5) of pre-Bonneville age. They are exposed above the highest Lake Bonneville shoreline along the Wasatch Range, and likely underlie Lake Bonneville deposits in Salt Lake Valley. The Qaf_4 fans are cut by Lake Bonneville shorelines and overlain by Lake Bonneville deposits near Neffs Canyon and in other places along the Wasatch Range (Personius and Scott, 1992; McKean and Solomon, 2018). On the north side of Mount Olympus Qaf_5 fans are deposited higher upslope then Qaf_4 fans and are incised, with younger alluvial fans (Qafy) inset into the older deposits. The Qaf_4 fans were deposited between the Lake Bonneville and Little Valley and/or Poles Point lake cycles (Scott and others, 1983; McCoy, 1987; Scott, 1988b, 1988c). The Qaf_5 fans are likely pre-Little Valley and/or Poles Point lake cycles (Machette, 1992).

Glacial deposits in and near Neffs Canyon (Qg, Qgbc, and Qgmbc) are mapped from near creek level to high-elevation cirques just east of the map area. While the deposits lack direct age control, they do have similar morphology, soil development, and vegetation to deposits in Big and Little Cottonwood Canyons that are of Bells Canyon age. In the Draper quadrangle to the south, Madsen and Currey (1979) demonstrated that the Bells Canyon glacial deposits are correlative with Pinedale glaciation (marine oxygen-isotope stage 2; Oviatt and others, 1999), and the Dry Creek glacial deposits are correlative with Bull Lake glaciation (marine oxygen-isotope stage 6; Madsen and Currey, 1979; Oviatt and others, 1999) from a type area in central Wyoming. The Bull Lake glaciation in the Wind River Range, Wyoming, has an age of about 130 to 100 ka (Phillips and others, 1997). The Madsen and Currey (1979) correlation was based on the degree of weathering, geologic relationships with Lake Bonneville deposits, and a ^{14}C age of 26,080 ± 1200/1100 yr B.P. on the underlying Majestic Canyon paleosol. Madsen and Currey (1979) named these younger glacial deposits the Bells Canyon till, and Personius and Scott (1992) mapped the deposits as “till” and “outwash of Bells Canyon age.” Based on ^{10}Be exposure ages measured from granite boulders in moraines north of the mouth of Little Cottonwood Canyon, the glacial maxima in the Bells Canyon till occurred about 17 to 15 ka (Lips and others, 2005; Laabs and others, 2011).

A number of Quaternary geologic hazards are mapped in the quadrangle, including landslide deposits (Qms) and surface fault ruptures (scarps). The study area contains a number of potential Holocene-active normal faults, including the East Bench and Cottonwood faults of the Salt Lake City segment of Wasatch fault zone. Other potentially active Quaternary faults in the quadrangle include a queried fault Van Horn (1972) originally mapped to the west of the East Bench fault and a concealed basin-bounding fault along the mountain front with evidence for displacement of pre-Bonneville deposits found in an exposure along Parleys Creek (Van Horn, 1972; Scott and Shroba, 1985) (now concealed by the construction of the east interchange of Interstate 215 and 80). These faults and other geologic hazards are described and discussed in more detail in the "Surface Fault Rupture" subsection of the "Selected Geologic Hazards" section.

PREVIOUS MAPPING

Numerous earlier geologic maps of the Salt Lake Valley and Sugar House quadrangle exist for the area (figure 1). These geologic maps focus on the bedrock geology, including Granger and others (1952) at a scale of 1:62,500 and Marsell and Threet (1960), who showed the geology of the Wasatch Range in a regional compilation at a scale of 1:63,360. Bryant (1990) mapped the Salt Lake City 30′ x 60′ quadrangle at a scale of 1:100,000. Crittenden (1965d) mapped the bedrock of the Sugar House quadrangle in greater detail at a scale of 1:24,000; I revised his bedrock map for this map.

Early maps of Quaternary deposits in the Salt Lake Valley include: (1) Morrison (1965) at 1:24,000 scale that included the southern part of the Sugar House quadrangle; (2) Van Horn (1972) at 1:24,000 scale of the entire Sugar House quadrangle; and (3) Miller (1980) at 1:100,000 scale of the Wasatch Front. For this map I revised those early interpretations of the Quaternary geology, and particularly of Lake Bonneville stratigraphy. The map of Scott and Shroba (1985) of the surficial geology of eastern Salt Lake Valley at 1:24,000 scale was the primary source used by Personius and Scott (1992) to compile a surficial geologic map of the Salt Lake City segment of the Wasatch fault zone at 1:50,000 scale. Also of interest are numerous derivative maps produced by Van Horn and others for the Salt Lake Valley in the Sugar House quadrangle that examined a range of topics from geologic hazards, to groundwater, to sources of construction materials, all published as a series (or folio) of maps of the Sugar House quadrangle in U.S. Geological Survey Miscellaneous Geologic Investigations Map I-766-(B through O) (see appended Sugar House Folio References at the end of the References section).

My mapping combines the separate bedrock mapping of Crittenden (1965d), surficial geologic mapping from two sources (Van Horn, 1972; Personius and Scott, 1992), a soils map (U.S. Natural Resources Conservation Service [USNRCS], 2015), and my revised stratigraphy of Quaternary surficial deposits. Contacts and units were field checked and changed where needed based on field observations and interpretation in 2015–2016. I remapped the glacial deposits, revised the bedrock geology, revised the traces of the Wasatch fault zone, and remapped landslides. The surficial geology of the quadrangle was mapped following the UGS surficial mapping guidelines that emphasize landforms and depositional processes (Doelling and Willis, 1995).

METHODS

Mapping of surficial deposits by the UGS is based on age and depositional environment or origin. The letters of the map units indicate (1) age (Q = Quaternary), (2) depositional environment or origin, determined from landform morphology, bedding, or other distinctive characteristics of the deposits, (3) grain size(s), and (4) age (Doelling and Willis, 1995) as related to the phases of Lake Bonneville. For example, unit Qaf_4 is a Quaternary (Q) surficial deposit of alluvial fan origin (af), and the subscript number four indicates it is older than Lake Bonneville. Letters "y" and "o" in place of a subscript indicate deposits younger and older than Lake Bonneville, respectively. Unit numbers indicate relative age with "1" being the youngest and increasing with age.

Mapping for the project was done using stereographic pairs of aerial photographs, including black-and-white aerial photographs at a scale of 1:20,000 and 1:10,000 from the U.S. Department of Agriculture (USDA) Agricultural Stabilization and Conservation Service (1937, 1958), black-and-white oblique aerial photography at various scales from 1:12,000 to 1:5000 from the Woodward-Lundgren & Associates Wasatch fault investigation (Cluff and others, 1970, complied in Bowman and others, 2015), and natural color aerial photographs at a scale of 1:15,840 from the USDA Forest Service (2001). Some unit contacts were mapped with the aid of USNRCS (2015) soil map data. Gravel pit outlines and some contacts were revised using 2012 orthophotographs (Utah Automated Geographic Reference Center [UAGRC], 2012). Most Quaternary faults, glacial deposits, landslides, and some additional contacts were revised using 2-meter and 0.5-meter lidar elevation data (UAGRC, 2006, 2013–2014). The geologic map was made by transferring the geology from the aerial photographs to a geographic information system (GIS) database in ArcGIS for a target scale of 1:24,000, using the lidar data, orthophotographs of Salt Lake County (UAGRC, 1977), and 2012 orthophotographs (UAGRC, 2012).

Surficial geology and the Cottonwood fault of the Wasatch fault zone were mapped in the areas disturbed by sand and gravel operations using the black-and-white aerial photographs (USDA, 1937) to show the pre-excavation geology and cross-cutting relationships. Pit outline(s) and fill pattern(s) on the map indicate areas of land disturbed by excavations (plate 1). The pre-excavation surficial geology, based on 1937 aerial photographs, is shown on the map so the Cottonwood fault is located correctly, along with the units that it offsets, and in the correct geologic context. At the time my map was created most of the evidence of the Cottonwood fault had been destroyed and most surficial deposits mapped in these areas had been removed by sand and gravel operations.

Cross-section A-A′ was created by combining available subsurface and gravity data from Cook and Berg (1961), Arnow and others (1970), Mattick (1970), Meiiji Resource Consultants (1983), Zoback (1983), Crone and Harding (1984), and Case (1985). Well logs from Case (1985), Meiiji Resource Consultants (1983), and others compiled online (UGS, undated) were used to estimate the subsurface contact between Quaternary unconsolidated deposits and Tertiary semiconsolidated to consolidated strata. West of 2100 East the depth to Mesozoic and Paleozoic bedrock is a minimum depth below unconsolidated and semiconsolidated material inferred from water well logs in the area (online well data from Utah Division of Water Rights, 2009). The actual depth to bedrock could be much greater, especially west of the East Bench fault.

SELECTED GEOLOGIC HAZARDS

Geologic hazards in the map area include surface fault rupture, landsliding (Qmsh, Qms, Qms?, Qmso, Qmc), and flooding (Qal_1, Qac, Qafy, and Qaly) as noted in the following sections. Other potential geologic hazards include debris flow (Qac, Qafy, and Qmdf), earthflow (Qmef), rockfall (Qmt and Qmc), earthquake ground shaking, liquefaction, tectonic subsidence/tilting, expansive soils, collapsible soils, shallow groundwater, corrosive soils, radon, and other problem soils. For example, alluvial and marsh deposits (Qlam) can indicate areas of shallow groundwater, while clay-rich lacustrine deposits (Qlf and Qlfp) can indicate soil problems. See the map unit descriptions and geologic map (plate 1) for more information and the locations of potential hazards. Additional geologic hazards may exist but are not addressed in this report. Comprehensive site-specific geotechnical and geologic hazard investigation are recommended.

Surface Fault Rupture

The Salt Lake City segment of the Wasatch fault zone includes three subsections that overlap, and are from north to south, the Warm Springs, East Bench, and Cottonwood faults (Personius and Scott, 1992). In the map area the East Bench and Cottonwood faults have scarps that indicate surface fault rupture; these faults are discussed below. Two other faults in the quadrangle are also discussed, a queried fault west of the East Bench fault and a concealed fault along the mountain front. Numerous available consultant surface-fault-rupture investigations in the Sugar House quadrangle provided valuable new information for the mapping of the fault location in the quadrangle (see for example, McKean, 2017a).

Cottonwood Fault

The Cottonwood fault is a roughly north-south trending down-to-the-west normal fault zone that bounds the east side of the Salt Lake Valley. It separates the valley floor from the Wasatch Range as far north as Mount Olympus and appears to terminate just north of Casto Spring. The fault continues south of the quadrangle but its trace has mostly been obscured by sand and gravel operations and disturbed by residential and commercial property development. Timing of surface-faulting earthquakes on the Cottonwood fault has not been studied in the quadrangle; for a detailed description of paleoearthquake timing on the fault in the Draper quadrangle see Swan and others (1981), Schwartz and Lund (1988), Black and others (1996), McCalpin (2002), and Hiscock and DuRoss (2016). For earthquake timing and recurrence rates for the entire Salt Lake City segment see DuRoss and Hylland (2015).

East Bench Fault

The East Bench fault is also a down-to-the-west normal fault zone. Offset on the Cottonwood fault "shifts" west to the East Bench fault near the intersection of Holladay Road and Highland Drive (see Marsell, 1964a, 1964b, 1969; Scott and Shroba, 1985). Located farther west into the Salt Lake Valley, the East Bench fault is a roughly north-south trending fault zone through the central part of the quadrangle. Timing of surface-faulting earthquakes on the East Bench fault in the map area has not been studied, but for paleoearthquake timing on the fault north of the quadrangle see Machette and others (1992) and DuRoss and others (2014). For earthquake timing and recurrence rates for the entire Salt Lake City segment see DuRoss and Hylland (2015). For a detailed discussion of the East Bench fault's location and description see Marsell (1964a, 1964b), Scott and Shroba (1985), and Personius and Scott (1992).

Fault West of the East Bench Fault

Van Horn (1972) mapped a possible fault west of the East Bench fault (a queried fault near the west quadrangle border), but Scott and Shroba (1985) and Personius and Scott (1992) did not show this fault. I have shown the fault even though the trace is obscured by development. North-south trending, down-to-the-west scarps that are subparallel to the East Bench fault are visible between ~1800 S and ~4000 S on the 0.5-meter lidar image (UAGRC, 2013–2014). Evidence and related observations on the fault include: (1) profiles from 0.5-meter lidar data across the feature(s) show subdued or eroded scarps between 5 and 10 feet (1.5 to 3 m) high; (2) faint scarps on 1937 aerial photographs; (3) scarps that cross elevation contour lines, indicating they are not shorelines; and (4) a spring near Nibley Park is near the trace and may indicate fault disruption of groundwater. The scarps are absent on younger alluvial deposits (Qaly), indicating offset is older than these late Holocene channels. The scarps are present on Lake Bonneville fine-grained deposits (Qlf) and post-Lake Bonneville alluvial fans (Qafy), suggesting a post-Lake Bonneville age; alternatively, the subdued nature of the scarps may indicate they are older faults over which lake sediments and post-Lake Bonneville alluvial fans are draped. No subsurface investigations have yet confirmed the existence of this fault and more work is needed to determine the nature and age of faulting.

Older Basin-Bounding Fault(s)

Crittenden (1965d) showed a concealed fault from Mount Olympus to Bonneville Park. Van Horn (1972) showed a basin-bounding fault cutting post-Lake Bonneville fan alluvium at the mouth of Parleys Canyon (now obscured by the construction of Interstates 80 and 215). However, Scott and Shroba (1985) suggested the offset occurred between Lake Bonneville and the Little Valley lake cycle. Evidence of faulting continues northward to an area of shallow bedrock near Foothill Drive. East of Foothill Drive this bedrock is offset relative to shallow bedrock west of Foothill Drive, as is shallow bedrock west of the Bonneville shoreline compared to exposures to the east (see Marsell, 1964a, 1964b, and 1969). Offset of pre-Lake Bonneville sediments in the Fort Douglas 7.5-minute quadrangle to the north provides additional evidence for the fault. Everitt (1979) noted a site at the University Hospital where pre-Lake Bonneville strata are offset by faulting. Pavlis and Smith (1980) and Scott and Shroba (1985) discussed the Virginia Street fault (City Cemetery fault of Van Horn and Crittenden, 1987), which could be a northern extension of this basin-bounding fault. Unfortunately, development at these sites has destroyed surficial evidence of this pre-Lake Bonneville fault. Some uncertainty remains regarding the location and nature of faulting along the south side of the Salt Lake salient and more study is needed.

Landslides

In the Sugar House quadrangle several landslides are active or have evidence of historical movement (Qmsh) that is visible on various sets of aerial photographs or through personal accounts from landowners of active movement. Other landslides (Qms, Qms?, and Qmc) and older landslides (Qmso) with subdued morphology (suggesting that they are older, weathered, and have not moved recently) continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); age and stability determinations require detailed geotechnical investigations. Also mapped are a few debris-flow (Qmdf) and earth-flow (Qmef) deposits. Additionally, younger alluvial fans (Qaf_1 and Qafy) contain undifferentiated debris-flow deposits and require detailed geotechnical investigations for risk reduction.

Flooding

Flood and other debris-flow hazard areas are primarily in, but are not limited to, alluvial channels (Qal_1, Qac, Qmc, and Qaly) and areas mapped as alluvial-fan deposits (Qaf_1 and Qafy), particularly steep alluvial fans. Delineation of flood and debris-flow hazards require detailed geotechnical investigation.

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qal_1 **Level-1 stream and floodplain deposits** (upper Holocene) – Poorly to moderately sorted pebble and cobble gravel, locally bouldery, with a matrix of sand and silt; contains thin discontinuous sand lenses; subangular to rounded clasts;

thin to medium bedded with planar bedding and cross-bedding; mapped in channels and active floodplains of Big and Little Cottonwood Creeks and on terraces less than 5 feet (1.5 m) above stream channels; locally includes minor colluvial deposits along steep stream embankments; equivalent to the younger part of young stream deposits (Qaly), but differentiated because active channels and bar-and-swale topography of Qal_1 can be mapped separately; some stream deposits are human modified (channelized, including channel embankments), but are too small to map separately as Qh; estimated thickness less than 15 feet (5 m).

Qal_2 **Level-2 stream deposits** (middle Holocene to upper Pleistocene) – Poorly to moderately sorted pebble and cobble gravel, locally bouldery, with a matrix of sand and silt; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded with planar bedding and low-angle cross-bedding; forms terraces 5 to 15 feet (1.5–5 m) above and adjacent to channels and floodplains of Big Cottonwood and Little Cottonwood Creeks that may be in the active floodplain; inset into Lake Bonneville deposits; equivalent to the older part of Qaly, but differentiated from level-1 stream deposits (Qal_1) where level-2 stream deposits are characterized by subdued bar-and-swale topography so can be mapped separately; estimated thickness less than 15 feet (5 m).

Qaly **Young stream deposits, undivided** (Holocene to upper Pleistocene) – Poorly to moderately sorted pebble and cobble gravel, locally bouldery, with a matrix of sand and silt; mapped in channels and active floodplains of Big Cottonwood, Parleys, Emigration, and Mill Creeks and small creeks; locally includes small alluvial-fan and colluvial deposits; includes level-2 stream deposits (Qal_2) incised by active streams with level-1 stream deposits (Qal_1); Qal_1 and Qal_2 deposits cannot be mapped separately, due to lack of bars and swales and because patches of deposits are too small to show separately at map scale; postdates regression of Lake Bonneville from the Provo shoreline and lower shorelines; thickness variable, probably less than 30 feet (10 m).

Qat **Stream-terrace deposits** (middle Holocene? to upper Pleistocene?) – Poorly to moderately sorted, pebble and cobble gravel, locally bouldery, with a matrix of sand and silt; contains thin sand lenses; subangular to rounded clasts; thin to thick bedded with planar bedding and low-angle cross-bedding; mapped along Big Cottonwood, Parleys, and Mill Creeks where age of deposits is unknown, but constrained since inset into Qldp (post-Provo) and cut by Qaly so likely regressive phase Lake Bonneville; may include minor alluvial fan, lacustrine, and colluvial deposits; estimated thickness 5 to 20 feet (1.5–6 m).

Qaf_1 **Level-1 alluvial-fan deposits** (upper Holocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; deposited by debris flows, debris floods, and streams at the mouth of Tolcats Canyon; may contain small debris-flow deposits (Qmdf) that cannot be shown separately at map scale; equivalent to the younger part of young alluvial-fan deposits (Qafy) but mapped where active small, discrete fans are not incised by younger channels and can be shown separately; no Lake Bonneville shorelines are present on these alluvial fans; estimated thickness less than 30 feet (10 m).

Qaf_2 **Level-2 alluvial-fan deposits** (middle Holocene to upper Pleistocene) – Poorly sorted pebble and cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and minor clay; clasts subangular to well-rounded; thin to thick planar bedding and low-angle cross-bedding; deposited by debris flows, debris floods, and streams; present downslope from regressive phase Lake Bonneville deltaic deposits (Qldp) and incised by active streams along Emigration and Mill Creeks and where several small creeks approach the East Bench fault; equivalent to the older part of Qafy, but mapped separately based on incision by active streams; exposed thickness less than 15 feet (5 m).

Qafy **Younger alluvial-fan deposits, undivided** (Holocene to upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; downslope gradational into mixtures of sand, silt, and clay on gentler slopes; clasts subangular to well-rounded; thin to thick planar bedding and low-angle cross-bedding; deposited by debris flows, debris floods, and streams at the mouths of small canyons draining the Wasatch Range and at the mouth of Neffs Canyon, and Emigration, Parleys, and Mill Creeks; includes both ages of younger alluvial-fan deposits (Qaf_1 and Qaf_2); postdates the regression of Lake Bonneville from the Provo shoreline and lower shorelines; a more specific age cannot be determined where incision by active streams in uncertain, or where areas of Qaf_1 and Qaf_2 are too small to show separately at map scale; Lake Bonneville shorelines are not present on these alluvial fans; most deposits between about 10 and 40 feet (3–12 m) thick but could be locally thicker.

Qafp **Alluvial-fan deposits, related to Provo shoreline and regressive phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and minor clay; clasts typically angular but well rounded where derived from Lake Bonneville gravel; medium to very thick bedded; deposited by debris flows, debris floods, and streams at the mouth of Big Cottonwood, Mill Creek, Parleys, and Emigration Canyons; downslope gradational into regressive Lake Bonneville deltaic deposits (Qldp); mapped by Personius and Scott (1992) as stream alluvium related to the regressive phase of Lake Bonneville (their unit alp) which are topset alluvial beds of a delta; deposits have fan-shaped morphologies, are mostly above the Provo shoreline, and grade downslope into deltaic deposits (Qldp); Qafp deposits are likely the subaerial part of a fan-delta complex; equivalent to the younger part of level-3 alluvial-fan deposits (Qaf_3) mapped elsewhere along the Wasatch Front (see af3 of Nelson and Personius, 1993), but in the Sugar House quadrangle only mapped separately; fan deposits near Mill Creek, Parleys, and Emigration Canyons have benches that "step down" to the north, likely indicating incision as the fans were deposited during Lake Bonneville regression; exposed thickness less than 30 feet (10 m).

Qafb **Alluvial-fan deposits, related to Bonneville shoreline and transgressive phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and minor clay; clasts subangular to rounded; thin to very thick planar bedding and low-angle cross-bedding; deposited by debris flows, debris floods, and streams at the mouths of Spring, Mill Creek, and smaller canyons; appear graded to slightly below the Bonneville (highest) shoreline of Lake Bonneville; inset into pre-Lake Bonneville alluvial-fan deposits (Qaf_4) and incised by post-Lake Bonneville alluvial-fan deposits (Qafy); equivalent to the older part of level-3 alluvial-fan deposits (Qaf_3) mapped elsewhere along the Wasatch Front (see Nelson and Personius, 1993), but mapped separately in the Sugar House quadrangle; exposed thickness less than 30 feet (10 m).

Qaf_4 **Level-4 alluvial-fan deposits, pre-Bonneville lake cycle** (upper to middle Pleistocene) – Poorly sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; clasts subangular to well-rounded; thin to very thick planar bedding and low-angle cross-bedding; forms small fans and fan remnants above the Bonneville shoreline at the mouth of Spring and Neffs Canyon, and in Olympus Cove; locally cut by the Bonneville shoreline; deposits of the same age likely underlie Lake Bonneville deposits in Salt Lake Valley, and are probably gradational into lacustrine deposits of the Little Valley or Pokes Point lake cycles; Little Valley lake cycle peaked at about 138,000 ^{14}C yr. B.P. (McCalpin, 1986), with the highstand of the Little Valley lake at about 4920 feet (1500 m) (Scott and others, 1983) or 5000 feet (~1525 m) (Scott, 1988b); the Pokes Point lake cycle highstand is at an elevation of 4685 feet (1428 m) in Little Valley (McCoy, 1987), with the ages for the Pokes Point lake cycle varying from more than ~271,000 years ago (^{230}Th corrected age, Balch and others, 2005), to oxygen-isotope stage 12 or about 430,000 years ago (Oviatt and others, 1999); exposed thickness less than 40 feet (12 m).

Qaf_5 **Level-5 alluvial-fan deposits, pre-Little Valley and/or Pokes Point lake cycles** (middle Pleistocene) – Poorly sorted, clast-supported pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; boulders are common on the weathered surface clasts subangular to rounded; thin to very thick planar bedding and low-angle cross-bedding; mapped south of Olympus Cove on north-sloping surfaces above the Bonneville shoreline; deposit lacks fan shape; Machette (1992) reported that level-5 alluvial fan-deposits (his af5), exposed in a stream gully on the divide east of Peteetneet Creek in the Payson Lakes quadrangle south of Utah Valley, contain isolated pods of Lava Creek B volcanic ash, (sanidine ^{40}Ar/^{39}Ar age of 0.640 ± 0.004 Ma on the ash from other sites) (Lanphere and others, 2002); alluvial and alluvial-fan deposits of this age likely underlie Lake Bonneville, Little Valley, or Pokes Point lacustrine deposits and interlake cycle alluvial deposits and probably gradational into deposits of pre-Pokes Point lake cycles; exposed thickness less than 30 feet (10 m).

Colluvial deposits

Qc **Colluvial deposits** (upper Holocene to middle Pleistocene?) – Pebble, cobble, and boulder gravel, commonly clast supported, with a matrix of sand, silt, and clay; clasts commonly angular to subangular, but includes some subrounded to round recycled lacustrine gravel below the Bonneville shoreline; very poorly sorted, poorly stratified, locally derived; sediment deposited by slopewash and soil creep; may include landslides, rockfalls, and debris flows that are too small to map separately; most bedrock is covered by at least a thin veneer of colluvium, but only the larger, thicker (> 3 feet [1 m]) deposits are mapped; mapped as small cones and debris aprons along the East Bench and Little Cottonwood faults; thickness between 3 and 15 feet (1–5 m).

Glacial deposits

Nomenclature of glacial deposits used here follows the work of McCoy (1977), Madsen and Currey (1979), Scott (1988a), Personius and Scott (1992), and dating of glacial deposits from Madsen and Currey (1979) and Laabs and others (2011). Deposits of Bells Canyon age are broadly equivalent to deposits of Pinedale age and those of Dry Creek age are broadly equivalent to deposits of Bull Lake age in the middle Rocky Mountains (Madsen and Currey, 1979). In the Draper quadrangle glacial deposits of Bells Canyon age were distinguished from Dry Creek age based on cross-cutting relationships where Bells Canyon moraines remained within or extended beyond the older Dry Creek moraines (McKean and Solomon, 2018) and the greater degree of weathering of clasts in the Dry Creek till (Madsen and Currey, 1979). No distinguishable Dry Creek-age moraines, based on cross-cutting relationships or degree of weathering, were identified in the Sugar House quadrangle.

Qg **Glacial deposits, undivided** (Pleistocene?) – Unsorted, non-stratified boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subrounded; mapped using lidar at the head of Norths Fork of Neffs Canyon where moraine and till deposits are visible and just south of Hobbs Peak where possible glacial deposits fill an unnamed peak's northwest-facing bowl; may include Bells Canyon and Dry Creek-age deposits; may include mass-movement and colluvial deposits too small to show at map scale; exposed thickness less than 30 feet (10 m).

Qgbc **Glacial deposits of Bells Canyon age** (upper Pleistocene) – Unsorted, non-stratified boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subrounded; mapped in Neffs Canyons where moraines and outwash are not distinct; may locally include mass-movement and colluvial deposits too small to show at map scale; likely Bells Canyon age, based on the lack of identifiable Dry Creek deposits; estimated thickness less than 30 feet (10 m).

Qgmbc **Glacial moraines of Bells Canyon age** (upper Pleistocene) – Unsorted, non-stratified boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subrounded; mapped in Neffs Canyon; distinct end, lateral, and regressional moraines; may locally include mass-movement and colluvial deposits too small to show at map scale; likely Bells Canyon age, based on the lack of identifiable Dry Creek deposits; estimated thickness less than 100 feet (30 m).

Human-derived

Qh **Fill and disturbed land** (historical) – Undifferentiated artificial (human) fill and disturbed land related to construction, road embankments, water storage, flood and debris flood control structures, bedrock mines, borrow pits, clay pits, and sand and gravel operations (commonly in Lake Bonneville deposits); the map outlines of fill and disturbed land are based on 1958 aerial photographs; outlines were updated using 2012 orthophotography; only the larger areas of disturbed land are mapped; unmapped fill is present in most developed areas; land within developed areas contains a complex and still changing mix of cuts and fills; thickness unknown.

Lacustrine deposits

Qlf **Lacustrine silt and clay, undivided** (upper Pleistocene) – Moderately sorted silt and clay with minor fine sand and locally pebble gravel; typically laminated or thin bedded; variably calcareous; ostracodes locally common; deposited in shallow to moderately deep parts of the Bonneville basin; commonly gradational upslope into lacustrine sand and silt (Qlsp); locally concealed by loess veneer; regressive Lake Bonneville shorelines typically poorly developed in contrast to shorelines on units Qlgp and Qlsp; mapped west of the East Bench fault where deposit is incised by Big and Little Cottonwood Creeks; exposed thickness less than 25 feet (7 m).

Deposits related to the Provo shoreline and regressive phase of Lake Bonneville: Located below the Provo shoreline, about 4810 to 4850 feet (1466–1480 m) in elevation in the Sugar House quadrangle (table 1).

Qldp **Deltaic deposits** (upper Pleistocene) – Moderately to well-sorted, pebble and cobble gravel with a matrix of sand and silt; locally includes thin beds of silt and sandy silt; clasts subrounded to rounded; locally weakly cemented with calcium carbonate; deposited as thin to thick planar and foreset beds; locally includes topset beds; exposed at the mouths of Big Cottonwood, Mill Creek, Parleys, and Emigration Canyons in delta-alluvial complexes related to the Provo shoreline; extent mapped from aerial photographs and lidar based on multiple regressive shorelines; exposed thickness less than 120 feet (35 m).

Qlgp **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, clast-supported, pebble to cobble gravel with a matrix of sand and pebbly sand; locally interbedded with and containing lenses of silt and sandy silt; thin to thick planar and cross-bedded beds; present north and west of Big Cottonwood Canyon below the Provo shoreline; commonly interbedded with or laterally gradational into lacustrine sand and silt (Qlsp); exposed thickness less than 60 feet (20 m).

Qlsp **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; thick to very thick bedded; commonly planar bedded, with some ripple marks and scour features; present downslope from the Big Cottonwood deltas, and downslope of the Provo shoreline gravel and sands (Qlgp); distinguished from (Qlfp) by the presence of sand as indicated in soil maps (USNRCS, 2015); exposed thickness less than 60 feet (20 m).

Qlfp **Lacustrine silt and clay** (upper Pleistocene) – Moderately sorted silt and clay with minor fine sand and locally pebble to cobble gravels; typically laminated or thin bedded; variably calcareous; ostracodes locally common; deposited in shallow to moderately deep parts of the Bonneville basin; in subsurface this deposit typically overlies lacustrine transgressive gravel, sand, silt, and clay deposits of Lake Bonneville as indicated by regressive-phase silt and clay overlying beach gravels; commonly gradational upslope into lacustrine sand and silt (Qlsp) and regressive delta deposits (Qldp); regressive shorelines typically poorly developed in contrast to unit Qldp and Qlsp; previously mapped by Personius and Scott (1992) as lacustrine clay and silt that was not separated into transgressive and regressive deposits, but here mapped as regressive due to their proximity to regressive delta deposits (Qldp), and the appearance of regressive beach gravels over silt and clay in consultant trenches observed near 3300 South and Highland Drive; Qlfp may include some undifferentiated transgressive deposits; Van Horn (1972) mapped the regressive silt and clay deposits as the Bonneville Formation (bm and bc) and Draper Formation (dm), these terms are no longer used (Scott and others, 1983); exposed thickness less than 15 feet (5 m), but total thickness may exceed several tens of feet.

Deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville: Mapped between the Bonneville and Provo shorelines. The Bonneville shoreline is at elevations from about 5160 to 5230 feet (1570–1595 m) in the Sugar House quadrangle (table 1).

Qldb **Deltaic deposits, undivided** (upper Pleistocene) – Moderately to well-sorted gravel and sand, locally including thin beds of silt and sandy silt; clasts subrounded to rounded; thin to thick planar and cross-bedded foreset beds; locally includes topset alluvial beds; locally weakly cemented with calcium carbonate; undivided (Qldb) where exposed in bluffs between streams or below terraces, subdivided into a gravelly unit (Qldbg) where delta contains clast-supported, pebble and cobble gravel in a matrix of sand and silt; present near the mouth of Big Cottonwood Canyon; previously mapped near the mouth of Big Cottonwood Canyon as outwash of Bells Canyon age by Personius and Scott (1992; gbco), but mapped here as deltaic based on the delta fan-shape and moderately to well-sorted, well-rounded gravel and sand in planar and foreset beds exposed in sand and gravel pits; exposed thickness less than 130 feet (40 m).

Qldbg **Deltaic gravel and sand** (upper Pleistocene) – Moderately to well-sorted gravel and sand, locally including thin beds of silt and sandy silt; clasts subrounded to rounded; thin to thick planar and cross-bedded foreset beds; locally includes topset alluvial beds; locally weakly cemented with calcium carbonate; undivided (Qldb) where exposed in bluffs between streams or below terraces, subdivided into a gravelly unit (Qldbg) where delta contains clast-supported, pebble and cobble gravel in a matrix of sand and silt; present near the mouth of Emigration Canyon; exposed thickness less than 130 feet (40 m).

Qlgb **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, clast-supported, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand and pebbly sand; locally interbedded with thin beds and lenses containing silt and clay; clasts commonly subrounded to rounded, but some deposits consist of poorly sorted, angular gravel derived from nearby bedrock outcrops; deposited between the Bonneville and Provo shorelines in planar and cross-bedded beds; typically overlies bedrock near the foot of the Wasatch Range; commonly covered by unmapped colluvium from adjacent steep slopes on erosional benches at the Bonneville shoreline; this colluvium is thin and does not cover the benches; exposed thickness less than 75 feet (25 m).

Qlsb **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; thin to thick bedded; commonly has ripple marks and scour features; deposited in relatively shallow water nearshore, downslope from transgressive gravel and sand (Qlgb); overlies coarsergrained beach gravel, indicating deposition in increasingly deeper water in the transgressing lake; exposed thickness less than 30 feet (10 m).

Qlb **Transgressive-phase deposits, undivided** (upper Pleistocene) – Moderately to well-sorted deposits of subrounded to rounded, fine to coarse sand, silt, and clay with pebbly gravel; locally includes thick beds of gravel and sand; limited to exposures in bluffs along stream terraces beneath Lake Bonneville regressive deposits where slope colluvium conceals the relative amounts of sand, silt, and clay in these transgressive deposits; may include pre-Bonneville deposits that have not been differentiated; exposed thickness less than 100 feet (30 m).

Mass-movement deposits

Qmdf **Debris-flow deposits** (historical to middle Pleistocene) – Unsorted, pebble, cobble, and boulder gravel with a matrix of sand, silt, and clay; forms valley bottom fill and lobate deposits in Spring and Carrigan Canyons; derived from the shale, mudstone, and sandstone of the Ankareh Formation; estimated thickness 10 to 30 feet (3–10 m).

Qmef **Earth-flow deposits** (historical to middle Pleistocene) – Unsorted sand, silt, and minor pebble and cobble gravel with a matrix of sand, silt, and clay; forms a broad subdued hummocky earth flow with approximate margins; likely gradational into slope colluvium; source rocks are the shale, mudstone, and sandstone of the Ankareh Formation; stability determinations require detailed geotechnical investigations; thickness highly variable.

Qmsh **Historical landslide deposits** (historical to middle Pleistocene?) – Poorly sorted clay- to boulder-sized material in slides, slumps, and minor flows; composition varies with source material; characterized by hummocky topography, main and internal scarps, toe thrusts, back-rotated blocks, and chaotic bedding in displaced bedrock; mapped in multiple locations in the quadrangle; includes two 1980s failures near Big Cottonwood Canyon, one is a side wall failure of the sand and gravel pit and the other is a failure above a clay mine in older landslide deposits; also includes a group of landslides in Pharaohs Glen between Grandeur Peak and Parleys Canyon; historical age based on accounts of active movement, or aerial photographic mapping with renewed movement on older landslides shown between the mid-1990s and 2012 (UAGRC, mid-1990s, 2012); age and stability determinations require detailed geotechnical investigations; thickness highly variable.

Qms, Qms?

Landslide deposits (historical? to middle Pleistocene) – Poorly sorted clay- to boulder-sized material in slides and slumps; composition varies with the source material; most of the landslides are small and characterized by hummocky topography, main and internal scarps, toe thrusts, back-rotated blocks, and chaotic bedding in displaced bedrock; not subdivided by apparent age because even landslides with subdued morphology (suggesting that they are older, weathered, and have not moved recently) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); stability determinations require detailed geotechnical investigations; smaller landslides are not mapped because they are too small to show at map scale; queried where identification uncertain; thickness highly variable.

Landslides in bedrock are mapped in many areas, including: (1) multiple landslides in the area of Spring and Carrigan Canyons are from the failure of shale, mudstone, and sandstone of the Ankareh Formation (TRau, TRam); (2) one landslide in Pharaohs Glen is from shale, mudstone, and sandstone of the Mahogany Member of the Ankareh Formation (TRam); and (3) a landslide located on the south side of Olympus Cove derived from the Ophir Formation (Єo). The Ophir Formation on the south side of Olympus Cove presently mapped as thrust-faulted strata could also be explained as large landslide bedrock blocks.

Numerous landslides are from failures in surficial deposits, including: (1) two possibly dry sand flows on the south side of Parleys Creek just west of the canyon mouth that were from failure of transgressive Lake Bonneville deposits (Qlb) and alluvial-fan deposits, related to the regressive phase of Lake Bonneville (Qafp); (2) one landslide derived from failure of transgressive Lake Bonneville gravel and sand deposits along the west side of Mount Olympus (Qlgb); (3) one younger landslide failure of an older landslide (Qmso) on the south side of Heughs Canyon; (4) one large landslide derived from regressive Lake Bonneville deltaic deposits (Qldp) mapped along the now mined-out bluff on the south side of Big Cottonwood Creek; (5) two landslides along the East Bench fault northeast of the 4500 South and Highland Drive intersection in Qlfp; and (6) one queried landslide southwest of the Van Winkle Expressway and 900 East intersection.

Qmso **Older landslide deposits** (Pleistocene?) – Poorly sorted colluvium and brecciated bedrock; characterized by subdued eroded scarps with benches and steps in the topography reminiscent of eroded slide blocks or back-rotated surfaces; much of the hummocky surface and identifiable features have been removed by erosion or filled by deposition; mapped south of Heughs Canyon in the Big Cottonwood Formation; potential evidence indicating an older age for these landslides are: (1) a remnant toe thrust is incised at the Bonneville shoreline, indicating landslide movement occurred before the highstand of Lake Bonneville; and (2) in Heughs Canyon the northern margin of the landslide is incised by a stream exposing what appears to be in-place bedrock on the south side of the canyon; landslides with subdued morphology (suggesting that they are older, weathered, and have not moved recently) may continue to have slow creep, and may not be old, but even so may be capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); these older landslides contain an internal younger landslide (Qms) and 1980s historical landslide (Qmsh); age and stability determinations require detailed geotechnical investigations; thickness unknown.

Qml? **Lateral spread deposits** (Holocene to upper Pleistocene) – Poorly sorted clay- to boulder-sized material in blocks of displaced sediment, displaced slumps, and grabens, with grain size varying with the nature of source material; characterized by displaced sediments in rotated blocks, chaotic bedding, small to no net offset in grabens, hummocky topography, and main and internal scarps; lateral spreads are a type of liquefaction-induced landslide triggered by strong earthquake ground motion; one deposit mapped along Little Cottonwood Creek in the southwest part of the quadrangle where consultant geotechnical investigations identified highly deformed bedding, small offset faults, and liquefaction dikes; slight hummocky graben topography visible on the aerial photography (USDA, 1937), but all surficial evidence has been removed by development; more lateral spread deposits are likely, but urbanization has concealed evidence of the deposits; age and stability determinations require detailed geotechnical investigations; thickness highly variable.

Qmt **Talus deposits** (historical to middle Pleistocene?) – Very poorly sorted, angular pebble-to cobble- and boulder-size rocks, with pebble-size to finer grained matrix; deposited principally by rockfall on and/or at the base of steep slopes; mapped above and below the Bonneville shoreline, in previously glaciated areas in Neffs Canyon, in Mill Creek Canyon, and on other steep slopes in the Wasatch Range; other small and thin talus deposits are not mapped due to map-scale limitations; includes unvegetated potentially active rockfall to partially vegetated stabilized slopes; 0 to 50 feet (0–15 m) thick.

Mixed-environment deposits

Qac **Alluvial and colluvial deposits, undivided** (Holocene to middle Pleistocene?) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment; rounded to angular clasts; mapped where alluvium and colluvium (slopewash and soil creep) grade into one another or are intermixed and cannot be shown separately at map scale; mapped at the base of steep slopes in the Wasatch Range where the alluvium is mostly fan alluvium and in small drainages where stream and fan alluvium and colluvium from the sides of the drainage are intermixed; small, unmapped deposits are likely present in most small drainages; Qac deposit areas have a potential for debris flow and flood risk; thickness less than 15 feet (5 m).

Qct **Colluvial and talus deposits, undivided** (Holocene to middle Pleistocene?) – Very poorly sorted, gravel-sized angular debris with a finer grained matrix; deposited at the base of steep slopes in Big Cottonwood and Mill Creek Canyons and on other steep slopes in the Wasatch Range; Qct is slopewash, soil creep, and rockfall deposits that are mixed and gradational into one another; typically distinguished from talus (Qmt) because they are almost entirely vegetated and on lower angle slopes; 0 to 50 feet (0–15 m) thick.

Qla **Lacustrine and alluvial deposits, undivided** (Holocene to upper Pleistocene) – Sand, silt, and clay in areas of mixed alluvial and lacustrine deposits that cannot be shown separately at map scale, or because the deposits are gradational into each other, or thin patches of one unit overlay the other; mapped along the Cottonwood and East Bench faults where lacustrine units are likely overlain by thin alluvial-fan deposits, and just north of Heughs Canyon regressive shorelines of Lake Bonneville that are cut into underlying alluvium; exposed thickness 10 to 40 feet (3–12 m).

Qlam **Lacustrine and alluvial and marsh deposits, undivided** (Holocene to upper Pleistocene) – Silt, clay, and minor sand and pebble, with organic-rich sediment associated with springs, ponds, seeps, and other wetlands; commonly wet, but seasonally dry; mapped in northwest corner of the quadrangle where marsh, alluvial, and lacustrine deposits that are patchy and intermixed; cannot be shown separately at map scale; estimated thickness 15 feet (5 m).

Qmc **Mass movement and colluvial deposits, undivided** (Holocene to middle Pleistocene?) – Mixed landslide, slump, slopewash, and soil creep that are gradational into one another; typically have a hummocky appearance on the lidar-derived elevation models but lack clear landslide scarps and lateral margins to allow separate mapping; mapped as thin deposits on steep bedrock slopes north of Spring Canyon, in Pharaohs Glen, and on the north and east sides of Mount Olympus; thickness 0 to 30 feet (0–10 m).

Stacked-Unit Deposits

Stacked units are mapped only near and east of Foothill Drive, in the dotted area in the north-central part of the quadrangle, where Marsell (1964a, 1964b, and 1969) identified shallow bedrock in a deep sewer trench in 1947. Shallow bedrock in a "labyrinth of trenches for both sewer lines and water mains" (Marsell, 1964a) was later included, in a modified form, in geologic maps by Granger and others (1952), Granger (1953), Marsell and Threet (1960), Marsell (1964b, 1969), and Crittenden (1965d). The numerous older maps do not agree on the interpretation of units or location of faults. In addition, these sites are no longer accessible, precluding definitive statements of depth, units, and locations. In this area several units may have been misidentified. Thin, faulted, red Ankareh Formation may be the red Boundary Ridge and Gypsum Spring Members of the Twin Creek Limestone and the adjacent Thaynes Formation may be Twin Creek Limestone members. This would simplify the hypothetical faults shown on previous older maps into unit contacts. Units and contacts shown on this map are after Crittenden (1965d), and are shown as thin surficial deposits over bedrock.

Qafy/Jtc, Qafy/J₮n, Qafy/₮a, Qafy/₮t

Younger alluvial-fan deposits over Jurassic and Triassic bedrock (Holocene to upper Pleistocene over Middle Jurassic and Triassic) – Poorly sorted pebble and cobble gravel with a matrix of sand, silt, and clay over bedrock (Jtc, J₮n, ₮a, and ₮t); estimated thickness of Qafy above bedrock is likely 0 to 15 feet (0–5 m).

Qafp/₮a

Alluvial-fan deposits, related to Provo shoreline and regressive phase of Lake Bonneville over Ankareh Formation (upper Pleistocene over Triassic) – Poorly to moderately sorted, pebble to cobble gravel with a matrix of sand, silt, and clay over ₮a; thickness of Qafp above bedrock is likely 0 to 15 feet (0–5 m).

Qldp/Jtc, Qldp/J₮n, Qldp/₮a, Qldp/₮t

Deltaic deposits related to the Provo shoreline and regressive phase of Lake Bonneville over Jurassic and Triassic bedrock (upper Pleistocene over Middle Jurassic and Triassic) – Moderately to well-sorted, pebble and cobble gravel with a matrix of sand and silt over bedrock (Jtc, J₮n, ₮a, and ₮t); thickness of Qldp above bedrock is likely 0 to 15 feet (0–5 m).

Qlgb/Jtc, Qlgb/J₮n, Qlgb/₮a, Qlgb/₮t

Lacustrine gravel and sand related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Middle Jurassic to Lower Triassic bedrock (upper Pleistocene over Middle Jurassic to Lower Triassic) – Moderately to well-sorted, clast-supported, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand and pebbly sand over bedrock (Jtc, J₮n, ₮a, and ₮t); thickness of Qlgb above bedrock is likely 0 to 15 feet (0–5 m).

Qlsb/Jtc, Qlsb/J₮n, Qlsb/₮a

Lacustrine sand and silt deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Jurassic and Triassic bedrock (upper Pleistocene over Middle Jurassic and Triassic) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel over bedrock (Jtc, J₮n, and ₮a); thickness of Qlsb above bedrock is likely 0 to 15 feet (0–5 m).

Qac/Jtc, Qac/J₮n, Qac/₮a

Alluvial and colluvial deposits, undivided, over Jurassic and Triassic bedrock (Holocene to middle Pleistocene? over Middle Jurassic and Lower Triassic) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment over bedrock (Jtc, J₮n, and ₮a); estimated thickness of Qac above bedrock is likely 0 to 15 feet (0–5 m).

Major unconformity

TERTIARY

Whole-rock geochemical data for igneous units in the Sugar House 7.5-miunte quadrangle are available in McKean (2017c). Geochemical rock names are from the total alkali-silica classification diagram for igneous rocks (see figure 2). Rock unit names are adapted from a previous geologic map by Crittenden (1965d).

Tld **Lamprophyric dikes and sill** (Oligocene?) – Grayish-yellow, medium-gray, to pale yellowish brown, porphyritic, highly altered, lamprophyric dikes and a sill with fine-grained matrix; highly altered phenocrysts that appear to be biotite; geochemically are now classified as trachydacites (see plate 1 and figure 2, samples SH2015-67, SH2015-68, and SH2015-73), but their composition prior to alteration is unknown; dikes are nonresistant to resistant; dikes and the sill are located in three main areas: (1) an east-west trending sill about 3 to 6 feet thick (1–2 m) mapped on the north side of Mill Creek Canyon subparallel to strike in the Weber Sandstone and nearby Mill Creek detachment (sample SH2015-67); (2) a north-south trending dike, about 10 to 20 feet (3–6 m) wide, mapped on the ridge south of Parleys Canyon that cuts Triassic rock perpendicular to strike (sample SH2015-68); and (3) a northeast-trending dike in Carrigan Canyon, about 6 to 10 feet (2–3 m) wide, was mapped by Crittenden (1965d) as an intermediate dike but here mapped as a lamprophyric dike because chemically (sample SH2015-73) it is more similar to the lamprophyric dikes; the Carrigan Canyon dike was mapped parallel to strike in the upper Ankareh Formation in isolated outcrops and through float; age uncertain, likely Oligocene; width exaggerated on plate 1 for visibility.

Tsd **Silicic dikes** (Oligocene?) – Pale yellowish brown to light brownish gray, highly altered, coarse-grained, porphyritic silicic dikes; phenocrysts, in order of abundance, are plagioclase and hornblende in altered microcrystalline (aphanitic) matrix; the dikes also contain xenocrysts of quartz (0.25 inch [0.5 cm] across) and partially resorbed megacrsyts of plagioclase up to 0.75 inch (2 cm) across; after alteration the dikes are geochemically dacite and rhyolite (see plate 1 and figure 2, samples SH2015-7 and SH2015-23); nonresistant, slope formers, mapped on the ridge north of the mouth of Big Cottonwood Canyon (southeast margin of map area) at an oblique angle to the strike of the Big Cottonwood Formation (sample SH2015-23); also mapped near Mule Hollow north of Big Cottonwood Canyon in a fold hinge and nearly perpendicular to strike in the Big Cottonwood Formation (sample SH2015-7); mapped only in isolated outcops and through float; age uncertain, likely Oligocene; dike 20 to 30 feet (6–9 m) wide; width exaggerated on plate1 for visibility.

Tind **Intermediate dikes and sills** (Oligocene?) – Light to dark greenish-gray, porphyritic, highly altered, intermediate dikes with hornblende and biotite phenocrysts in a microcrystalline (aphantitic) matrix; some dikes also contain xenocrysts of quartz and large phenocrysts of hornblende (0.5 inch [1 cm] across); geochemically they are altered to latite (see plate 1 and figure 2, samples SH2015-9, SH2015-13, SH2015-41, and SH2015-203); not resistant and poorly exposed; mapped in three locations: (1) northwest-trending sills, subparallel to strike in the Big Cottonwood Formation, located on the north side of Big Cottonwood Canyon and are 3 to 6 feet (1–2 m) thick (samples SH2015-9 and SH2015-13); (2) a small northwest-trending dike in Neffs Canyon is roughly perpendicular to strike of Mississippian strata and about 3 feet (~1 m) thick, is highly altered with no identifiable phenocrysts, and was mapped by Crittenden (1965d) as a lamprophryic dike but chemically is more similar to the intermediate dikes, (sample SH2015-41); and (3) a small, 3- to 6-foot (1–2 m) thick, east-west trending dike parallel to strike in the Ophir Formation and a nearby fault on the south side of Olympus Cove, was mapped as a lamprophryic dike by Crittenden (1965d) but is chemically (sample SH2015-203) more similar to the intermediate dikes; dikes and sills were mapped only in isolated outcrops and through float; age uncertain, likely Oligocene; width exaggerated on plate1 for visibility.

Major unconformity

Limited fossil data are available for Mesozoic through Precambrian strata in and near the map area. Ages are from more distant studies of strata assumed to be equivalent geologic units.

The apparent thickness of the Mesozoic and Paleozoic rock units is highly variable because of structural attenuation and thickening due to folding and faulting. The reported thicknesses are approximate.

MESOZOIC

JURASSIC

Twin Creek Limestone – Subdivided by Imlay (1967) into seven members, from top to bottom (youngest to oldest): Giraffe Creek, Leeds Creek, Watton Canyon, Boundary Ridge, Rich, Sliderock, and Gypsum Spring Members. The Giraffe Creek Member has not been identified in the quadrangle as the upper part of the Twin Creek likely is not preserved. Here the Gypsum Spring Member is removed from the Twin Creek and mapped as a separate formation after Sprinkel and others (2011), who recommend that it be called Gypsum Spring Formation like the type area in northeast Wyoming. This nomenclature change is based on isotopic ages from the Devils Slide, Utah, area that suggest the Gypsum Spring is separated from the Twin Creek by a major (~9 Ma) unconformity (Sprinkel and others, 2011). The Twin Creek's Middle Jurassic age is from Imlay (1980) and Sprinkel and others (2011). Estimated complete unit thickness 2400 to 2900 feet (730–885 m) in Emigration Canyon; however, units are highly variable due to folding within the quadrangle. On the north side of Emigration Canyon Granger (1953) measured a thickness of 2821 feet (860 m) but several covered intervals may be faults. Imlay (1967) reported a measured thickness at Burr Fork in Emigration Canyon of 2851 feet (870 m).

Jtl **Leeds Creek Member** (Middle Jurassic, Callovian) – Light-gray, thin-bedded, shaly to silty, micritic limestone, with minor interbedded ripple-laminated silty or sandy limestone; contains interbeds of thin-bedded, greenish-gray siltstone, medium-bedded, very fine to fine-grained sandstone, calcareous sandstone, or shaley limestone; also uncommon interbeds of blocky weathering bioclastic limestone that increase in abundance toward the top of the unit; poorly exposed slope former that weathers to a scree-covered gray soil; variably spaced cleavage, typically bedding-normal pencil cleavage; lower contact is gradational with the resistant limestone of the Watton Canyon Member and visible in some locations as a double vegetation band, near the contact, which might be the platy limestone at the base of the Leeds Creek; mapped in the Emigration Canyon and Parleys Canyon synclines; Middle Jurassic (Callovian) age from Imlay (1980); mapped unit may include undifferentiated strata of the Giraffe Creek Member, but characteristic sandy beds not recognized; estimated thickness greater than 1500 feet (>457 m); Imlay (1967) reported 1520 feet (464 m) thickness from Burr Fork on the north side of Emigration Canyon.

Jtw **Watton Canyon Member** (Middle Jurassic, Bathonian) – Gray, resistant, blocky, ledge-forming, medium-bedded micritic limestone to wackestone; oolitic limestone beds common and locally a thin red mudstone interval; limestone has blocky weathering due to presence of tectonic stylolites and cleavage at high angles to bedding; some thin silty layers but much less than Leeds Creek and Rich Members; mapped in Emigration and Parleys Canyon synclines; lower contact is mapped at the sharp transition from the more resistant limestone of Watton Canyon to the slope-forming red beds of the upper Boundary Ridge; mined for aggregate in Parleys Canyon; Middle Jurassic (Bathonian) age from Imlay (1980); estimated thickness 420 to 580 feet (~128–177 m); Imlay (1967) reported 348 feet (107 m) thickness in Brigham Fork (near Burr Fork) on the north side of Emigration Canyon.

Jtb **Boundary Ridge Member** (Middle Jurassic, Bathonian) – Red to red-brown mudstone and siltstone with interbedded gray oolitic to bioclastic thick-bedded limestone; upper part is mostly mudstone and forms a swale with red soil; basal part is mostly a thick bed of oolitic to bioclastic limestone that forms a resistant ridge; mapped in Emigration and Parleys Canyon synclines; lower contact below the resistant limestone, with a local thin interval of red mudstone or yellow siltstone above the gray shaly limestone of the Rich; Middle Jurassic (Bathonian) age from Imlay (1980); estimated thickness 120 to 160 feet (~36–49 m); Imlay (1967) reported 102 feet (31 m) thickness in Brigham Fork (near Burr Fork) on the north side of Emigration Canyon.

Jtr **Rich Member** (Middle Jurassic, Bajocian) – Gray, thin-bedded, shaly micritic limestone; typically has close-spaced cleavage at high angles to bedding that results in pencil cleavage and weathering to a scree-covered non-resistant slope or swale; mapped in Emigration and Parleys Canyon synclines; lower contact mapped at the gradational change from gray shaly limestone to resistant bioclastic and oolitic limestone of the Sliderock; Middle Jurassic (Bajocian) age from Imlay (1980); estimated thickness 220 to 250 feet (~67–76 m); Imlay (1967) reported 391 feet (119 m) thickness in Burr Fork on the north side of Emigration Canyon.

Jts **Sliderock Member** (Middle Jurassic, Bajocian) – Medium-gray, thick-bedded, bioclastic limestone with oolitic limestone and micritic, medium-bedded limestone in upper part; micritic limestone typically has wide-spaced stylolitic cleavage at high angles to bedding that results in a blocky appearance; lower thick-bedded bioclastic and oolitic limestone forms resistant ridge and blocky ledges; mapped in Emigration and Parleys Canyon synclines; lower contact mapped at sharp contact with red beds of the Gypsum Spring Formation; Middle Jurassic

(Bajocian) age from Imlay (1980); isotopic ages from Sprinkel and others (2011) at Devils Slide are a sanidine $^{40}Ar/^{39}Ar$ age of 168.0 ± 1.0 Ma and a U-Pb zircon age of 173.6 ± 1.0 Ma, that may be too old and may indicate the zircons are detrital rather than an air-fall deposit; estimated thickness 120 to 130 feet (~37–40 m); Imlay (1967) reported 150 feet (46 m) thickness in Burr Fork on the north side of Emigration Canyon.

Jtc **Twin Creek Limestone and Gypsum Spring Formation, undivided** (Middle Jurassic to Lower Jurassic?) – Mostly gray to greenish-gray, thin bedded, shaly to silty to sandy limestone and calcareous siltstone; undivided because individual members cannot be distinguished due to fracturing and poor exposures; mapped as small outcrops, a road cut, and as shallow bedrock (Qafy/Jtc, Qldp/Jtc, Qlgb/Jtc, Qlsb/Jtc, and Qac/Jtc) along Foothill Drive between Parleys and Emigration Canyons; estimated complete unit thickness 2400 to 2900 feet (730–890 m), but highly variable due to folding of the unit within the quadrangle.

Jtsg **Sliderock Member of Twin Creek Limestone and Gypsum Spring Formation, undivided** (Middle Jurassic to Lower Jurassic?) – Mapped where the Sliderock Member and Gypsum Spring Formation form a strike valley slope adjacent to the contact with the Nugget Sandstone and the two units cannot be distinguished in the field or on the aerial photography; folding and faulting may have removed or thinned the Gypsum Spring Formation leaving only the Sliderock Member; see respective units for estimated thicknesses.

J-2 Unconformity (between Twin Creek Limestone and Gypsum Spring Formation)

Jgs **Gypsum Spring Formation** (Middle Jurassic to Lower Jurassic?) – Poorly exposed red to red-brown mudstone and siltstone, with rare brecciated limestone; mapped where unit forms red soil along a strike valley slope adjacent to the contact with the Nugget Sandstone; where better exposed the Gypsum Spring contains dolomite, sandstone, glauconitic (green) fine-grained rocks, and gypsum; lower contact at the sharp change to eolian sandstone beds of the Nugget Formation; the unit is extensively thinned throughout the quadrangle, likely the result of a detachment fault that accommodates disharmonious folding between the Nugget Sandstone and Twin Creek Limestone in the Emigration and Parleys Canyon synclines; estimated thickness 0 to 150 feet (~0–45 m); Imlay (1967) reported 140 feet (42 m) thickness in Burr Fork on the north side of Emigration Canyon.

The Gypsum Spring is herein treated as a separate formation rather than a member of the Twin Creek Limestone following Sprinkel and others (2011). The age of the Gypsum Spring Formation is a topic of current research. Imlay (1980) reported the late Bajocian (Middle Jurassic) gastropod *Lyosoma powelli* White from the unit and noted unconformities above and below the formation. Sprinkel and others (2011) reported an $^{40}Ar/^{39}Ar$ age of 184.6 ± 0.2 Ma from sanidine and a U-Pb zircon age of 183.2 ± 0.49 Ma from a sample of an ash bed in the Gypsum Spring Formation near Devils Slide. These isotopic ages suggest a Pliensbachian (Lower Jurassic) age for the formation. Sprinkel and others (2011) also correlated the Gypsum Spring Member/ Formation with the Temple Cap Formation; however, D.A. Sprinkel (UGS, verbal communication, January 22, 2018) no longer thinks that the two units are time correlative. More work is needed to determine the age of the Gypsum Spring Formation (was member of the Twin Creek Limestone), with the type Gypsum Spring Formation in Wyoming. Sprinkel and others (2011) reported the presence of the J-1 unconformity below and J-2 unconformity above the formation.

J-1 Unconformity

JURASSIC-TRIASSIC

J₸n **Nugget Sandstone** (Lower Jurassic to Upper Triassic?) – Pale grayish-orange to reddish-orange, fine- to medium-grained, well-sorted, quartz sandstone; eolian; cross-bedded to planar bedded; cliff former; mapped in Parleys Canyon, and on the ridges south of Carrigan and north of Spring Canyon; lower contacted mapped at the unconformity with the red shale and mudstone of the upper member of the Ankareh Formation; Jurassic age from Imlay (1980), Triassic age from Sprinkel and others (2011) on the south flank of the Uinta Mountains where the Ankareh Formation is not present; estimated thickness is 800 to 1300 feet (244–400 m); at the mouth of Parleys Canyon, on the north side, Granger (1953) measured a thickness of 830 feet (253 m); Granger and others (1952) reported a thickness of 800 feet (244 m) east of Salt Lake City; in the Fort Douglas quadrangle Van Horn and Crittenden (1987) reported a thickness of about 1300 feet (400 m).

J-0 Unconformity? (Pipiringos and O'Sullivan, 1978; Imlay, 1980)

TRIASSIC

TRa **Ankareh Formation, undivided** (Upper Triassic to Lower Triassic) – Mapped only as a stacked unit, see the unit descriptions for Qac/TRa, Qafy/TRa, Qafp/TRa, Qlsb/TRa, Qlgb/TRa, and Qldp/TRa.

TR-5 Unconformity? (in the upper Ankareh [Lucas, 1993])

TRau **Ankareh Formation, upper member** (Upper Triassic) – Medium reddish-brown, grayish-red, or red, thin-bedded shale, mudstone, siltstone, and fine-grained sandstone; locally includes rare lenses of pebble conglomerate; ripple-laminated with reduction spots; slope former; exposed near Parleys Canyon, and near Carrigan and Spring Canyons; prone to landslides (Carrigan Canyon); lower contact mapped at the top of the sandstone beds of the Gartra Grit Member; previously called Stanaker Member by some geologists (Thomas and Krueger, 1946); where Gartra Grit Member is absent upper unit is indistinguishable from Mahogany Member; age from Stewart and others (1972b) based on upper member being roughly equivalent to Chinle Formation; estimated undeformed thickness is 500 to 700 feet (150–210 m); on south side of Parleys Canyon Granger (1953) measured 384 feet (117 m), while Granger and others (1952) reported a thickness of 700 feet (213 m).

TRag **Ankareh Formation, Gartra Grit Member** (Upper Triassic) – White to pale-red, purple, cross-bedded, coarse-grained sandstone, with subangular to well-rounded quartz grains and some feldspar; well-sorted, medium-bedded; ledge to cliff former; exposed near Parleys Canyon, and near Carrigan and Spring Canyons; not mapped near the mouth of Carrigan Canyon where the resistant ridge is not present; lower contact is likely an unconformity with red beds of the underlying Mahogany Member; age based on rough correlation with Chinle Formation (Stewart and others, 1972b), but not the same unit as Shinarump Member of the Chinle Formation (Poole and Stewart, 1964; Stewart and others, 1972b); thickness 70 to 100 feet (20–30 m); thickness reported as 50 to 100 feet (15–30 m) by Granger and others (1952) and 60 feet (18 m) measured by Granger (1953) on the south side of Parleys Canyon.

TR-3 Unconformity

TRam **Ankareh Formation, Mahogany Member** (Lower Triassic) – Medium reddish-brown, grayish-red or red, thin-bedded shale, mudstone, and fine-grained sandstone to siltstone, with minor thin limestone beds; ripple laminated with reduction spots and mud cracks; slope former; mapped south of Parleys Canyon, and in Carrigan and Spring Canyons; prone to landslides (Carrigan Canyon); lower contact is mapped at top of limestone beds of Thaynes Formation; age based on rough correlation with upper part of Moenkopi Formation (Stewart and others, 1972a); estimated undeformed thickness is 800 to 900 feet (245–280 m); Granger (1953) measured 855 feet (260 m) thickness on the south side of Parleys Canyon; Granger and others (1952) reported a thickness of 800 feet (244 m).

TRt, TRtl **Thaynes Formation** (Lower Triassic) – Interbedded, medium- to thick-bedded, light-gray limestone, light brown-gray, very fine grained sandstone and siltstone, and minor olive-gray and light-red shale; contains light-gray, thick- to very thick bedded, medial resistant limestone marker bed (TRtl) that appears to be the limestone bed at base of the upper calcareous siltstone member of Kummel (1954) near Devils Slide and Salt Lake City (Coogan and King, 2016); locally fossiliferous, fossils include bivalves, gastropods, and ammonites; light brown-gray chert, both nodular and bedded (thin and discontinuous); ledge to cliff former; mapped near Grandeur Peak and the Spring Canyon anticline ridge north of Carrigan Canyon; divided into multiple members by Coogan and King (2016); though not found in the map area, Granger (1953) measured a red-brown shale that may be the Decker Tongue of the Ankareh Formation in middle of the Thaynes Formation in the Fort Douglas quadrangle; lower contact is mapped at the transition from limestone beds to the red beds of the Woodside Shale; Kummel (1954) defined the base of the Thaynes Formation as the *Meekoceras* bed, but the *Meekoceras* bed was not found during my mapping; regional age from Kummel (1954) and more local age from Solien and others (1979); estimated thickness is 1800 to 2400 feet (550–730 m); Granger (1953) reported a thickness of 1931 feet (589 m) on the ridge between Red Butte and Emigration Canyons, but he used a different lower contact, below the lower contact *Meekoceras* bed of Kummel (1954), and may include more strata as Thaynes Formation.

TRw **Woodside Shale** (Lower Triassic) – Grayish-red, reddish-brown, and red shale, siltstone, and fine-grained sandstone; slope former with very few outcrops; mapped on the north side of Mill Creek Canyon and south of Grandeur Peak; at the base of the unit, above the Park City carbonates, is a thin greenish-gray shale that is likely part of the Dinwoody Formation, but here is less than 6 to 9 feet (2–3 m) thick; age based on stratigraphic position; estimated thickness 400 to 1000 feet (120–300 m), and may thin to the north; Granger (1953) reported a unit thickness of about 384 feet (120

m) at the mouth of Dry Canyon in the Fort Douglas quadrangle, but described it as pale-brown, raising a question as to the unit designation; Granger and others (1952) reported a thickness of 1000 feet (300 m) south of Parleys Canyon.

₸-1 Unconformity

PALEOZOIC

PERMIAN

Pp **Park City and Phosphoria Formations** (Permian, Leonardian and Guadalupian) – Light- to medium-gray, sandy limestone and dolomite, calcareous and dolomitic sandstone, and dark-gray medial phosphatic shale; rocks are cherty (both nodular and bedded); fossils include brachiopods, crinoids, bryozoans, and fossil hash; brecciated nature of the outcrop on the north side of Mill Creek Canyon obscured fossils from identification; regionally these rocks are typically divided into three units: upper unit mostly of Franson Member of Park City Formation (and thin other members of both formations), middle unit of Meade Peak Phosphatic Shale of Phosphoria Formation, and lower unit of Grandeur Member of Park City Formation (McKelvey and others, 1959); not subdivided here because rocks are folded, sheared, and brecciated, and more work would be needed to potentially split out individual units; slope to ledge former; less resistant than the interbedded sandstone and limestone of the Weber Sandstone; regionally Phosphoria and Park City unit is early Leonardian and Guadalupian in age (McKelvey and others, 1959); estimated thickness of about 700 to 900 feet (210–280 m), but highly deformed; Granger (1953) reported the unit is 974 feet (297 m) thick in the Fort Douglas quadrangle; Granger and others (1952) reported a thickness of 600 feet (180 m) south of Parleys Canyon.

PERMIAN-PENNSYLVANIAN

PIPw **Weber Sandstone** (Lower Permian to Middle Pennsylvanian) – Yellowish-gray to very light gray, fine- to medium-grained, quartzose sandstone with interbedded thin- to thick-bedded, medium-gray to very light gray limestone and dolomite; black chert locally; forms ledges and cliffs on dip slope into and just north of Mill Creek Canyon; the fault/detachment horizon along Mill Creek Canyon may be equivalent to the swale below the capping resistant bed in Weber Canyon, shown as the lower detachment in a Permian shale of Yonkee and Weil (2011); lower contact is gradational into the Round Valley Limestone and is placed at the first thick sandstone bed (greater than 3 feet thick [1 m]); fossils from the uppermost beds of the Weber Sandstone near the mouth of Mill Creek Canyon are Desmoinesian (Crittenden, in Van Horn and Crittenden, 1987) (no Upper Pennsylvanian); Middle Pennsylvanian and Early Permian age from Bissell and Childs (1958) and Bissell (1964) is based on fusulinids; estimated thickness of the folded and faulted Weber Sandstone is 1200 to 3000 feet (365–900 m); Granger (1953) estimated the thickness in the City Creek area is about 1200 feet (365 m), and my upper estimate is based on thicknesses repeatedly calculated from dip, outcrop width, and topography.

PENNSYLVANIAN

IPrv **Round Valley Limestone** (Lower Pennsylvanian) – Light- to medium-gray, thin- to thick-bedded limestone, fossiliferous limestone, and silty, low-angle cross-bedded bioclastic limestone; pinkish-gray to gray nodules and thinner beds of chert and silicified fossils; fossils include crinoids, corals, brachiopods, and fossil hash; ledge to slope former; mapped on the north side of Neffs Canyon; lower contact is gradational; contact placed at change from dark-gray Doughnut Formation limestone to lighter gray Round Valley Limestone; Early Pennsylvanian (Atokan and Morrowan) age from Sadlick (1955); estimated thickness is 500 to 1000 feet (120–300 m).

MISSISSIPPIAN

Mdo **Doughnut Formation** (Upper Mississippian) – Light to dark-gray, fossiliferous, cherty limestone, shaly limestone, and minor beds of rusty-weathering, silty, calcareous sandstone; fossils include crinoids, bivalves, rugose corals, brachiopods, bryozoans, and fossil hash; thin- to medium-bedded limestone; locally some beds appear to be highly silicified and very dense; nodular dark gray to black chert; slope former; mapped on the north side of Neffs Canyon; the lower contact is the Mount Raymond thrust, which may be in the lower Doughnut shale that is visible near Morgan (see Coogan and others, 2015); Late Mississippian age from Baker and Crittenden (1961); in the Morgan quadrangle Coogan and others (2015) reported a Morrowan (Early Pennsylvanian) palynomorph age on the upper Doughnut, but strata like their clastic-poor upper Doughnut have not been identified during my mapping; estimated thickness 1000 feet (300 m).

Mount Raymond Thrust

Mh **Humbug Formation** (Upper Mississippian) – Interbedded, medium to dark-gray limestone and light-brown, calcareous, quartz sandstone; both medium-bedded and light-brown weathering; limestone is fine to medium grained, with shell hash, and is locally dolomitic; sandstone is fine to medium grained with moderately sorted and rounded grains, and low-angle cross-stratification; weathers to ledges and slopes; exposed in Neffs Canyon and truncated by the Mount Raymond thrust; lower contact with the Deseret Limestone is gradational and occurs near the change from limestone (Md) to alternating sandstone and limestone (Mh), such that reported thicknesses may not be based on the same contact; regional age from Morris and Lovering (1961); estimated thickness is 700 to 900 feet (210–280 m); in City Creek Canyon, Granger (1953) reported a Humbug Formation thickness of 727 feet (220 m), and Granger and others (1952) reported a thickness of 400 feet (120 m) in the Cottonwood Canyons area.

Md **Deseret Limestone** (Upper to Lower Mississippian) – Medium- to dark-gray, medium- to very thick bedded limestone and dolomite; nodular to lensoid thin beds of chert that are mostly dark gray to black and brown; fossils include rugose corals, crinoids, brachiopods, bryozoans, and fossil hash; beds of coquina (fossil hash) composed of fragments of shells, crinoid columnals, and corals in laminae and low-angle cross-beds; slope to ledge former; mapped in Neffs Canyon; the lower contact is placed at the change from fossiliferous limestone of the Gardison Limestone to cherty limestone of the Deseret Limestone (Md); a small saddle at the base of the Deseret may be the basal Delle Phosphatic Member, a poorly exposed black phosphatic shale/shaly limestone; regional age from Sandberg and Gutschick (1984); in the Sugar House quadrangle the unit is cut by a subsidiary thrust in the Mount Raymond thrust zone system; estimated thickness is between 500 and 900 feet (150–275 m); in City Creek Canyon reportedly about 450 feet (140 m) thick but Granger (1953) may have used different contacts; Granger and others (1952) reported 800 to 900 feet (244–275 m) thickness in the Cottonwood Canyons area.

Mg **Gardison Limestone** (Lower Mississippian) – Medium-gray to dark-gray limestone, fossiliferous limestone, and locally dolomitic limestone; medium- to very thick bedded; fossils include rugose and colonial corals, brachiopods, crinoids, distinctive gastropods, and bryozoans; contains nodular chert in the upper part and minor intraformational (flat-pebble) conglomerate beds; ledge forming; mapped in Neffs Canyon; the lower contact is distinguished by the very light gray dolomite at the top of the Fitchville Formation; age from Morris and Lovering (1961); estimated thickness 350 to 600 feet (100–180 m); in the Fort Douglas quadrangle 650 feet (200 m) thick (Madison limestone of Granger, 1953); 450 feet (137 m) thick in the Cottonwood Canyons area (Madison limestone of Granger and others, 1952).

MISSISSIPPIAN-DEVONIAN

MDf **Fitchville Formation** (Lower Mississippian to Upper Devonian) – Gray to light-gray, medium- to thick-bedded dolomite; upper part is a dark-gray dolomite, with a 4-foot (1.2 m) very light gray dolomite at the top of the formation; locally pebbly sandstone at the base (Crittenden, 1965d); slope to ledge forming; mapped in Neffs Canyon and on the northern lowermost part of Mount Olympus, where it is in thrust fault contact with the Tintic Quartzite and Ophir Formation; lower contact is an extensive unconformity above the Ophir Formation, and where present, the Maxfield Limestone; regional age from Morris and Lovering (1961); estimated thickness 150 to 200 feet (50–60 m); Granger and others (1952) (their basal Mississippian dolomite unit) reported a unit thickness of about 120 to 150 feet (36–45 m) in the Cottonwood Canyons area.

Major Unconformity

CAMBRIAN

Ꞓm **Maxfield Limestone** (Middle Cambrian) – Light-gray to dark-gray limestone, dolomite, sandy and silty limestone, and calcareous to dolomitic shale; thin to medium bedded; only thin “sliver” of Maxfield Limestone is mapped in Neffs Canyon as remnant below major Devonian and Ordovician erosional unconformity; lower contact mapped at transition to brown limy sandstone of the Ophir Formation; Middle Cambrian age based on *Elrathia* sp. trilobites reported by Rigo (1968) in Ogden Canyon and placed in the Maxfield Limestone by Yonkee and Lowe (2004); estimated thickness in map area 0 to 60 feet (0–20 m); thickens northward to about 1000 feet (~300 m) in the Fort Douglas quadrangle (Granger, 1953).

Ꞓo **Ophir Formation** (Middle Cambrian) – Upper part is brown limy and shaly siltstone and fine-grained sandstone; middle part is light- to medium-gray, thin- to medium-bedded limestone with orange-tan weathering silty laminae or partings; lower part is olive-gray to brown micaceous shale and siltstone; slope former; mapped on slope north of Mount Olympus and in Neffs Canyon; poorly exposed; lower contact with the Tintic Quartzite is gradational with alternating quartzite and micaceous shale beds; Middle Cambrian age based on *Ehmaniella* sp., and *Glossopleura* sp. trilobites in Ogden Canyon (Rigo, 1968); thickness is highly variable on the north side of Mount Olympus from being thickened and thinned tectonically or perhaps by landsliding; undeformed thickness estimated to be 170 to 250 feet (50–75 m) in the map area; in City Creek Canyon area Granger (1953) reported a thickness of about 400 feet (120 m), and in the Little and Big Cottonwood Canyons area Granger and others (1952) reported a thickness of 400 feet (120 m).

Ꞓt **Tintic Quartzite** (Middle and Lower Cambrian?) – White- to pinkish-gray, dark-yellowish-orange weathering, moderately to well sorted, fine- to coarse-grained, quartzose, well-cemented sandstone (orthoquartzite); thin- to thick-bedded with widespread cross-beds; contains lenses of moderately to poorly sorted quartz pebble conglomerate; feldspathic in lower part; cliff former; exposed along the northern part of Mount Olympus and in Neffs Canyon; lower contact with the Mutual Formation is an unconformity; trace fossils in the upper part of the formation in the Ogden Canyon area include *Skolithus* tubes and *Plagiogmus* traces that indicate Middle Cambrian age (Peterson and Clark, 1974); estimated thickness 1000 to 1400 feet (300–400 m) in the map area; 1000 feet (300 m) thick in the Fort Douglas quadrangle (Brigham quartzite of Granger, 1953) and the Cottonwood Canyons area (Granger and others, 1952).

Unconformity

PROTEROZOIC

NEOPROTEROZOIC

Zm **Mutual Formation** (Neoproterozoic) – Grayish-red to red-purple quartzite and argillite; quartzite is fine- to medium-grained with medium sorting, well bedded with common cross-bedding; locally the unit contains pebble conglomerate; the quartzite forms cliffs and ridges and the argillite forms slopes; located on the north side of Mount Olympus and in Neffs Canyon; lower contact is an unconformity with the argillite unit of Big Cottonwood Formation (Zbcs); farther to the east in Big Cottonwood Canyon the Mineral Fork Formation is present between these two units (Crittenden, 1965c, 1977), but in the Sugar House quadrangle it is completely missing; age based on stratigraphic position; unit thickness is an estimated 800 to 1200 feet (250–365 m); Granger and others (1952) reported a maximum thickness of 1200 feet (365 m) in the Cottonwood Canyons area.

Unconformity

Zbcq, Zbcs

Big Cottonwood Formation (Neoproterozoic) – Interbedded greenish-gray, gray, and reddish- to bluish-purple, thin-bedded shale and siltstone (metamorphosed to argillite) (Zbcs), and grayish-white, greenish-gray, and gray, rusty-weathering orthoquartzite to quartzite (Zbcq); Crittenden (1965a, 1965b, 1977) divided the formation into thirds but did not map them; the lower third is bluish-purple, thin-bedded argillite interbedded with gray orthoquartzite; the middle third is greenish-gray or gray argillite (metashale) interbedded with gray and greenish-gray orthoquartzite; and the upper third is variegated greenish-gray and red argillite and meta-siltstone interbedded with white quartzite; cross-bedding, mud cracks, ripple marks, raindrop prints, and laminated beds, interpreted as tidal rhythmites, suggest shallow-water deposition (Crittenden, 1977; Chan and others, 1994; Ehlers and others, 1997); mapped from Mount Olympus south and east beyond the quadrangle boundary; the base of the unit is not exposed in the quadrangle; Neoproterozoic age based on possible correlation with the <770 Ma Uinta Mountain Group strata (U-Pb age data from detrital zircons) (Mueller and others, 2007; Dehler and others, 2010); the upper approximately 12,000 feet (~3800 m) of the total 16,000 feet (5000 m) is exposed in the Sugar House quadrangle (Crittenden, 1965d, 1977); these thicknesses may be overestimated by complex folding and faulting.

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Table 1. *Ages of major shoreline occupations of Lake Bonneville, Gilbert episode, and Great Salt Lake with shoreline elevations in the Sugar House quadrangle.*

Lake Cycle and Phase	Shoreline (map symbol)	Age: radiocarbon years (^{14}C yr B.P.)	Age: calibrated years (cal yr B.P.)[1]	Shoreline Elevation feet (meters)
Lake Bonneville				
Transgressive phase	Stansbury shorelines	22,000–20,000[2]	26,000–24,000	4480–4500 (1365–1372)
	Bonneville (B) flood	~15,000[3]	~18,000	5160–5230 (1573–1595)
Overflowing phase	Provo (P)	15,000–12,600[4]	18,000–15,000	4810–4850 (1466–1478)
Regressive phase	Regressive shorelines (r)	12,600–11,500[4]	15,000–13,000	4400–4800 (1341–1463)
Gilbert episode	Gilbert (G)	10,000[5]	11,500	Not present[6]
Great Salt Lake	early Holocene highstand	9700–9400[7]	11,000–10,500	Not present[6]
	late Holocene highstand	4200–2100[8]	5000–2000	Not present[6]
	Historical highstand		late 1860s to early 1870s and 1986–87[9]	Not present[6]

[1] All calibrations made using OxCal ^{14}C calibration and analysis software (version 4.3.2; Bronk Ramsey, 2009; using the IntCal13 calibration curve of Reimer and others, 2013), rounded to the nearest 500 years.

[2] Oviatt and others (1990)

[3] Bonneville shoreline highstand duration may have been shorter than our rounding error of 500 years; age represents lake culmination (Oviatt, 2015; Miller, 2016; and references therein)

[4] Godsey and others (2005, 2011), Oviatt (2015), Miller (2016) for the timing of the occupation of the Provo shoreline and subsequent regression of Lake Bonneville to near Great Salt Lake level. Alternatively, data in Godsey and others (2005) may suggest that regression began earlier, shortly after 16.5 cal ka (see sample Beta-153158, with an age of 13,660 ± 50 ^{14}C yr B.P. [16.5 cal ka] from 1.5 m below the Provo shoreline). Also, lacustrine carbonate deposits in caves reported by McGee and others (2012) seem to support an earlier Lake Bonneville regression beginning around 16.4 cal ka.

[5] Gilbert-episode highstand may have been very short lived; age represents lake culmination (Oviatt and others, 2005; Oviatt, 2014).

[6] Gilbert episode and Great Salt Lake shoreline data are provided for reference only, as they are only present downslope of the lowest elevations in the quadrangle.

[7] Murchison (1989), Currey and James (1982)

[8] Miller and others (2005)

[9] Arnow and Stephens (1990)