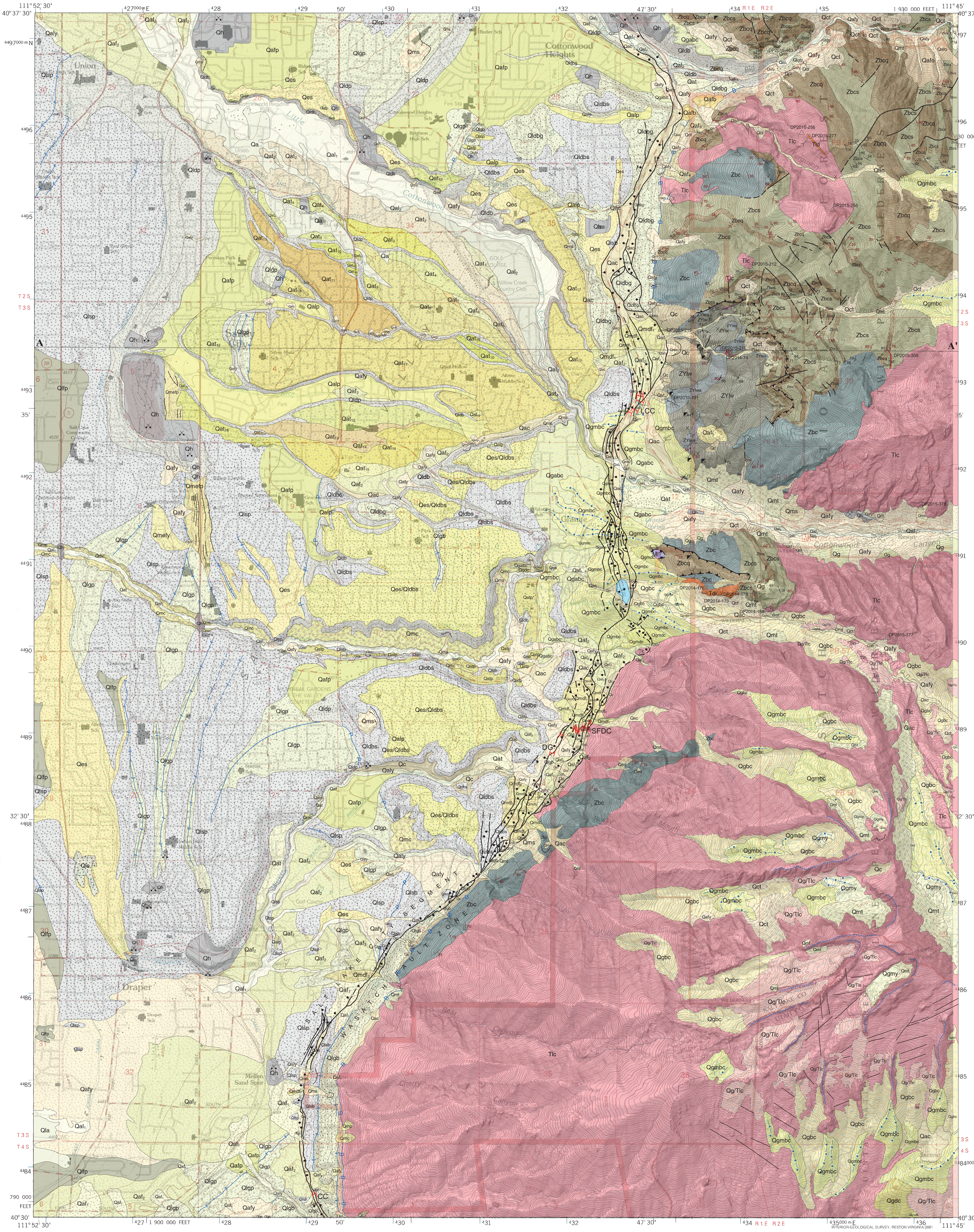

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This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number G14AC00214 (2014). The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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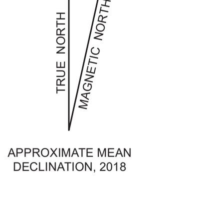


APPROXIMATE MEAN DECLINATION, 2018

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 10 FEET

INTERIM GEOLOGIC MAP OF THE DRAPER QUADRANGLE, SALT LAKE COUNTY, UTAH

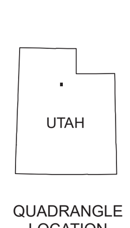
by

Adam P. McKean[1] and Barry J. Solomon[2]

2018

[1]Utah Geological Survey, P.O. Box 146100, Salt Lake City, UT 84114-6100

[2]Utah Geological Survey, retired



QUADRANGLE LOCATION

Base from USGS Draper 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 shift between geology and the base map. The geology is accurately shown relative to cultural and topographic features on the base map.

Project Manager: Jon K. King
Mapping of surficial geology:
Barry J. Solomon, 2008–2009
Surifical and bedrock geologic mapping:
Adam P. McKean, 2014–2015
GIS and Cartography: Jay C. Hill,
Adam P. McKean, and Martha L. Jensen

Utah Geological Survey
1594 West North Temple, Suite 3110
P.O. Box 146100, Salt Lake City, UT 84114-6100
(801) 537-3300
geology.utah.gov

1	2	3
4		5
6	7	8

1. Salt Lake City South
2. Sugar House
3. Mount Aire
4. Midvale
5. Dromedary Peak
6. Jordan Narrows
7. Lehi
8. Timpanogos Cave

ADJOINING 7.5' QUADRANGLE NAMES

INTERIM GEOLOGIC MAP OF THE DRAPER QUADRANGLE, SALT LAKE AND UTAH COUNTIES, UTAH

by

Adam P. McKean [1] and Barry J. Solomon [2]

[1] *Utah Geological Survey , P.O. Box 146100, Salt Lake City, UT 84114-6100*
[2] *Utah Geological Survey, retired*

Disclaimer

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UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 683DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2018

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INTRODUCTION

Location and Geographic Setting

The Draper quadrangle covers southeastern Salt Lake Valley and the western margin of the adjoining Wasatch Range (figure 1). Within the quadrangle are the cities of Sandy in the west-central part, Midvale and Cottonwood Heights in the northern part, and Draper to the south. The cities lie within the urbanized central Wasatch Front and in the Salt Lake City metropolitan area and Salt Lake County. The eastern part of the quadrangle includes the lower parts of Big Cottonwood and Little Cottonwood Canyons, portals to the Wasatch National Forest and popular winter recreation resorts to the east in the Wasatch Range. The Wasatch Range in and near the Draper quadrangle is the site of two mining districts, the Big Cottonwood and Little Cottonwood (Alta) districts, that were active from the late 19th century to the mid-20th century (Butler and others, 1920; Calkins and Butler, 1943; James, 1979, 2006). Big Cottonwood, Little Cottonwood, and Dry Creeks are the primary streams in the quadrangle, flowing northwest from the Wasatch Range to the Jordan River. Regionally, groundwater flows toward or along the Jordan River and eventually into Great Salt Lake (see Wallace and Lowe, 2009). Deaf Smith Canyon was previously named Little Willow Canyon, for which the Little Willow Formation is named, as there were two Little Willow Canyons in the Draper quadrangle.

The valley part of the quadrangle is covered by a dense network of local roads, providing access to Interstate 15 about 2 miles (3 km) west of the quadrangle and Interstate 215 about 1 mile (2 km) to the north. Access to Big Cottonwood and Little Cottonwood Canyons is by State Routes 190 and 210, respectively.

GEOLOGY

Bedrock Stratigraphy and Geologic Structure

Bedrock exposed in the Draper quadrangle east of Salt Lake Valley includes folded and faulted metamorphosed rocks of the likely Mesoproterozoic and/or Neoproterozoic Little Willow Formation (ZYlw) unconformably overlain by metamorphosed sedimentary rocks of the Big Cottonwood Formation (Zbc) (Granger and others, 1952; Condie, 1965, 1967) of Neoproterozoic age (Dehler and others, 2010; Spencer and others, 2012). A small outcrop of Mississippian limestone (Granger and others, 1952) forms an erosional remnant above a gently west-dipping fault at the mouth of Bells Canyon. The metamorphosed sedimentary strata are intruded and bounded on the east and south by the large, multi-phase, granitic to granodioritic Little Cottonwood stock, dated at 30.5 ± 0.5 Ma (John and others, 1997; Vogel and others, 1997). At the mouth of Bells Canyon, a large diorite body (Tdi), likely of Oligocene age, is intruded near the Little Cottonwood stock (Tlc). In the North Fork of Deaf Smith Canyon an east-west trending Oligocene (?) intermediate dike (Tind) cuts across both the Big Cottonwood Formation (Zbcs) and the Little Willow Formation (ZYlw). Between Big Cottonwood and Little Cottonwood Canyons, a granitic dike (Tgd) intrudes the Big Cottonwood Formation (Zbcs, Zbcq). In Deaf Smith Canyon a north-south trending granitic dike (Tgd) intrudes amphibolite of the Little Willow Formation (ZYlwa). A lamprophyric dike (Tld) cuts across the Little Cottonwood stock (Tlc) in Ferguson Canyon and another in the Big Cottonwood Formation (Zbcs, Zbcq) in Big Cottonwood Canyons (Crittenden, 1965a). These dikes are likely of Oligocene age, but they lack numerical ages.

Bedrock in the Draper quadrangle has undergone several episodes of deformation. Rocks of the Little Willow Formation show complex folding and more than one generation of faulting, but the geologic structure is not well understood (James, 1979). Younger Proterozoic rocks of the Big Cottonwood Formation are less deformed and have a crude northeast trending dip. The Proterozoic rocks are exposed in the core of a broad uplift, plunging anticline, antiform, or dome of the central Wasatch Range (see Eardley, 1968, 1969; Crittenden, 1977; and Bryant, 1990). Proterozoic and younger rocks were deformed by Cretaceous to Eocene (ca. 130–50 Ma) contractional folding and faulting of the Sevier orogeny (see for example, Willis, 1999; and DeCelles, 2006), extensional faulting during late Eocene and Oligocene "collapse" of the Sevier orogenic belt (Constenius, 1996; Constenius and others, 2003), coeval intrusion of the Little Cottonwood stock (about 31 to 30 Ma) with associated deformation and shearing of the host rock (John and others, 1997; Vogel and others, 2001), and middle Miocene to recent (ca. 18–0 Ma) basin-and-range faulting (see for example Parry and Bruhn, 1986, on Wasatch fault zone). The most prominent and youngest aspect of extensional faulting in the map area is the Salt Lake City segment of the Wasatch fault zone (see for example Personius and Scott, 1992), which separates Salt Lake Valley from the Wasatch Range.

Quaternary Geology

Glacial and Related Deposits

The oldest recognized Quaternary deposits in the Draper quadrangle are limited to small remnants of glacial till near the mouth of Bells Canyon and below the Second Hamongog in the southeast corner of the quadrangle. Richmond (1964) correlated these deposits with early Bull Lake glaciation, whose type locality is Bull Lake in central Wyoming, and the older of the two most widely recognized glaciations in the mountain west. Madsen and Currey (1979) named the mapped deposits (Qgdc) for Dry Creek that drains Bells Canyon. They thought that the degree of weathering of the Dry Creek till confirmed the correlation of Richmond (1964) and stated that the till was deposited during marine oxygen-isotope stage 6, which ended about 130 ka (Bassinot and others, 1994), though Bull Lake glaciation retreat is younger (Philips and others, 1997). Personius and Scott (1992) mapped the deposits as "till of Dry Creek age" and thought that the degree of till weathering suggested an age of about 150 ka, consistent with marine oxygen isotope stage ages but not with glacial ages. A uranium-trend age of 250 ± 90 ka obtained on fan alluvium (Qaf_4) near South Fork Dry Creek, possible outwash of Dry Creek age (J.N. Rosholt, written communication, 1984, in Scott and Shroba, 1985), indicated to Personius and Scott (1992) that some glacial deposits of Dry Creek age may be older (marine oxygen-isotope stage 8 is about this age, see Bassinot and others, 1994).

Remnants of coalesced middle to upper Pleistocene alluvial-fan deposits (Qaf_4, Qaf_5) are exposed above and slightly below the highest Lake Bonneville shoreline along the base of the Wasatch Range (Personius and Scott, 1992) and likely underlie Lake Bonneville deposits in the Salt Lake Valley. The Qaf_4 fans were deposited between the Bonneville and Little Valley lake cycles in the Bonneville basin (Scott and others, 1983; McCoy, 1987; Scott, 1988b,1988c), or near the end of the Little Valley lake cycle. The Little Valley lake cycle peaked about 138,000 years ago (McCalpin, 1986), is correlative with the later part of marine oxygen-isotope stage 6 (Oviatt and others, 1999), and is largely contemporaneous with Bull Lake glaciation (Phillips and others, 1997). The highest level of the Little Valley lake cycle is about 5000 feet (~1520 m) above sea level, or below the elevation of the subsequent Lake Bonneville highstand (Scott and others, 1983; Scott, 1988b) and thus is buried throughout most of the Bonneville basin, although Personius and Scott (1992) showed several exposures in Salt Lake Valley outside of the Draper quadrangle.

Younger glacial deposits near Big Cottonwood and Little Cottonwood Canyons (Qgabc, Qgmbc, and Qgbc) are more extensive and are contemporaneous with late Pleistocene Lake Bonneville (Oviatt and others, 1992). Richmond (1964) correlated these deposits with late Bull Lake glaciation, but Madsen and Currey (1979) demonstrated that they are correlative with Pinedale glaciation (marine oxygen-isotope stage 2; Oviatt and others, 1999) whose type area is in central Wyoming. Their 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 till occurred about 17 to 15 ka (Lips and others, 2005).

Madsen and Currey (1979) observed that Lake Bonneville deposits both underlie and overlie Bells Canyon till. Lips and others (2005; Lips p. 440–445 in Godsey and others, 2005a) interpreted the till as deposits of two different glacial advances during marine oxygen-isotope stage 2, one advance occurring before the Lake Bonneville transgression and highstand and one after the highstand (glacial maxima). Lips and others (2005; Lips in Godsey and others, 2005a) identified three lines of geomorphic evidence that support at least one glacial advance after the Bonneville highstand.

1. The large delta surface west of Bells and Little Cottonwood Canyons was formed during a sustained period of stream discharge throughout the Bonneville highstand, but prominent moraines (left and right lateral moraines near Little Cottonwood Canyon and the end moraine near Bells Canyon) would have blocked sediment discharge from the canyons to the delta, and therefore the moraines must have formed after the delta.

2. The cross-sectional area of the Dry Creek ravine is much larger than the notch eroded into the end moraine of Bells Canyon, indicating that after the ravine was eroded through Lake Bonneville highstand deposits, the Bells Canyon glacier advanced past the canyon mouth, and Dry Creek eroded the notch into the post-highstand end moraine at a lower flow rate than prior to the ravine erosion.

3. Fluvial terraces (Qat and Qatp) and an alluvial fan (Qafp) near the floor of Dry Creek suggest that there was sustained flow through Dry Creek after the Bonneville flood, while the lake was at the Provo stillstand.

In and near high-elevation cirques we identified potentially much younger glacial deposits (Qgmy), possibly as young as late Holocene, but these deposits lack age control. They are potentially similar to the Hogum Fork and Devils Castle till of Madsen and Currey (1979) and are herein distinguished based on a lack of vegetation and the presence of sharp moraine crests. More work is needed to determine the age and timing of these potentially younger glacial deposits.

Lake Bonneville

Deposits and shorelines of Pleistocene Lake Bonneville dominate the surficial geology of the Draper quadrangle. Lake Bonneville was a large lake that covered much of northwestern Utah and adjacent parts of Idaho and Nevada in the Bonneville basin. The lake occupied the basin from 30,000 to 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, 2005b, 2011; Oviatt, 2015; see table 1 for ages and elevation ranges).

The earliest of the regionally recognized shorelines is the Stansbury group, which resulted from climatically induced lake-level oscillations from about 26,000 to 24,000 years ago during transgression of Lake Bonneville. The Stansbury shorelines formed at elevations of about 4420 to 4520 feet (1347–1378 m); these elevations are presently found in the northwest corner of the Draper quadrangle, but the shoreline(s) cannot be identified because subsequent deposition during Lake Bonneville regression and erosion by Little Cottonwood Creek made significant changes to the landscape.

Lake Bonneville reached its highest level sometime after about 18,500 years ago, with an overflow outlet near Zenda, in southern Idaho (Oviatt and others, 1992; Oviatt, 2015). The Bonneville shoreline, which can be traced across most of northwest Utah, was created at the highstand and forms the highest bench near the base of the Wasatch Range in the Draper quadrangle.

About 18,000 years ago rapid downcutting through the Zenda threshold lowered the lake by 340 feet (100 m) during the catastrophic Bonneville flood (Gilbert, 1890; Malde, 1968; Jarrett and Malde, 1987; Oviatt and others, 1992; Oviatt, 2015), perhaps in less than one year (O'Conner, 1993). Lake Bonneville then stabilized at a new lower threshold near Red Rock Pass, Idaho (Janecke and Oaks, 2011) and the Provo shoreline began to form (Miller and others, 2012; Miller, 2016).

Rivers flowing into the lake while it was at or near the Provo shoreline formed large deltas, such as the delta at the mouth of Little Cottonwood Canyon in the Draper quadrangle. About 15,000 years ago, climatic factors (higher evaporation and lower precipitation) induced further lowering of the lake level within the Bonneville basin (Godsey and others, 2005b, 2011; Oviatt, 2015; Miller, 2016). By about 13,000 years ago, the level of Lake Bonneville had fallen below the elevation of present Great Salt Lake (Currey and others, 1988; Godsey and others, 2005b; Oviatt, 2015). A subsequent minor lake expansion in the Bonneville basin culminated about 11,500 years ago, the Gilbert-episode lake, regarded as a separate lake, rather than a phase of the Bonneville or Great Salt Lake cycles (Oviatt, 2014). The Gilbert-related shoreline (Oviatt, and others, 2005) formed at elevations below any in the Draper quadrangle. After the Gilbert expansion, the lake fell to near the current level of Great Salt Lake, leaving Great Salt Lake and Utah Lake as its two most prominent remnants (table 1).

Isostatic rebound following the Bonneville flood, as well as displacement along the Wasatch fault zone, altered the elevations of regionally recognized shorelines in the Bonneville basin (Crittenden, 1963; Currey, 1982; Bills and others, 2002). The amount of isostatic rebound (uplift) is greater toward the center (deepest part) of the basin where the volume of "removed" water was greatest; Crittenden (1963) originally estimated a maximum isostatic uplift of 210 feet (64 m) near the Lakeside Mountains west of Great Salt Lake, but Currey (1982) estimated maximum isostatic uplift of 240 feet (74 m) using additional topographic data and aerial photographs. The maximum elevation of the Bonneville shoreline in the Draper quadrangle is about 5280 feet (1610 m) compared to the lake's threshold elevation of 5092 feet (1552 m) at Zenda. The maximum elevation of the Provo shoreline in the quadrangle is about 4850 feet (1480 m) compared to its threshold elevation of 4737 feet (1444 m) at Red Rock Pass (table 1; Currey, 1982). The relative contribution of displacement along the Wasatch fault zone in the Draper quadrangle is greatest for the Bonneville shoreline, which is on the footwall of the fault zone, whereas the Provo shoreline is on the hanging wall of the fault zone.

Other Surficial Deposits

Other surficial deposits in the quadrangle are mostly younger than Lake Bonneville and reflect post-glacial landscape evolution. Streams incised in response to the lowering base level as Lake Bonneville regressed. The streams deposited alluvium in the channels and floodplains of Big Cottonwood and Little Cottonwood Creeks that are inset into Lake Bonneville deltaic deposits west of the Wasatch Range, and in smaller range-front drainages and alluvial fans. Locally, steeper slopes underlain by shoreline and deltaic deposits of Lake Bonneville failed. The largest slope failures are previously unmapped earth flows along the steep front of the Little Cottonwood delta, evident on aerial photographs taken prior to development, but now obscured; these mass movements began during regression of Lake Bonneville. Some slope failures in the Draper quadrangle may be associated with earthquakes on the Wasatch fault zone. Some landsliding is historical.

Wind locally reworked Lake Bonneville sands into eolian blankets and low dunes (Qes). Common in the quadrangle is a thin but widespread mantle of calcareous loess mostly derived from desert areas of western Utah, Idaho, and Nevada, present on stable geomorphic surfaces (Shroba, 1984). The loess is friable to moderately firm, homogenous, nonstratified, and porous, and forms steep to vertical faces where exposed in stream cuts. Most argillic B horizons of late Pleistocene-age soils in the region are formed in this loess (Machette, 1992), which is typically less than 3 feet (1 m) thick in the Draper quadrangle. Loess deposits were not mapped as a separate unit because they are thin, weathered, and commonly mixed with underlying sediments.

PREVIOUS GEOLOGIC MAPPING

Many geologic studies of bedrock in the Wasatch Range of the Draper quadrangle have been completed, some more than a century ago. Much of the earliest work was unpublished and related to mining in the Big Cottonwood mining district that began just prior to 1870 (James, 1979). The following summary focuses on geologic mapping and ground-breaking studies and is not an exhaustive list. Figure 2 shows selected geologic maps of adjacent quadrangles. Loughlin (1913) published the first geologic map of the Wasatch Range in the quadrangle at a reconnaissance scale of 1:250,000. Birch (1940) mapped the geology between Little Cottonwood and Big Cottonwood Canyons at a scale of 1:31,680 for an M.S. thesis concentrating on Precambrian stratigraphy. Granger and others (1952) published the first detailed geologic map of bedrock in the Draper quadrangle at a scale of 1:62,500 as part of their map of the Wasatch Range east of Salt Lake Valley; future maps benefited from the level of detail included in their map. Marsell and Threet (1960) showed the geology of the Wasatch Range at a scale of 1:63,360 in their map of Salt Lake County. Precambrian geology was also the subject of Neff (1962), who mapped the area near Little Willow and Little Cottonwood Canyons at a scale of 1:12,000 for his M.S. thesis. Condie (1965, 1967) worked farther north around Big Cottonwood Canyon for his Ph.D. dissertation. Crittenden (1965a) mapped the Draper quadrangle at a scale of 1:24,000; his bedrock map is revised here and provided the framework for discussion of the geology of the Big Cottonwood mining district by James (1979). Lawton (1980) studied the Little Cottonwood stock and adjacent metamorphic rocks, mapping geology at a scale of 1:48,000.

Geologic maps by Lofgren (1947) and Morrison (1965) at 1:24,000 scale, Van Horn (1975) at 1:48,000 scale, and Miller (1980) at 1:100,000 scale, were early attempts to map the Quaternary unconsolidated deposits of Salt Lake Valley and place them in a stratigraphic framework. However, interpretations of Quaternary geology, and particularly of Lake Bonneville stratigraphy, continued to evolve. 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.

Our mapping adds detail to the surficial deposits on the valley floor. We also remapped the glacial deposits, revised the bedrock geology, changed the configuration of some strands of the Wasatch fault zone along the Wasatch Range front, and mapped new landslides along the steep front of Lake Bonneville deltas at the mouths of Big Cottonwood and Little Cottonwood Canyons.

METHODS

Mapping of surficial deposits by the Utah Geological Survey (UGS) is based on age and depositional environment or origin. The letters of the map units indicate (1) age (geologic period, e.g., Q for Quaternary); (2) depositional environment or origin, and (3) morphology, texture, lithology, or other distinctive characteristics of the deposits and relative age (Doelling and Willis, 1995). For example, unit Qaf_4 is a Quaternary surficial deposit of alluvial fan origin, and the number four indicates it is older than Lake Bonneville. In contrast Qat_{1-17} are stream terraces with number 1 being the youngest and number 17 being the oldest, but all are younger than the Bonneville shoreline. Note that units having the same number are not necessarily the same age (see correlation chart).

Co-author Solomon used 1:10,000-scale black-and-white aerial photographs from the U.S. Department of Agriculture (USDA) Agricultural Stabilization and Conservation Service (Soil Conservation Service) (1958) to map surficial geology prior to most development in the quadrangle. (Most surficial geology can only be accurately mapped from aerial photos that pre-date development.) He conducted limited field checking in the spring of 2009 to study significant Quaternary features. He interpreted the contacts between some of his Quaternary units from the U.S. Soil Conservation Service (now Natural Resources Conservation Service) soil maps of the Salt Lake Valley (Woodward and others, 1974). Solomon made the unpublished geologic map by transferring the geology from the aerial photographs to a mashup of a orthophotographic and topographic base map and then to a geographic information system (GIS) database using ArcGIS, at a target scale of 1:24,000. Solomon retired before his mapping of the Draper quadrangle surficial deposits could be formally published.

Our geologic map is from revised surficial mapping of Solomon, revised bedrock mapping of Crittenden (1965a), and new mapping by co-author McKean. It was done in a geographic information system (GIS) database using ArcGIS and computer-aided design (CAD) VrOne and VrTwo (digital stereographic mapping) programs for a target scale of 1:24,000. As needed McKean revised the surficial mapping using Solomon's original aerial photographic mapping. In addition to the 1958 aerial photographs, McKean used stereographic pairs of black-and-white aerial photographs from the U.S. Department of Agriculture (USDA) Agricultural Stabilization and Conservation Service (1937), and black-and-white oblique aerial photography from the Woodward-Lundgren & Associates Wasatch fault investigation (Cluff and others, 1970, complied in Bowman and others, 2015). Natural color, digital, aerial photographs from the USDA National Agriculture Imagery Program (2009) were used in digital stereo software to map the glacial deposits in the quadrangle. Gravel pit outlines and some contacts were revised using 2012 orthophotographs (Utah Automated Geographic Reference Center [UAGRC], 2012). Most Quaternary active faults, glacial deposits, landslides, and some additional contacts were revised using lidar elevation data (2 meter data available from UAGRC [2006]; and 0.5 meter from UAGRC [2013–2014]). Over 200 surface fault rupture investigations conducted by private consultants for construction were reviewed to supplement fault mapping (McKean, 2017a). These reports were collected by the UGS and are available online from the UGS Geo-Data Archive System website (https://geodata.geology.utah.gov/). Our surficial mapping is similar to and in places revised from Personius and Scott (1992). McKean revised bedrock geologic mapping from previous mapping by Crittenden (1965a); contacts and units were field checked and changed where needed based on field observations and interpretation. McKean remapped and field checked the surficial, glacial, and bedrock deposits in 2014 and 2015.

Cross-section A–A′ was created by combining available subsurface information and gravity data from several sources, including Cook and Berg (1961), Arnow and Mattick (1968), Arnow and others (1970), Mattick (1970), Bashore (1982), Meiiji Resource Consultants (1983), Zoback (1983), Case (1985), and Radkins and others (1989). Lithologic well logs from Case (1985), Meiiji Resource Consultants (1983), and others compiled online (UGS, undated), were used to determine the subsurface contact between Quaternary deposits (unconsolidated sediments) and Tertiary strata (semiconsolidated to consolidated strata). The subsurface position of the Little Cottonwood stock below the Tertiary strata is based on gravity data from Meiiji Resource Consultants (1983), Bashore (1982), and minimum vertical offsets calculations across the Wasatch fault zone and gravity interpretations by Zoback (1983).

PALEOSEISMOLOGY

The Draper quadrangle is in the Intermountain Seismic Belt, one of the most seismically active regions in the interior of the U.S. (Smith and Arabasz, 1991). The region includes many faults that have been repeatedly active in the late Quaternary. The most significant of these faults is the 230-mile-long (370 km), range-bounding Wasatch fault zone. The Wasatch fault zone strikes north-south through northern Utah and has been divided into 10 segments, each capable of generating strong earthquakes (Machette and others, 1992). The five central segments (the Brigham City, Weber, Salt Lake City, Provo, and Nephi segments) are the most active.

The Salt Lake City segment cuts through the quadrangle. Its mean recurrence for Holocene surface-faulting events is ~1.3–1.6 ky (DuRoss and Hylland, 2015), and it has the potential to generate earthquakes with a moment magnitude of about 7.1 (Working Group on Utah Earthquake Probabilities [WGUEP], 2016). Earthquakes of this size pose extensive geologic risk (Solomon and others, 2004). The Salt Lake City segment includes three subsections separated by left steps, and are, from north to south, the Warm Springs, East Bench, and Cottonwood faults (Personius and Scott, 1992). Most of the Cottonwood fault is in the Draper quadrangle, forming a prominent, complex zone of faulting along the Wasatch Range front from just north of Big Cottonwood Canyon to the Traverse Mountains. At the mouth of Little Cottonwood Canyon, the fault forms a 160-foot-wide (50 m) graben with an 80-foot-high (25 m) main scarp and 30-foot-high (10 m) antithetic scarp. Farther south at South Fork Dry Creek, the graben is a 1300-foot-wide (400 m) fault zone.

The complexity of the fault zone and poor recognition of low antithetic fault scarps has precluded accurate determination of net tectonic displacement. However, profiling of moraine surfaces across the fault zone in the Little Cottonwood Canyon area indicates approximately 45 to 50 feet (14–14.5 m) of net vertical tectonic displacement (Madsen and Currey, 1979; Swan and others, 1981). From paleoseismic trench studies at four locations on the Cottonwood fault, the main fault zone shows stratigraphic evidence for seven surface-faulting earthquakes since 15 ka (McCalpin and Nelson, 2000), and estimates of displacement per event vary from 5 to 15 feet (1.5–5 m) (Schwartz and Lund, 1988; Black and others, 1996). Based on structural geology, distribution and size of fault scarps, and comparisons with large historical earthquakes elsewhere, surface ruptures on the Salt Lake City segment may initiate at the southern end of the Cottonwood subsection and propagate northward (Bruhn and others, 1987; Personius and Scott, 1992).

Paleoearthquake-timing data for the Salt Lake City segment is from multiple paleoseismology studies from the Draper quadrangle summarized below (see approximate locations on plate 1). For earthquake timing and recurrence rates for the entire segment see DuRoss and Hylland (2015). An early study at the Little Cottonwood Canyon site (see LCC on plate 1, SW1/4 section 1, T. 3 S., R. 1 E., Salt Lake Base Line and Meridian [SLBLM]) found evidence for two to three Holocene earthquakes, but was only able to determine an early Holocene minimum limiting age for the second oldest (penultimate) earthquake (Swan and others, 1981). About 3 miles (5 km) south of Little Cottonwood Canyon, Schwartz and Lund (1988) excavated four trenches across three of the six scarps at the South Fork Dry Creek site (see SFDC on plate 1, NE1/4 section 23, T. 3 S., R. 1 E., SLBLM). Their study produced maximum limiting ages for two events, but Schwartz and Lund (1988) cautioned that the earthquake chronology at this site remained incomplete because not all of the scarps were trenched. In a follow-up study at the South Fork Dry Creek site, Black and others (1996) excavated five trenches (resulting in trenching of all scarps at the site) and determined maximum limiting ages for four events. The South Fork Dry Creek data, combined with the results of a geotechnical trench excavation at Dry Gulch (see DG on plate 1, NE1/4 section 23, T. 3 S., R. 1 E., SLBLM) (see Lund, 1992; and Black and others, 1996), established the current chronology of four earthquakes in 6 kyr on the Cottonwood fault. This chronology, however, is based on apparent mean residence time (AMRT) radiocarbon ages, which are difficult to interpret given the uncertainties in what is actually being dated. In 1999, McCalpin (2002) reoccupied the Little Cottonwood Canyon site, and with a "megatrench" investigation, extended the paleoseismic record for the southern Salt Lake City segment into the latest Pleistocene. McCalpin (2002) identified seven post-Bonneville (<17 ka) earthquakes, including three younger than about 5 ka. A significant finding from that study is that the average earthquake recurrence interval is much longer between 6 and 15 ka than it is after 6 ka. In 2014 Hiscock and DuRoss (2016) opened a paleoseismic trench in Corner Canyon (see CC on plate 1, NE1/4 section 4, T. 4 S., R. 1 E., SLBLM); preliminary results identified six events; the older four occurred between about 5 and 1 ka and correlated with previously identified earthquakes at Penrose Drive (located to the north in the Fort Douglas quadrangle), Little Cottonwood Canyon (see LLC on plate 1) and South Fork Dry Creek (See SFDC on plate 1) sites (DuRoss and others, 2014; DuRoss and Hylland, 2015). The youngest two events (younger than 1 ka) postdate previously identified Salt Lake City segment earthquakes and may record spillover rupture from the Provo segment (Hiscock and DuRoss, 2016).

These paleoseismology studies (Swan and others, 1981; Schwartz and Lund, 1988; Black and others, 1996; McCalpin, 2002; Hiscock and DuRoss, 2016), combined with many available consultant surface fault rupture investigations, provided valuable scientific information for our mapping of the Wasatch fault zone in the quadrangle.

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qa **Alluvial deposits** (Holocene to upper Pleistocene) – Silt and minor clay, sand, and gravel, in deposits of streams, alluvial fans, and sheetwash that grade imperceptibly into one another on nearly flat stream terraces south of Little Cottonwood Creek; thickness less than about 10 feet (3 m).

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 parallel bedding and cross-bedding; mapped in channels and active floodplains of Big Cottonwood, Little Cottonwood, Dry, and Willow Creeks, and smaller tributaries, and on minor terraces mostly 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 where active channels and bar-and-swale topography can be mapped separately; exposed thickness less than 10 feet (3 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 parallel bedding and cross-bedding; forms low terraces 5 to 15 feet (1.5–5 m) above and adjacent to channels and floodplains of Big Cottonwood and Little Cottonwood Creeks, inset into deposits of the Bonneville lake cycle; deposits may be in the active flood plain; 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 that can be mapped separately; exposed 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 minor silt and clay; deposited in the upper reaches of several streams near the Wasatch Range front; locally includes small alluvial-fan and colluvial deposits; includes level-2 stream deposits (Qal_2) incised by active stream channels that are too small to show separately at map scale or where the specific age of post-Lake Bonneville deposits cannot be determined; postdates regression of Lake Bonneville from the Provo shoreline and lower shorelines; thickness variable, probably less than 15 feet (5 m).

Qalp **Stream deposits related to Provo shoreline and regressive phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, clast-supported pebble and cobble gravel, locally bouldery, with a matrix of sand and silt; contains thin discontinuous sand lenses; subangular to rounded clasts; thin- to thick-bedded with parallel bedding and cross-bedding; deposited in (1) six small channels between Big Cottonwood and Little Cottonwood Creeks, graded to or slightly below the Provo shoreline and incised into transgressive Lake Bonneville gravel, sand, and silt deposits (Qldbg, Qldbs); (2) two large channels between Little Cottonwood and Dry Creeks, graded to or slightly below the Provo shoreline and incised into transgressive Lake Bonneville deltaic deposits (Qldb); and (3) two small channels hanging above Willow Creek, incised into transgressive Lake Bonneville sandy deltaic deposits (Qldbs) and regressive sand and silt (Qlsp); northernmost channel near Big Cottonwood Creek was identified as a "paleostream channel" by Personius and Scott (1992), but its deposits, and other similar deposits in small channels between Big Cottonwood and Little Cottonwood Creeks, were not mapped; deposits in channels between Little Cottonwood and Dry Creeks were mapped as stream alluvium related to regressive phase of Lake Bonneville by Personius and Scott (1992); they also included topset beds of alluvial origin deposited during regressive Lake Bonneville in their alluvial unit; we restrict the unit to deposits in clearly defined channels, commonly with fluvial scarps along both edges, and map the topset beds as part of Qafp; exposed thickness less than 15 feet (5 m).

Qat, $Qat_{1\text{-}17}$

Stream-terrace deposits (middle Holocene to upper Pleistocene) – Poorly to moderately sorted, clast-supported 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 parallel bedding and cross-bedding; deposited by streams graded to the Provo shoreline and other shorelines of the regressive phase of Lake Bonneville, with preserved fluvial scarps, and as topset beds on regressive deltaic deposits (Qldp); deposited as undivided stream terraces, and as many as 17 levels of gently sloping terraces near Little Cottonwood Creek, with subscripts denoting relative position above the active stream channel, likely in a down-cutting sequence with 1 being the lowest level, see table 2 for summary heights and positions above the active stream channel; level 1 deposits (Qat_1) are 15 to 20 feet (5–6 m) above the active stream and are incised by it; levels 2 through 11 (Qat_2 through Qat_{11}) are closely spaced at increasing relative heights of 20 to 120 feet (5–40 m) above the active stream in a narrow area on the south side of Little Cottonwood Creek; remnants of level 12 (Qat_{12}) are up to 150 feet (45 m) above the active stream on both sides of Little Cottonwood Creek; levels 13 through 17 (Qat_{13} through Qat_{17}) are up to 240 feet (70 m) above Little Cottonwood Creek on its south side; level 17 covers flats that extend from the mouth of Little Cottonwood Canyon, overlying remnants of the transgressive Lake Bonneville delta (Qldb), and grade to faint regressive Provo shorelines etched into the downslope toe of the flats (terrace mapping similar to Morrison, 1965); numbered subscripts are relative to each other and do not indicate a specific age; subscripts are absent near Big Cottonwood Creek and at the mouth of Little Cottonwood Creek east of the Wasatch fault zone because terraces cannot be correlated between drainage basins and the effects of fault displacement on stream terraces cannot be determined; the highest (oldest) terraces (Qat_{17}) grade downslope to the Provo shoreline, and the lowest (youngest) terraces (Qat_1 and Qat_2) are incised into the regressive Lake Bonneville delta, suggesting a late Pleistocene to middle Holocene age; thicknesses typically 5 to 15 feet (1.5–5 m) for each map unit.

Qatp **Stream-terrace deposits related to Provo shoreline and regressive phase of Lake Bonneville** (upper Pleistocene) – Moderately to poorly sorted pebble and cobble gravel, locally bouldery, with a matrix of sand, silt, and minor clay;

subangular to rounded clasts; deposited on a terraces above Dry Creek; terrace appears to grade to the Provo shoreline; age equivalent to Qafp; subscripts are absent along Dry Creek because terraces cannot be correlated with stream-terrace deposits (Qat_{1-17}) in the drainage basins to the north; exposed thickness less than 15 feet (5 m).

Qaf_1 **Level-1 alluvial-fan deposits** (upper Holocene) – Poorly to moderately sorted, weakly to non-stratified, pebble to cobble gravel, locally bouldery, with a matrix of sand, silt, and minor clay; clasts subangular to well-rounded, commonly derived from Lake Bonneville gravel; thin to thick parallel bedding and cross-bedding; deposited by debris flows, debris floods, and streams graded to active streams at the mouths of small canyons along the fronts of the Wasatch Range and Traverse Mountains; may contain small debris-flow deposits ($Qmdf_1$) that cannot be differentiated at map scale; equivalent to the younger part of young alluvial-fan deposits (Qafy) but differentiated where active small, discrete fans are not incised by younger channels and can be shown separately at map scale; Personius and Scott (1992), using the terminology of Birkeland (1984), described typical soil profiles of this unit as ranging from A-Cn to A-Bw-Cox-Cn; exposed thickness less than 15 feet (5 m).

Qaf_2 **Level-2 alluvial-fan deposits** (middle Holocene to upper Pleistocene) – Poorly sorted pebble and cobble gravel, locally bouldery, with a matrix of sand, silt, and minor clay; clasts subangular to well-rounded, commonly derived from Lake Bonneville gravel; thin to thick parallel bedding and cross-bedding; deposited by debris flows, debris floods, and streams graded slightly above active streams at the mouths of several small canyons south of Little Cottonwood Canyon, and in larger deposits near Draper at the convergence of Willow Creek and its tributaries and at the mouth of Corner Canyon; may contain small debris-flow and level-1 alluvial-fan deposits ($Qmdf_1$ and Qaf_1) that cannot be differentiated at map scale; equivalent to the older part of Qafy, but differentiated where deposits are incised by active streams and can be mapped separately; Personius and Scott (1992), using the terminology of Birkeland (1984), described typical soil profiles of this unit as ranging from A-Bw-Cox-Cn to A-Bt(weak)-Cox-Cn; 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, grading to mixtures of sand, silt, and clay on gentler slopes; clasts subangular to well-rounded, commonly derived from Lake Bonneville gravel; thin to thick parallel bedding and 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 Corner Canyon in Draper; includes level-1 and level-2 alluvial-fan deposits (Qaf_1 and Qaf_2) that postdate the regression of Lake Bonneville from the Provo shoreline, mapped where these levels cannot be differentiated at map scale and in areas where the specific age of Holocene deposits cannot be determined; no Lake Bonneville shorelines are found on these alluvial fans; thickness variable, probably less than 30 feet (10 m).

Qafp **Alluvial-fan deposits related to Provo shoreline and regressive phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, locally bouldery, 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 stream flow at the mouth of Big Cottonwood and Little Cottonwood Canyons, grading downslope to regressive Lake Bonneville deltaic deposits (Qldp); mapped by Personius and Scott (1992) as stream alluvium related to the regressive phase of Lake Bonneville (their alp), however the deposits have fan-shaped morphologies and grade downslope to deltaic deposits (Qldp), representing the subaerial part of the fan-delta complex and some topset alluvial beds that cannot be differentiated; 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); in the Draper quadrangle deposits related to the regression of Lake Bonneville (Qafp) can be mapped separately from older af3 deposits (see Qafb below); Personius and Scott (1992) describe typical soil profiles of this unit, using the terminology of Birkeland (1984), as ranging from A-Bt(weak)-Cox-Cn to A-Bt-Cox-Cn; 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, locally bouldery, with a matrix of sand, silt, and minor clay; clasts subangular to rounded; thin to very thick parallel bedding and cross-bedding; deposited by debris flows, debris floods, and stream flow at the mouth of Ferguson Canyon, a tributary to Big Cottonwood Canyon, graded slightly below the highest (Bonneville) shoreline of Lake Bonneville; incised into pre-Bonneville alluvial-fan deposits (Qaf_4) and incised by post-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 af3 of Nelson and Personius, 1993), but in the Draper quadrangle deposits related to the transgression of Lake Bonneville (Qafb) can be mapped separately; Personius and Scott (1992), using the terminology of Birkeland (1984), described the typical soil profile of this unit as A-Bt-Cox-Cn; exposed thickness less than 15 feet (5 m).

Qafo **Older alluvial-fan deposits, undivided** (upper to middle? Pleistocene) – Poorly to moderately 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 thick parallel bedding and cross-bedding; deposited by debris flows, debris floods, and streams on the south side of Big Cottonwood Canyon; may include some older colluvial and talus; likely Lake Bonneville age alluvial-fan deposits (see af3 of Nelson and Personius, 1993) and/or older alluvial-fan deposits that predate Lake Bonneville (Qaf_4); incised by younger alluvial-fan deposits (Qafy); thickness variable, probably less than 30 feet (10 m).

Qaf_4 **Level-4 alluvial-fan deposits, pre-Bonneville lake cycle** (upper to middle Pleistocene) – Poorly sorted, clast-supported pebble to cobble gravel, with matrix-supported interbeds in the upper part and locally bouldery, with a matrix of sand, silt, and clay; clasts subangular to rounded; thin to very thick parallel bedding and cross-bedding; forms small fans and fan remnants above, and commonly cut by, the Bonneville shoreline; correlative deposits likely underlie Lake Bonneville deposits in Salt Lake Valley, and probably grade laterally to lacustrine sediment of the Little Valley or Pokes Point lake cycles below an elevation of about 4920 feet (~1500 m) for the Little Valley lake cycle (Scott, 1988b), and the elevation of Pokes Point lake cycle 4685 feet (1428 m) in Little Valley (McCoy, 1987); Personius and Scott (1992), using the terminology of Birkeland (1984), described the typical soil profile of this unit as A-Bt(moderate-strong)-Cox-Cn; exposed thickness less than 15 feet (5 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 matrix-supported interbeds in the upper part and locally bouldery, in a matrix of sand, silt, and clay; clasts subangular to rounded; thin to very thick parallel bedding and cross-bedding; present on a ridge north of Little Cottonwood Canyon in an eroded fan remnant high (between 820 and 1150 feet [250–350 m]) above the active channel of Little Cottonwood Creek; deposit lacks fan morphology; may be a deposit of glacial till that lacks morainal morphology; Machette (1992) reported that level 5 alluvial fan-deposits are exposed in a stream gully on the divide east of Peteetneet Creek in the Payson Lakes quadrangle south of Utah Valley, and contain isolated pods of 0.640 ± 0.004 Ma Lava Creek B volcanic ash (Lanphere and others, 2002); correlative alluvial deposits likely underlie Lake Bonneville deposits and probably grade laterally into lacustrine sediment of older pre-Pokes Point lake cycles; Personius and Scott (1992), using the terminology of Birkeland (1984), described the typical soil profile of this unit as A-Bt(strong)-Cox-Cn; 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 and silt; clasts commonly angular to subangular, but includes some subround to round recycled lacustrine gravel below the Bonneville shoreline; very poorly sorted, poorly stratified, locally derived sediment deposited by slopewash and soil creep; includes landslides, rock falls, and debris flows too small to map separately; most bedrock is covered by at least a thin veneer of colluvium, and only the larger, thicker deposits are mapped; mapped as small cones and debris aprons above the Bonneville shoreline between Big Cottonwood and Little Cottonwood Canyons, derived from Paleozoic rocks; along the steep sides of Bells Canyon, derived from Tertiary granite; locally covers the Bonneville bench south of Bells Canyon; derived from adjacent oversteepened bedrock slopes; along the banks of Willow Creek, derived from transgressive Lake Bonneville deltaic deposits; thickness between 3 and 30 feet (1–10 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 is from Madsen and Currey (1979) and Laabs and others (2011). Deposits of Bells Canyon age are broadly equivalent to deposits of Pinedale age in the middle Rocky Mountains. Deposits of Dry Creek age have weathering characteristics similar to those of deposits of Bull Lake age in the middle Rocky Mountains.

Qg **Glacial deposits, undivided** (Holocene? to middle Pleistocene) – Unsorted boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subround; non-stratified; mapped along the canyon walls of Little Cottonwood Canyon, and on the ridge between Little Cottonwood and Bells Canyon where till is stranded high on the ridge and may be older; also mapped as a stacked unit (Qg/Tlc) that includes Bells Canyon and Dry Creek age deposits; may locally include mass-movement and colluvial deposits too small to show separately at map scale; exposed thickness less than 30 feet (10 m).

Qgmy **Young glacial moraines, undivided** (Holocene? to upper Pleistocene?) – Unsorted boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subround; non-stratified; moraines are comparatively less vegetated and appear younger than the Bells Canyon age deposits; mapped in high-elevation cirques where sharp moraine crests are visible on aerial photographs and lidar imagery; may locally include mass-movement and colluvial deposits too small to show separately at map scale; estimated thickness less than 50 feet (15 m).

Qgbc **Glacial deposits of Bells Canyon age** (upper Pleistocene) – Unsorted boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subround; non-stratified; mapped in Little Cottonwood and Bells Canyons and at higher elevations in cirques and canyons in the Wasatch Range where moraines and outwash are not distinct; may locally include mass-movement and colluvial deposits too small to show separately at map scale; exposed thickness less than 30 feet (10 m).

Qgmbc **Glacial moraines of Bells Canyon age** (upper Pleistocene) – Unsorted boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subround; non-stratified; mapped at the mouths of Little Cottonwood and Bells Canyons where distinct U-shaped end, lateral, and regressional moraines are visible, and at higher elevations in the Wasatch Range in cirques and canyons; at the mouth of Bells Canyon, end moraine is partially overlapped by a wedge of transgressive Lake Bonneville lacustrine gravel and sand (Qlgb) (Madsen and Currey, 1979); may locally include mass-movement and colluvial deposits too small to show separately at map scale; estimated maximum thickness less than 240 feet (70 m).

Qgabc **Glacial outwash of Bells Canyon age** (upper Pleistocene) – Poorly to moderately sorted clast-supported cobble and pebble gravel, locally bouldery, with a minor matrix of sand and silt; clasts subangular to rounded; thin to thick parallel bedding and cross-bedding; deposited by glacial meltwater streams at the mouths of Big Cottonwood, Little Cottonwood, and Bells Canyons; overlie (younger than) Bonneville-level deltaic deposits at the mouth of Big Cottonwood Canyon; graded to stream-terrace deposits (Qat_{17}) at the mouth of Little Cottonwood Canyon that in turn grade to the Provo shoreline; exposed thickness up to 130 feet (40 m).

Qgdc **Glacial deposits of Dry Creek age** (middle Pleistocene) – Unsorted boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subround; non-stratified; small exposures mapped below transgressive Bonneville deltaic deposits (Qldb) and outwash of Bells Canyon age (Qgabc) along the banks of Dry Creek near the mouth of Bells Canyon (Madsen and Currey, 1979) and below the Second Hamongog in the southeast corner of the quadrangle; surface of deposits commonly contain grus derived from weathered granite boulders; Personius and Scott (1992), using the terminology of Birkeland (1984), described the typical soil profile of this unit as A-Bt(moderate-strong)-Cox-Cn; exposed thickness less than 25 feet (8 m).

Qgmdc **Glacial moraines of Dry Creek age** (middle Pleistocene) – Unsorted boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subround; non-stratified; mapped on the north and south margins of Bells Canyon at elevations above moraines of Bells Canyon age (Qgmbc), and below the Second Hamongog in the southeast corner of the quadrangle; surface of deposits commonly contain grus derived from weathered granite boulders; Personius and Scott (1992), using the terminology of Birkeland (1984), described the typical soil profile of this unit as A-Bt(moderate-strong)-Cox-Cn; estimated maximum thickness less than 200 feet (60 m).

Human-derived

Qh **Fill and disturbed land** (historical) – Undifferentiated artificial (human) fill and disturbed land related to construction, borrow pits, and sand and gravel operations, commonly in both transgressive (Qldb, Qlgb, and Qlsb) and regressive (Qldp, Qlgp, and Qlsp) Lake Bonneville deposits; the outlines of artificial fill and disturbed land are based on 1958 aerial photographs, 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

Deposits related to the Provo shoreline and regressive phase of Lake Bonneville: Only mapped below the Provo shoreline, which is at elevations from about 4780 to 4850 feet (1460–1480 m) in the Draper quadrangle (table 1). Currey (1982) estimated an elevation of 4787 feet (1459 m) for the Provo shoreline in the quadrangle at the crest of a southwest-trending spit (N1/2 section 21, T. 3 S., R.1 E., SLBLM).

Qldp **Deltaic deposits** (upper Pleistocene) – Moderately to well-sorted, clast-supported, 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 parallel and cross-bedded foreset beds having original dips of 5 to 30 degrees; locally deposited as topset beds, and commonly capped with topset beds of poorly sorted, silty to sandy, pebble and cobble alluvium in stream-terrace (Qat) and alluvial-fan deposits (Qafp); exposed along the steep fronts of large delta complexes graded to the Provo shoreline at the mouths of Big Cottonwood and Little Cottonwood Canyons, and also exposed in bluffs along stream terraces where Little Cottonwood Creek incised the deltas; exposed thickness about 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 beds and lenses of silt and sandy silt; gastropods locally common in sandy lenses; gravel commonly cemented with calcium carbonate (tufa); thin to thick bedded; deposited below the Provo shoreline in parallel and cross-bedded, thin to thick horizontal beds and in beds dipping as much as 15 degrees; deposited in beaches, bars, and spits, and in small deltas that do not have distinctive deltaic morphology; commonly interbedded with or laterally gradational to lacustrine sand and silt of the regressive phase (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 laminated, with some ripple marks and scour features; gastropods locally common; deposited below the Provo shoreline, commonly downslope from the Big Cottonwood and Little Cottonwood delta fronts; most of this unit was mapped as regressive lacustrine sand and gravel by Personius and Scott (1992; lpg), but we have divided their unit into one unit that is predominantly sand (Qlsp) and another unit that is predominantly gravel (Qlgp); locally concealed by loess veneer and reworked into eolian deposits (Qes) along west edge of the quadrangle, south of Dry Creek; 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 gravel; typically laminated or thin bedded; variably calcareous; ostracodes locally common; deposited in quiet water in shallow to moderately deep parts of the Bonneville basin; in subsurface typically overlies lacustrine silt and clay of Lake Bonneville transgression (Qlfb), and contact not exposed in the Draper quadrangle; commonly grades upslope into lacustrine sand and silt (Qlsp); locally concealed by loess veneer; regressive lacustrine shorelines typically poorly developed, in contrast to units Qlgp and Qlsp; mapped in small areas along the west edge of the quadrangle; previously mapped by Personius and Scott (1992) as the eastern edge of more extensive deposits of lacustrine clay and silt that were not divided between transgressive and regressive deposits because of a lack of distinguishing characteristics, but here assigned to the regressive phase because of their proximity to clearly regressive coarser deposits (Qlgp, Qlsp), although Qlfp may include some undifferentiated transgressive deposits; 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: Only mapped between the Bonneville and Provo shorelines. The highest Bonneville shoreline is at elevations from about 5180 to 5280 feet (1580–1610 m) in the Draper quadrangle (table 1).

Qldb **Deltaic deposits, undivided** (upper Pleistocene) – Moderately to well-sorted deposits of gravel and sand; clasts subrounded to rounded; locally includes thin beds of silt and sandy silt, and locally weakly cemented with calcium carbonate; undivided (Qldb) where exposed in bluffs along stream terraces, but commonly subdivided into a gravelly unit with clast-supported, pebble and cobble gravel in a matrix of sand and silt (Qldbg) and a sandy unit (Qldbs) with thin beds and lenses of gravel; deposited west of Big Cottonwood and Little Cottonwood Canyons as thin to thick parallel and cross-bedded foreset beds having original dips of 5 to 30 degrees; locally includes topset alluvial beds; previously mapped as transgressive lacustrine sand and gravel by Personius and Scott (1992; lbg), but remapped as deltaic because of distinctive fan-shaped morphology at the mouths of major canyons draining into Lake Bonneville at its highstand; exposed thickness about 120 feet (35 m).

Qldbg **Deltaic gravel and sand** (upper Pleistocene) – Moderately to well-sorted deposits of gravel and sand; clasts subrounded to rounded; locally includes thin beds of silt and sandy silt, and locally weakly cemented with calcium carbonate; undivided (Qldb) where exposed in bluffs along stream terraces, distinguished from sandy unit (Qldbs) by abundance of gravel; deposited west of Big Cottonwood and Little Cottonwood Canyons as thin to thick parallel and cross-bedded foreset beds having original dips of 5 to 30 degrees; locally includes topset alluvial beds; previously mapped as transgressive lacustrine sand and gravel by Personius and Scott (1992; lbg), but remapped as deltaic because of distinctive fan-shaped morphology at the mouths of major canyons draining into Lake Bonneville at its highstand; exposed thickness about 120 feet (35 m).

Qldbs **Deltaic sand and silt** (upper Pleistocene) – Moderately to well-sorted deposits of sand and silt; thin to thick beds of silt and sandy silt, with thin beds and lenses of gravel, and locally weakly cemented with calcium carbonate; gravel clasts subrounded to rounded; undivided (Qldb) where exposed in bluffs along stream terraces, distinguished from gravelly unit (Qldbg) by abundance of sand; deposited west of Big Cottonwood and Little Cottonwood Canyons as thin to thick parallel and cross-bedded foreset beds having original dips of 5 to 30 degrees; locally includes topset alluvial beds; previously mapped as transgressive lacustrine sand and gravel by Personius and Scott (1992; lbg), but remapped as deltaic because of distinctive fan-shaped morphology at the mouths of major canyons draining into Lake Bonneville at its highstand; exposed thickness about 120 feet (35 m).

Qlgb **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, clast-supported, pebble to cobble gravel and rare boulders, with a matrix of sand and pebbly sand; locally interbedded with thin beds and lenses of 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 parallel and cross-bedded, thin horizontal beds, and in beds dipping as much as 15 degrees; typically deposited below and on erosional benches at the Bonneville shoreline near the base of the Wasatch Range southwest of Little Willow Canyon and in Big Cottonwood Canyon; commonly covered by unmapped deposits of colluvium from adjacent oversteepened slopes that are not mapped because the colluvium is thin and underlying gravel benches retain their distinctive morphology; 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; thick to very thick bedded; commonly has ripple marks and scour features; gastropods locally common; deposited in relatively shallow water nearshore at the base of the Wasatch Range southwest of Little Willow Canyon, downslope of transgressive gravel and sand (Qlgb), and on the steep bluffs south of Dry Creek; overlies coarse-grained beach gravel, implying deposition in increasingly deeper water of a transgressing lake; exposed thickness less than 30 feet (10 m).

Qlfb **Lacustrine silt and clay** (upper Pleistocene) – Moderately to well-sorted, silt and clay with minor fine sand; very thin to thick bedded; variably calcareous; mapped in a single location in a bluff on the south side of Dry Creek, overlying transgressive deltaic sand and silt (Qldbs), implying deposition in increasingly deeper, quieter water; exposed thickness less than 15 feet (5 m).

Eolian deposits

Qes **Eolian sand** (Holocene to upper Pleistocene) – Moderately to well-sorted, fine to coarse wind-blown sand, with minor silty sand; sand is mostly siliceous; loose to moderately firm where cemented by secondary calcium carbonate; thin to very thick bedding, commonly cross-bedded; forms sheets and small parabolic and longitudinal dunes; mapped on a terrace on the north side of Little Cottonwood Creek, reworked from sandy alluvium on terraces; on the surface of the transgressive Lake Bonneville compound delta at the mouths of Little Cottonwood and Bells Canyon, mapped as eolian sand (Qes) reworked from lacustrine sand and silt (Qlsp) and as a stacked unit Qes/Qldbs where sandy deltaic deposits (Qldbs) and thin eolian deposits are indistinguishable; located between Dry and Willow Creeks on the western edge of the quadrangle, reworked from regressive sand and silt (Qlsp); and in a similar setting in smaller areas south of Willow Creek; 3 to 15 feet (1–5 m) thick.

Mass-movement deposits

Qmefy **Younger earth-flow deposits** (Holocene to upper Pleistocene?) – Unsorted sand, silt, and minor pebble and cobble gravel with a matrix of sand, silt, and clay; forms an elongated lobe extending downslope from older earth-flow deposits (Qmefp) at the front of the Bells Canyon-Little Cottonwood Creek compound delta, north of Dry Creek; the main scarp of the younger earth-flow deposits is slightly above (east of) the regressive wave-cut shoreline that truncates the older earth-flow deposits, indicating that the younger earth-flow moved after older slope failure; thickness less than 15 feet (5 m).

Qmefp **Lake Bonneville-age earth-flow deposits** (upper Pleistocene) – Unsorted pebbly sand, sand, and minor silt and clay below the Provo shoreline; mapped in two areas near the regressive delta front between Little Cottonwood and Dry Creeks; derived from regressive lacustrine sand (Qlsp) and deltaic deposits (Qldp); characterized by arcuate longitudinal ridges on the surface of the deposit; mass movement occurred soon after lacustrine deposition during regression of Lake Bonneville as indicated by a minor regressive shoreline that truncates the downslope edge of the southern exposure, this indicates a late Pleistocene age for these earthflow deposits, but later movement may have occurred in the northern exposure; both exposures have been extensively modified, first by sand and gravel pits (Qh) and later by commercial and residential development; longitudinal scarps visible on aerial photographs before sand and gravel extraction are mapped with dotted lines as concealed features in areas of disturbed land (Qh); thickness probably less than 50 feet (15 m).

$Qmdf_1$ **Younger Holocene debris-flow deposits** (upper Holocene) – Very poorly sorted clast-supported pebble, cobble, and boulder gravel with a matrix of sand, silt, and clay; very thick bedding; commonly covered with coarse, angular rubble and distinct overlapping levees and channels; forms fan-shaped to lobate deposits at the mouths of four small canyons along the Wasatch Range front; Personius and Scott (1992), using the terminology of Birkeland (1984), described the typical soil profile of this unit as ranging from A-Cn to A-Bw-Cox-Cn; thickness less than 15 feet (5 m).

$Qmdf_2$ **Older Holocene debris-flow deposits** (middle Holocene to upper Pleistocene?) – Very poorly sorted, clast-supported pebble, cobble, and boulder gravel with a matrix of sand, silt, and clay; very thick bedding; commonly covered with coarse, angular rubble and hummocky surface of relict levees and channels; forms fan-shaped deposits at the mouths of South Fork Dry Creek and Big Willow Creek that are incised by younger debris-flow deposits ($Qmdf_1$), and lobate deposit at the mouth of Bear Canyon that diverted alluvial-fan deposits (Qaf_1) southward; Personius and Scott (1992), using the terminology of Birkeland (1984), described the typical soil profile of this unit as ranging from A-Bw-Cox-Cn to A-Bt(weak)-Cox-Cn; thickness less than 15 feet (5 m).

Qms **Landslide deposits** (historical? to middle Pleistocene) – Poorly sorted clay- to boulder-sized material in slides and slumps, with grain and rock composition varying with the nature of source material; landslides are mapped in several areas, including: (1) two landslides north of Little Willow Canyon slightly above the Bonneville shoreline along the steep Wasatch Range front, derived from failure of Precambrian bedrock (Zbc and ZYlw), either exposed or beneath a shallow cover of colluvium or talus (Qc and Qct); (2) one landslide near the mouth of Little Cottonwood Canyon, derived from glacial deposits (Qgmbc and Qgabc); (3) two landslides near Cherry Canyon along the steep front of the Bonneville bench derived from failure of transgressive Lake Bonneville deposits (Qlgb and Qlsb); (4) one landslide south of Dry Creek, slightly above the Provo shoreline, derived from sandy Lake Bonneville deposits (Qldbs); (5) multiple landslides derived from failure of Lake Bonneville deposits along the steep bluffs of Dry Creek (Qldb and Qlsb); (6) landslides mixed with colluvium in lacustrine and deltaic deposits are mapped along Dry Creek bluffs as undivided mass movement and colluvial deposits (Qmc); (7) multiple landslides in Lake Bonneville deltaic deposits (Qldb) are mapped along the steep bluff on the north side of Little Cottonwood Creek; (8) one landslide and one nearby small debris flow are mapped below the steep Lake Bonneville delta front between Big Cottonwood and Little Cottonwood Creeks; the landslide exhibits two clearly defined scarps on 1958 aerial photographs and displaces closely spaced regressive shorelines etched into regressive Lake Bonneville gravel (Qlgp)—the shorelines are preserved in the landslide mass, the small debris flow appears to be the result of a canal failure in the 1958 aerial photographs; and (9) several rock falls characterized by blocky car to house sized collapse deposits are likely related to deglaciation in Little Cottonwood Canyon, Bells Canyon, and at the head of South Fork of Dry Creek; 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; thickness highly variable.

Qmt **Talus deposits** (historical to middle Pleistocene?) − Very poorly sorted, angular cobble- and boulder-size rocks and minor amounts of finer-grained interstitial sediment; deposited principally by rock fall on and/or at the base of steep slopes; mapped above and below the Bonneville shoreline, and in previously glaciated areas in the Wasatch Range;

other small and thin talus deposits are not mapped due to map scale limitations; includes fresh, potentially active rock fall to partially vegetated stabilized talus slopes; generally less than 20 feet (6 m) thick.

Mixed-environment deposits

Qac **Alluvial and colluvial deposits, undivided** (upper Holocene to middle Pleistocene?) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment; mapped where deposits of alluvium, slopewash, and soil creep grade imperceptibly into one another; mapped at the base of steep slopes in the Wasatch Range where the alluvial component is mostly fan alluvium, in small channels where the alluvial component is mostly stream alluvium, and in fault grabens where alluvial and colluvial deposits are mixed; small, unmapped deposits are likely in most small drainages; thickness less than 15 feet (5 m).

Qct **Colluvial and talus deposits, undivided** (upper Holocene to middle Pleistocene?) – Gravel and angular debris with a finer grained matrix; deposited at the base of steep slopes in Big Cottonwood and Little Cottonwood Canyons and other steep slopes in the Wasatch Range; mapped deposits of slopewash, creep, and rock fall are mixed and grade imperceptibly into one another; thickness less than 30 feet (10 m).

Qla **Lacustrine and alluvial deposits, undivided** (upper Holocene to upper Pleistocene) – Sand, silt, and clay in areas of mixed alluvial (Qal_1) and lacustrine (Qlfp) deposits that cannot be mapped separately because the units grade imperceptibly into one another; mapped in the southwest corner of the Draper quadrangle where spring-fed streams incise lake beds; thickness less than 10 feet (3 m).

Qle **Lacustrine and eolian deposits, undivided** (upper Holocene to upper Pleistocene) – Sand, silt, and clay in an area of mixed lacustrine and eolian deposits that cannot be mapped separately because the units grade imperceptibly into one another; mapped in northwest Draper City; thickness less than 10 feet (3 m).

Qmc **Mass movement and colluvial deposits, undivided** (Holocene to middle Pleistocene?) – Mixed landslide, slump, slopewash, and soil creep that grade imperceptibly into one another; mapped along Dry Creek and Willow Creek in areas where deposits derived from sandy Lake Bonneville units (Qlsp and Qldb) lack the cohesion needed to maintain morphologies characteristic of the depositional process, and in thin deposits on steep bedrock slopes in Ferguson Canyon; thickness less than 30 feet (10 m).

Stacked-Unit Deposits

Qes/Qldbs

Eolian sand over sandy deltaic deposits (related to the Bonneville shoreline and transgressive phase of Lake Bonneville) (Holocene to upper Pleistocene/upper Pleistocene) – Eolian deposits over sandy deltaic deposits; mapped on the large delta surface west of Bells and Little Cottonwood Canyons; the eolian deposits are between about 3 and 15 feet (1–5 m) thick.

Qg/Tlc **Glacial deposits, undivided over Little Cottonwood stock** (Holocene? to middle Pleistocene/Oligocene) – Glacial deposits (Qg) overlie and conceal the Little Cottonwood stock (Tlc) in Bells Canyon and on Lone Peak; small bedrock knobs are included in the unit and not mapped separately due to map scale limitations; glacial deposit thickness likely between 3 and 30 feet (1–10 m).

Major unconformity

TERTIARY

Whole-rock geochemical data for volcanic units in the Draper 7.5-minute quadrangle are available in McKean (2017c). Rock names are from the total alkali-silica classification diagram for volcanic rocks (see figure 3).

Tld **Lamprophyric dikes** (Oligocene) – Light brownish-gray, porphyritic, lamprophyric dikes in a microcrystalline matrix; two dikes are mapped that have similar trachydacitic geochemical results (see figure 3); (1) the southern dike, as mapped between Big Cottonwood and Ferguson Canyons intruding the Little Cottonwood stock (Tlc), is modified from Crittenden's (1965a) lamprophyric dike (see plate 1 and figure 3, sample DP2015-277); the dike and phenocrysts are likely highly altered; phenocrysts in order of abundance, are plagioclase, hornblende, and biotite, with hornblende that appears to be altered to chlorite; dike is poorly exposed and only mapped in isolated outcrops and through float; (2) the northern dike is newly mapped near the mouth of Big Cottonwood Canyon on the northside (see plate 1 and figure 3, sample DP2015-463), and it cuts Big Cottonwood Formation (Zbcs, Zbcq), but is not as altered or weathered as the southern dike; phenocrysts in order of abundance are plagioclase, quartz, biotite, and hornblende; neither dike is isotopically dated but is likely Oligocene in age; dikes are 10 to 30 feet (3–6 m) wide, with width exaggerated on plate 1 for visibility.

Tgd **Granitic dikes** (Oligocene) – Light-gray to medium-gray, fine-grained to porphyritic granitic dikes; phenocrysts, in order of abundance, are plagioclase, quartz, biotite, and hornblende in a microcrystalline matrix; locally more quartz and plagioclase rich; geochemically the sampled dikes are granite (plate, 1, figure 3, samples DP2014-74 and DP2015-309), similar to the Little Cottonwood stock (Tlc); two dikes are mapped in Deaf Smith Canyon, one was previously mapped as intermediate and cutting the Big Cottonwood Formation by Crittenden (1965a) (sample DP2015-309), and the other is a newly mapped dike that intrudes the amphibolite of the Little Willow Formation (ZYlwa) (sample DP2014-74); ages uncertain, but similar to the stock and thus likely Oligocene; dike 3 to 20 feet wide (1–6 m), with width exaggerated on plate1 for visibility.

Tind **Intermediate dike** (Oligocene) – Dark greenish-gray, fine-grained, intermediate dike with hornblende phenocrysts in a microcrystalline matrix; the east-west trending nonresistant dike is located on the north side of the North Fork of Deaf Smith Canyon, and intrudes the Big Cottonwood (Zbcs) and Little Willow Formations (ZYlw); dike is geochemically a monzonite (see plate 1 and figure 3, sample DP2014-52); age uncertain, likely Oligocene; dike 10 to 20 feet wide (3–6 m), width exaggerated on plate1 for visibility.

Tlc **Little Cottonwood stock** (Oligocene) – Medium-light-gray to medium-gray, equigranular to coarsely porphyritic granite to quartz monzonite to granodiorite; phenocrysts, in order of abundance, are plagioclase, quartz, potassium feldspar, biotite, and hornblende with accessory magnetite, sphene, apatite, zircon, and allanite; potassium feldspar commonly occurs as megacrysts 1 to 2.5 inches (2–6 cm) across; includes minor aplite dikes (see for example Lawton, 1980; Hanson, 1995; Marsh and Smith, 1997; John and others, 1997; and Vogel and others, 2001); two fingers (or apophyses) extend from the Little Cottonwood stock into the Big Cottonwood Formation (Zbcs) between Ferguson and Deaf Smith Canyons—a geochemical sample (DP2015-212, see plate 1 and figure 3) shows the sample to be slightly more silica rich than the main body of the Little Cottonwood stock; east-west and north-south joints are common in the stock on Lone Peak; weathers to grussified soils; alteration is common near the Wasatch fault zone (Evans and others, 1997), but was not mapped separately for this map (see for example Biek, 2005b); unmapped colluvium is present in many areas of the map unit, but is too small or thin to show separately at map scale; sericite from the alteration zone yielded a K-Ar age of 17.6 ± 0.7 Ma and dates movement on the Wasatch fault zone, with an estimated depth of formation between 4.5 and 7.1 miles (7.2–11.4 km) (Parry and Bruhn, 1986); the lower western part of the stock had an emplacement depth of about 7 miles (11 km) (John, 1989); Vogel and others (1997) summarized emplacement ages for the Little Cottonwood stock including several K-Ar hornblende ages ranging from 29.80 ± 0.89 to 31.1 ± 0.9 Ma from the northwestern part of the stock (Crittenden and others, 1973; John and others, 1997) and U-Pb zircon ages from the eastern part of the stock are 30.5 ± 0.6 and 30.5 ± 0.5 Ma (Constenius, 1998); John and others (1997) reported a $^{40}Ar/^{39}Ar$ hornblende total fusion age of 30.41 ± 0.11 Ma; see plate 1 for locations and figure 3 for geochemical plots for the Little Cottonwood stock (Tlc), samples DP2014-188, DP2015-212, DP2015-255, DP2015-256, DP2015-377, and DP2015-378; thickness unknown.

Tdi **Diorite** (Oligocene) – Medium-gray to dark greenish-gray equigranular to porphyritic diorite; phenocrysts, in order of abundance, are plagioclase, quartz, hornblende, and biotite, with hornblende altered to chlorite; Crittenden (1965a) showed the diorite as older than the Little Cottonwood stock, but it is only in contact with Big Cottonwood Formation on the north side of Bells Canyon; geochemically dike samples are diorite to gabbroic diorite (see plate 1 and figure 3, samples DP2014-178, and DP2014-179; with DP2014-176 likely altered as it plots in the granodiorite field); age uncertain, likely Oligocene, but could be older; thickness unknown.

MISSISSIPPIAN

Ml? **Limestone** (Mississippian?) – Medium to dark-gray, brecciated, crinoidal limestone remnant; mapped above gently dipping fault at the mouth of Bells Canyon; previously mapped as a Paleozoic limestone klippe (thrust sheet erosional remnant) by Crittenden (1965a); previously mapped as undivided Mississippian Madison and Deseret Formations

(Granger and others, 1952; Marsell and Threet, 1960) (Gardison Limestone and Deseret Formation of Bryant, 1990); thickness likely less than 50 feet (15 m).

Gently dipping fault

PROTEROZOIC

Pak (1999) identified six Oligocene metamorphic zones or isograds extending away from the Oligocene Little Cottonwood stock into the Proterozoic country rock (Big Cottownwood and Little Willow Formations), in order of increasing grade towards the stock: biotite zone, cordierite+biotite zone, andulusite+biotite zone, andalusite+K-feldspar zone, sillimanite zone, and a second sillimanite zone. Their zones have not been mapped and are only shown on figures by Pak (1999) and Wohlers and Baumgartner (2013); see these references for these mineral isograds related to the Little Cottonwood stock.

Zbc, Zbcq, Zbcs

Big Cottonwood Formation (Neoproterozoic) – Interbedded greenish-gray, gray, and reddish- to bluish-purple, thin-bedded shale and siltstone (Zbcs), and white, greenish-gray, and gray, rusty-weathering orthoquartzite (Zbcq), metamorphosed to argillite, schist, and quartzite; undifferentiated (Zbc) where poorly exposed, altered by metamorphism, or highly fractured; in Deaf Smith Canyon the shale is locally highly altered to schist (Crittenden, 1965a); andalusite and pseudomorphs after andalusite are common from Ferguson Canyon to Little Cottonwood Canyon; cross-bedding, mud cracks, ripple marks, rain-drop prints, and tidal rhythmites found in the formation suggest shallow water deposition (Crittenden, 1977; Chan and others, 1994; Ehlers and others, 1997); Crittenden (1965a, 1977) divided the formation into thirds; the lower third is a bluish-purple, thin-bedded shale or siltstone interbedded with gray orthoquartzite; the middle third is a greenish-gray or gray shale interbedded with gray and greenish orthoquartzite; the upper third is a variegated greenish-gray and red shale and siltstone interbedded with white quartzite; quartzites may be geologically distinct enough to map across quadrangle boundaries; the top of the unit is not exposed in the quadrangle, but is unconformably overlain by the Mineral Fork Tillite and Mutual Formation (Crittenden, 1977); the base of the unit is marked by an unconformity with the higher grade metamorphosed Little Willow Formation below; however, the contact is difficult to map where both units have been contact-metamorphosed next to the Little Cottonwood stock.

In Little Cottonwood Canyon, Neff (1962) and Kohlmann (1980) mapped the rocks in contact with the Little Cottonwood stock as a migmatite of the Little Willow Formation. However, Crittenden (1965a) and Pak (1999) mapped the migmatite as Big Cottonwood Formation undivided and we agree with them because the quartzite and pelite units of the Big Cottonwood Formation can be mapped north of the migmatite in Little Cottonwood Canyon, and rocks within the migmatite zone are metapelitic and 90 percent quartzite, like the Big Cottonwood Formation (Wohlers and Baumgartner, 2013).

Likely Neoproterozoic in age, and possibly correlative with the <770 Ma Uinta Mountain Group strata, based on U-Pb data from detrital zircon (Mueller and others, 2007; Dehler and others, 2010); only the lower 7000 feet (2100 m) of the total 16,000 feet (5000 m) are exposed in the Draper quadrangle (Crittenden, 1965a, 1977), and these thicknesses may be inflated by complex folding and faulting.

Unconformity

ZYlw, ZYlwa

Little Willow Formation (Neoproterozoic and/or Mesoproterozoic?) – Interbedded (in order of abundance) gneiss, chlorite-quartz-biotite schist, biotite and muscovite schist, quartzite, and thin stretched-pebble metaconglomerate; amphibolite and chlorite schist that cross-cut other Little Willow rocks are mapped separately (ZYlwa); the metaconglomerate, shown separately by Crittenden (1965a) as "cg" could not be consistently located in the field so it is combined with unit ZYlw; the amphibolite and chlorite schist could be an ortho- or para-amphibolite (mafic igneous rock or calcareous sedimentary rock protolith, respectively) (Neff, 1962); see plate 1 for ZYlwa sample locations and figure 3 for geochemical plots, samples DP2015-191, DP2015-211, and DP2015-219, and McKean (2017c) for sample whole-rock geochemical data; andalusite and pseudomorphs after andalusite are common throughout the Little Willow Formation and into the Big Cottonwood Formation; metamorphism is amphibolite grade (Neff, 1962; Wohlers and Baumgartner, 2013) or greenschist to middle amphibolite grade (Crittenden, 1965a; Spencer and others, 2012); the greenschist metamorphism could be retrograde (Neff, 1962) and related to the Wasatch fault zone; the Little Willow Formation is a lower metamorphic grade than the Farmington Canyon Complex (Bryant, 1988); we were unable to locate any almandine garnets in outcrop or thin section of the Little Willow Formation, despite descriptions in Kohlmann (1980) and as noted by Neff (1962); estimated exposed thickness based on map pattern is 6500 feet (2000 m), amphibolite is about 300 to 700 feet thick (100–200 m).

The age of the Little Willow is problematic. The Little Willow Formation has long been considered a Middle or Early Proterozoic metamorphic complex (Birch, 1940; Neff, 1962; Crittenden, 1965a; Kohlmann, 1980; Bryant, 1988), but confirmation of a sedimentary formation or metamorphic age is lacking. Despite an apparent unconformity and differences in lithology (in particular the amphibolite schist), Spencer and others (2012) used U-Pb detrital zircon age data from what they called Little Willow Formation to suggest that the Little Willow Formation is not a Mesoproterozoic or Paleoproterozoic metamorphic complex, but rather the more metamorphosed part of the Neoproterozoic Big Cottonwood Formation (see Paris, 1935). However, based on our mapping their samples may have come from the Big Cottonwood Formation. Mueller and others' (2011) sample of the Little Willow suggests a Paleoproterozoic or older age. More work is needed on the Little Willow Formation to determine its true origin, geologic history, and age. Samples of the formation have been collected and processed, and results are pending.

ACKNOWLEDGMENTS

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey (USGS), National Cooperative Geologic Mapping Program through USGS STATEMAP award number G14AC00214 (2014). UGS staff Ben Erickson, Adam Hiscock, Jessica Castleton, and intern Collin Jensen assisted with fieldwork and sampling. Discussions with many individuals helped in the development of this map including Ron Harris (Brigham Young University), Christopher Spencer (Curtin University, Australia), and Carl Hoiland (Stanford University); and Jon K. King (UGS). UGS staff members Jon K. King, Grant Willis, and Kimm Harty also improved this map through their reviews. Jay Hill (UGS) assisted in preparation of the map and supporting materials. We are grateful to all the property owners who allowed us access to their property for field mapping purposes.

REFERENCES

Arnow, T., and Mattick, R.E., 1968, Thickness of valley fill in the Jordan Valley east of the Great Salt Lake, Utah, *in* Geological Survey Research, 1968: U.S. Geological Survey Professional Paper 600–B, p. B79–82.

Arnow, T., and Stephens, D., 1990, Hydrologic characteristics of the Great Salt Lake, Utah—1847–1986: U.S. Geological Survey Water-Supply Paper 2332, 32 p., scale 1:125,000.

Arnow, T., Van Horn, R., and LaPray, R., 1970, The pre-Quaternary surface in the Jordan Valley, Utah, *in* Geological Survey Research, 1970: U.S. Geological Survey Professional Paper 700–D, p. D257–261.

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

Baker, A.A., and Crittenden, M.D., Jr., 1961, Geologic map of the Timpanogos Cave quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ–132, 1 plate, scale 1:24,000.

Bashore, W.M., 1982, Upper crustal structure of the Salt Lake Valley and the Wasatch fault from seismic modeling: Salt Lake City, University of Utah M.S. Thesis, 95 p.

Bassinot, F.C., Labeyrie, L.D., Vincent, E., Quidelleur, X., Shackleton, N.J., and Lancelot, Y., 1994, The astronomical theory of climate and the age of the Brunhes-Matuyama magnetic reversal: Earth and Planetary Science Letters, v. 126, p. 91–108.

Biek, R.F., 2005a, Geologic map of the Jordan Narrows quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey Map 208, 2 plates, scale 1:24,000.

Biek, R.F., 2005b, Geologic map of the Lehi quadrangle and part of the Timpanogos Cave quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey Map 210, 2 plates, scale 1:24,000.

Bills, B.G., Wambeam, T.J., and Currey, D.R., 2002, Geodynamics of Lake Bonneville, *in* Gwynn, J.W., editor, Great Salt Lake—an overview of change: Utah Department of Natural Resources Special Publication, p. 7–32.

Birch, R.O., 1940, Geology of the Little Willow district, Wasatch Mountains, Utah: Salt Lake City, University of Utah, M.S. thesis, 44 p.

Birkeland, P.W., 1984, Soils and geomorphology: New York, Oxford University Press, 372 p.

Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah—Paleoseismology of Utah, Volume 7: Utah Geological Survey Special Study 92, 22 p.

Bowman, S.D., Hiscock, A.I., and Unger, C.D., 2015, Paleoseismology of Utah, Volume 26—Compilation of 1970s Woodward-Lundgren & Associates Wasatch fault investigation reports and low-sun-angle aerial photography, Wasatch Front and Cache Valley, Utah and Idaho: Utah Geological Survey Open-File Report 632, 8 p., 6 plates, 9 DVD set.

Bronk Ramsey, C., 2009, Bayesian analysis of radiocarbon dates: Radiocarbon, v. 51, no. 1, p. 337–360.

Bruhn, R.L., Gibler, P.R., and Parry, W.T., 1987, Rupture characteristics of normal faults—an example from the Wasatch fault zone, Utah, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., editors, Continental extensional tectonics: Geological Society of America Special Publication no. 28, p. 337–353.

Bryant, B., 1988, Geology of the Farmington Canyon Complex, Wasatch Mountains, Utah: U.S. Geological Survey Professional Paper 1476, 54 p., 1 plate, scale 1:50,000.

Bryant, B., 1990, Geologic map of the Salt Lake City 30′ x 60′ quadrangle, north-central Utah, and Uinta County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1944, 2 plates, scale 1:100,000.

Butler, B.S., Loughlin, G.F., and Calkins, F.C., and others, 1920, The ore deposits of Utah: U.S. Geological Survey Professional Paper 111, 672 p, 57 plates.

Calkins, F.C., Butler, B.S., 1943, Geology and ore deposits of the Cottonwood-American Fork area, Utah: U.S. Geological Survey Professional Paper 201, 152 p, 51 plates.

Case, W.F., 1985, Significant drill holes of the Wasatch Front valleys including Cache Valley and Tooele Valley: Utah Geological and Mineral Survey Open-File Report No. 82, 181 p.

Chan, M.A., Kvale, E.P., Archer, A.W., and Sonett, C.P., 1994, Oldest direct evidence of lunar-solar tidal forcing encoded in sedimentary rhythmites, Proterozoic Big Cottonwood Formation, central Utah: Geology, v. 22, p. 791–794.

Cluff, L., Brogran, G., and Glass, C., 1970, Wasatch fault, northern portion, earthquake fault investigation & evaluation, a guide to land use planning: Oakland, California, Woodward-Clyde and Associates, unpublished consultant's report for the Utah Geological and Mineralogical Survey, variously paginated.

Condie, K.C., 1965, Petrology and geochemistry of late Precambrian rocks of northeastern Great Basin: San Diego, University of California, Ph.D. dissertation, 240 p.

Condie, K.C., 1967, Petrology of Late Precambrian tillite(?) association in northern Utah: Geological Society of America Bulletin, v. 78, p. 1317–1344.

Constenius, K.N., 1996, Late Paleogene extensional collapse of the Cordilleran foreland fold and thrust belt: Geological Society of America Bulletin, v. 108, p. 20–39.

Constenius, K.N., 1998, Extensional tectonics of the Cordilleran foreland fold and thrust belt and the Jurassic-Cretaceous Great Valley forearc basin: Tucson, University of Arizona, Ph.D. dissertation, 116 p.

Constenius, K.N., 2007, Geologic map of the Wasatch Range part of the Timpanogos Cave quadrangle, Utah County, Utah: Utah Geological Survey unpublished mapping, scale 1:24,000.

Constenius, K.N., Esser, R.P., and Layer, P.W., 2003, Extensional collapse of the Charleston-Nebo salient and its relationship to space-time variations in Cordilleran orogenic belt tectonism and continental stratigraphy, *in* Raynolds, R.G., and Flores, R.M., editors, Cenozoic systems of the Rocky Mountain region: Denver, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 303–353.

Cook, K.L., and Berg, J.W., 1961, Regional gravity survey along the central and southern Wasatch Front, Utah: U.S. Geological Survey Professional Paper 316-E, plate 13, p. 75–89.

Crittenden, M.D., Jr., 1963, New data on the isostatic deformation of Lake Bonneville: U.S. Geological Survey Professional Paper 454-E, 31 p.

Crittenden, M.D., Jr., 1965a, Geology of the Draper quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-377, 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., 1965b, Geology of the Dromedary Peak quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-378, 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., 1965c, Geology of the Mount Aire quadrangle, Salt Lake County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ–379, 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., 1965d, Geology of the Sugar House quadrangle, Salt Lake County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-380, 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., 1977, Stratigraphic and structural setting of the Cottonwood area, Utah, *in* Gilmore Hill, J., editor, Geology of the Cordilleran hingeline: Denver, Rocky Mountain Association of Geologists, 1976 Symposium, p. 363–379.

Crittenden, M.D., Jr., Stuckless, J.S., Kistler, R.W., and Stern, T.W., 1973, Radiometric dating of intrusive rocks in the Cottonwood area, Utah: U.S. Geological Survey Journal of Research, v. 1, no. 2, p. 173–178.

Currey, D.R., 1982, Lake Bonneville—Selected features of relevance to neotectonic analysis: U.S. Geological Survey Open-File Report 82–1070, 30 p., scale 1:500,000.

Currey, D.R., Berry, M.S., Green, S.A., and Murchison, S.B., 1988, Very late Pleistocene red beds in the Bonneville Basin, Utah and Nevada: Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 411.

Currey, D.R., and James, S.R., 1982, Paleoenvironments of the northeastern Great Basin and northeastern Basin Rim region—a review of geological and biological evidence, *in* Madsen, D.B., and O'Connell, J.F., editors, Man and environment in the Great Basin: Society for American Archeology Papers, no. 2, p. 27–52.

Davis, F.D., 2000, Geologic map of the Midvale quadrangle, Salt Lake County, Utah: Utah Geological Survey Map 177, scale 1:24,000.

DeCelles, P.G., 2006, Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western U.S.A.: American Journal of Science, v. 304, p. 105–168.

Dehler, C.M., Fanning, C.M., Link, P.K., Kingsbury, E.M., and Rybczynski, E., 2010, Maximum depositional age and provenance of the Uinta Mountain Group and Big Cottonwood Formation, northern Utah—Paleogeography of rifting western Laurentia: Geological Society of America Bulletin, v. 122, p. 1686–1699 and Data Repository item 2010129.

Doelling, H.H., and Willis, G.C., 1995, Guide to authors of geologic maps and text booklets of the Utah Geological Survey: Utah Geological Survey Circular 89, 98 p.

DuRoss, C.B., and Hylland, M.D., 2015, Synchronous ruptures along a major graben-forming fault system—Wasatch and West Valley fault zones, Utah: Bulletin of the Seismological Society of America, v. 105, no. 1, p. 14–37.

DuRoss, C.B., Hylland, M.D., McDonald, G.M., Crone, A.J., Personius, S.F., Gold, R.D., Mahan, S.A., 2014, Holocene and latest Pleistocene paleoseismology of the Salt Lake City segment of the Wasatch fault zone, Utah, at the Penrose drive trench site, *in* DuRoss, C.B., and Hylland, M.D., Evaluating surface faulting chronologies of graben-bounding faults in Salt Lake Valley, Utah—new paleoseismic data from the Salt Lake City segment of the Wasatch fault zone and the West Valley fault zone—Paleoseismology of Utah, Volume 24: Utah Geological Survey Special Study 149, 39 p., 1 plate, 6 appendices.

Eardley, A.J., 1968, Regional geologic relations of the Park City district, *in* Erickson, A.J., Jr., Phillips, W.R., and Garmoe, W.J., editors, Guidebook to the geology of Utah—Park City district, Utah: Utah Geological Society Guidebook 22, p. 3–9.

Eardley, A.J., 1969, Charting the Laramide structures of western Utah, *in* Jensen, M.L., editor, Guidebook of northern Utah: Utah Geological Survey Bulletin 82, p. 51–65.

Ehlers, T.A., Chan, M.A., and Link, P.K., 1997, Proterozoic tidal, glacial, and fluvial sedimentation in Big Cottonwood Canyon, Utah, *in* Link, P.K., and Kowallis, B.J., editors, Proterozoic to recent stratigraphy, tectonics, and volcanology, Utah, Nevada, southern Idaho, and central Mexico: Brigham Young University Geology Studies, v. 42, part 1, p. 31–58.

Evans, J.P., Yonkee, W.A., Parry, W.T., and Bruhn, R.L., 1997, Fault-related rocks of the Wasatch normal fault, *in* Link, P.K., and Kowallis, B.J., editors, Mesozoic to Recent geology of Utah: Brigham Young University Geology Studies v. 42, part II, p. 279–297.

Gilbert, G.K., 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Godsey, H.S., Atwood, G., Lips, E., Miller, D.M., Milligan, M., and Oviatt, C.G., 2005a, Don R. Currey Memorial Field Trip to the shores of Pleistocene Lake Bonneville, *in* Pederson, J., and Dehler, C.M., editors, Interior Western United States: Geological Society of America Field Guide 6, p. 419–448.

Godsey, H.S., Currey, D.R., and Chan, M.A., 2005b, New evidence for an extended occupation of the Provo shoreline and implications for regional climate change, Pleistocene Lake Bonneville, Utah, USA: Quaternary Research, v. 63, p. 212–223.

Godsey, H.S., Oviatt, C.G., Miller, D.M., and Chan, M.A., 2011, Stratigraphy and chronology of offshore to nearshore deposits associated with the Provo shoreline, Pleistocene Lake Bonneville, Utah: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 310, issues 3–4, p. 442–450.

Granger, A.E., Sharp, B.J., Crittenden, M.D., Jr., and Calkins, F.C., 1952, Geology of the Wasatch Mountains east of Salt Lake City, Utah, *in* Marsell, R.E., editor, Geology of the central Wasatch Mountains, Utah: Utah Geological Society, Guidebook to the Geology of Utah, no. 8, p. 1–37.

Hanson, S.L., 1995, Mineralogy, petrology, geochemistry and crystal size distribution of Tertiary plutons of the central Wasatch Mountains, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 371 p.

Hiscock, A.I., and DuRoss, C.B., 2016, Late Holocene chronology of surface-faulting earthquakes at the Corner Canyon site on the Salt Lake City segment of the Wasatch fault zone, Utah: unpublished Utah Geological Survey final technical report to the U.S. Geological Survey, National Earthquake Hazards Reduction Program, award no. G14AP00057, 24 p. 3 appendices, 2 plates.

James, L.P., 1979, Geology, ore deposits, and history of the Big Cottonwood Mining District, Salt Lake County, Utah: Utah Geological Survey Bulletin 114, 98 p., 4 plates.

James, L.P., 2006, Big and Little Cottonwood (Alta) Mining Districts, Salt Lake County, Utah, *in* Bon, R.L., Gloyn, R.W., and Park, G.M., editors, Mining districts of Utah: Utah Geological Association Publication 32, p. 42–66.

Janecke, S.U., and Oaks, R.Q., Jr., 2011, New insights into the outlet conditions of late Pleistocene Lake Bonneville, southeastern Idaho, USA: Geosphere, v. 7, no. 6, p.1369–1391.

Jarrett, R.D., and Malde, H.E., 1987, Paleodischarge of late Pleistocene Bonneville Flood, Snake River, Idaho, computed from new evidence: Geological Society of America Bulletin, v. 99, p. 127–134.

John, D.A., 1989, Geologic setting, depths of emplacement, and regional distribution of fluid inclusions in intrusions of the central Wasatch Mountains, Utah: Economic Geology, v. 84, p. 386–409.

John, D.A., Turrin, B.D., and Miller, R.J., 1997, New K-Ar and $^{40}Ar/^{39}Ar$ ages of plutonism, hydrothermal alteration, and mineralization in the central Wasatch Mountains, Utah, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah: Society of Economic Geologists Guidebook Series, v. 29, p. 47–57.

Kohlmann, N.A.J., 1980, The polymetamorphism of the Little Willow Formation Wasatch Mountains, Utah: Duluth, University of Minnesota Duluth, M.S. thesis, 119 p., 2 plates.

Laabs, B.J.C., Marchetti, D.W., Munroe, J.S., Refsnider, K.A., Gosse, J.C., Lips, E.W., Becker, R.A., Mickelson, D.M., and Singer, B.S., 2011, Chronology of latest Pleistocene mountain glaciation in the western Wasatch Mountains, Utah, U.S.A.: Quaternary Research, v. 76, p. 272–284.

Lanphere, M.A., Champion, D.E., Christiansen, R.L., Izett, G.A., and Obradovich, J.D., 2002, Revised ages for tuffs of the Yellowstone Plateau volcanic field—assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event: Geological Society of America Bulletin, v. 114, no. 5, p. 559–568.

Lawton, T.F., 1980, Petrography and structure of the Little Cottonwood stock and metamorphic aureole, central Wasatch Mountains, Utah: Palo Alto, California, Stanford University, M.S. thesis, 76 p.

Lips, E.W., Marchetti, D.W., and Gosse, J.C., 2005, Revised chronology of late Pleistocene glaciers, Wasatch Mountains, Utah [abstract]: Geological Society of America Abstracts with Programs, v. 37, no. 7, p. 41.

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

Lofgren, B.E., 1947, Quaternary geology of southeastern Jordan Valley, Utah: Salt Lake City, University of Utah, M.S. thesis, 52 p.

Loughlin, G.F., 1913, Reconnaissance in the southern Wasatch Mountains, Utah: Journal of Geology, v. 21, p. 436–452.

Lund, W.R., 1992, New information on the timing of earthquakes on the Salt Lake City segment of the Wasatch fault zone—Implications for increased earthquake hazard along the central Wasatch Front: Utah Geological Survey, Wasatch Front Forum, v. 8, no. 3, p. 12–13.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, 26 p., 1 plate, scale 1:50,000.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1992, Paleoseismology of the Wasatch fault zone—a summary of recent investigations, interpretations, and conclusions: U.S. Geological Survey Professional Paper 1500, p. A1–A71.

Madsen, D.B., and Currey, D.R., 1979, Late Quaternary glacial and vegetation changes, Little Cottonwood Canyon area, Wasatch Mountains, Utah: Quaternary Research, v. 12, p. 254–270.

Malde, RE., 1968, The catastrophic late Pleistocene Bonneville Flood in the Snake River Plain, Idaho: U.S. Geological Survey Professional Paper 596, 52 p.

Marsell, R.E., and Threet, R.L., 1960, Geologic map of Salt Lake County, Utah, *in* Crawford, A.L., editor, 1964, Geology of Salt Lake County: Utah Geological and Mineralogical Survey Bulletin 69, 190 p., 1 plate, scale 1:63,360.

Marsh, A.J., and Smith, R.K., 1997, The Oligocene Little Cottonwood stock, central Wasatch Mountains, Utah—an example of compositional zoning by side-wall fractional crystallization of an arc-related intrusion: Mountain Geologist, v. 34, no. 3, p. 83–95.

Mattick, R.E., 1970, Thickness of unconsolidated to semiconsolidated sediments in Jordan Valley, Utah, *in* Geological Survey Research 1970: U.S. Geological Survey Professional Paper 700-C, p. C119–124.

Meiiji Resource Consultants, 1983, Gravity based interpretive bedrock geology of Jordan Valley, Salt Lake County, Utah: Utah Geological and Mineral Survey Open-File Report 38, 21 p., 4 plates.

McCalpin, J.P., 1986, Thermoluminescence (TL) dating in seismic hazard evaluations, an example from the Bonneville Basin, Utah, *in* Wood, S.H., editor, Proceedings of the 22nd symposium on engineering geology and soils engineering, Boise, Idaho, 1986: Boise State University/Idaho Department of Transportation, p. 156–176.

McCalpin, J.P., 2002, Post-Bonneville paleoearthquake chronology of the Salt Lake City segment, Wasatch fault zone, from the 1999 “megatrench” site: Utah Geological Survey Miscellaneous Publication 02-7, 37 p.

McCalpin, J.P., and Nelson, C.V, 2000, Long recurrence records from the Wasatch fault zone, Utah: U.S. Geological Survey, National Earthquake Hazards Reduction Program Final Technical Report, Contract No. 99HQGR0058, 61 p.

McCoy, W.D., 1977, A reinterpretation of certain aspects of the late Quaternary glacial history of Little Cottonwood Canyon, Wasatch Mountains, Utah: Salt Lake City, University of Utah, M.A. thesis, 84 p.

McCoy, W.D., 1987, Quaternary aminostratigraphy of the Bonneville Basin, western United States: Geological Society of America Bulletin, v. 98, no. 1, p. 99–112.

McGee, D., Quade, J., Edwards, R.L., Broecker, W.S., Cheng, H., Reiners, P.W., and Evenson, P., 2012, Lacustrine cave carbonates—novel archives of paleohydrologic change in the Bonneville Basin (Utah, USA): Earth and Planetary Science Letters, v. 351–352, p. 182–194.

McKean, A.P., in preparation, Interim geologic map of the Sugar House quadrangle, Utah: Utah Geological Survey Open-File Report, booklet, 1 plate, scale 1:24,000.

McKean, A.P., 2017a, Geologic tools for mapping in urban areas, with examples from the Salt Lake Valley, Utah, *in* Lund, W.R., Emerman, S.H., Wang, W., and Zanazzi, A., editors, Geology and resources of the Wasatch—back to front: Utah Geological Association Publication 46, p. 361–374.

McKean, A.P., 2017b, Interim geologic map of the Salt Lake City South quadrangle, Salt Lake County, Utah: Utah Geological Survey Open-File Report 676, 17 p., 1 plate, scale 1:24,000.

McKean, A.P., 2017c, Whole-rock geochemical data for the Salt Lake City North, Sugar House, and Draper quadrangles, Utah: Online, Utah Geological Survey Open-File Report 663, 5 p., http://ugspub.nr.utah.gov/publications/open_file_reports/ofr-663/ofr-663.pdf.

Middlemost; E.A.K., 1994, Naming materials in the magma/igneous rock system: Earth-Science Reviews, Volume 37, Issues 3–4, p. 215–224.

Miller, D.M., 2016, The Provo shoreline of Lake Bonneville, *in* Oviatt, C.G., and Shroder, J.F., Jr., editors, Lake Bonneville—a scientific update: Amsterdam, Netherlands, Elsevier, Developments in earth surface processes, v. 20, chapter 7, p. 127–144.

Miller, D.M., Oviatt, C.G., Dudash, S.L., and McGeehin, J.P., 2005, Late Holocene highstands of Great Salt Lake at Locomotive Springs, Utah: Geological Society of America Abstracts with Programs, v. 37, no. 7, p. 335.

Miller, D.M., Oviatt, C.G., and McGeehin, J.P., 2012, Stratigraphy and chronology of Provo shoreline deposits and lake-level implications, Late Pleistocene Lake Bonneville, eastern Great Basin, USA: Boreas, v. 42, p. 342–361.

Miller, R.D., 1980, Surficial geologic map along part of the Wasatch Front, Salt Lake Valley, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1198, 13 p., 2 plates, scale 1:100,000.

Morrison, R.B., 1965, Lake Bonneville, Quaternary stratigraphy of eastern Jordan Valley, south of Salt Lake City, Utah: U.S. Geological Survey Professional Paper 477, 80 p., 4 plates, scale 1:24,000.

Mueller, A., Foster, D.A., Mogk, D.W., Wooden, J.L., Kamenow, G.D., and Vogt, J.J., 2007, Detrital mineral chronology of the Uinta Mountain Group—implications for the Grenville flood in southwestern Laurentia: Geology, v. 35, p. 431–434.

Mueller, P.A., Wooden, J.L., Mogk, D.W., and Foster, D.A., 2011, Paleoproterozoic evolution of the Farmington zone—implications for terrane accretion in southwestern Laurentia: Lithosphere, v. 3, p. 401–408, data repository item 2011350 available online, http://www.geosociety.org/pubs/ft2011.htm.

Murchison, S.B., 1989, Fluctuation history of Great Salt Lake, Utah, during the last 13,000 years: Salt Lake City, University of Utah, Ph.D. dissertation, 137 p.

Neff, T.R., 1962, Petrology and structure of the Little Willow Series, Wasatch Mountains, Utah: Salt Lake City, University of Utah, M.S. thesis, 83 p.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 1 plate, scale 1:50,000.

O'Conner, J.E., 1993, Hydrology, hydraulics, and geomorphology of the Bonneville Flood: Geological Society of America Special Paper 274, 83 p.

Oviatt, C.G., 2014, The Gilbert episode in the Great Salt Lake basin, Utah: Utah Geological Survey Miscellaneous Publication 14-3, 20 p.

Oviatt, C.G., 2015, Chronology of Lake Bonneville, 30,000 to 10,000 yr B.P.: Quaternary Science Reviews, v. 110, p. 166–171, Appendix A supplementary data available online, http://dx.doi.org/10.1016/j.quascirev.2014.12.016.

Oviatt, C.G., Currey, D.R., and Miller, D.M., 1990, Age and paleoclimatic significance of the Stansbury shoreline of Lake Bonneville, northeastern Great Basin: Quaternary Research, v. 33, p. 291–305.

Oviatt, C.G., Currey, D.R., and Sack, D., 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225–241.

Oviatt, C.G., Miller, D.M., McGeehin, J.P., Zachary, C., and Mahan, S., 2005, The Younger Dryas phase of Great Salt Lake, Utah, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 219, no. 3–4, p. 263–284.

Oviatt, C.G., Thompson, R.S., Kaufman, D.S., Bright, J., and Forester, R.M., 1999, Reinterpretation of the Burmester Core, Bonneville basin, Utah: Quaternary Research, v. 52, p. 180–184.

Pak, T.M., 1999, Solubility of simple pelite and granite mineral assemblages in supercritical aqueous chloride solutions: Madison, University of Wisconsin-Madison, Ph.D. dissertation, 252 p.

Paris, O.L., 1935, A study of the Precambrian rocks between Big Cottonwood and Little Cottonwood Canyons in the Central Wasatch Mountains: Salt Lake City, University of Utah, M.S. thesis, 44 p.

Parry, W.T., and Bruhn, R.L., 1986, Pore fluid and seismogenic characteristics of fault rock at depth on the Wasatch fault, Utah: Journal of Geophysical Research, v. 91, no. B1, p. 730–744.

Personius, S.F., and Scott, W.E., 1992, Surficial geologic map of the Salt Lake City segment and parts of adjacent segments of the Wasatch fault zone, Davis, Salt Lake, and Utah Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I–2106, 1 plate, scale 1:50,000.

Phillips, F.M., Zreda, M.G., Gosse, J.C., Klein, J., Klein, J., Evenson, E.B., Hall, R.D., Chadwick, O.A., and Sharma P., 1997, Cosmogenic ^{36}Cl and ^{10}Be ages of Quaternary glacial and fluvial deposits of the Wind River Range, Wyoming: Geological Society of America Bulletin, v. 109, no. 11, p. 1453–1463.

Radkins, H.C., Murphy, M., and Schuster, G.T., 1989, Subsurface map and seismic risk analysis of the Salt Lake Valley: Utah Geological and Mineralogical Survey Open-File Report 152, 82 p., 4 plates.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., and van der Plicht, J., 2013, IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP: Radiocarbon, v. 55, no. 4, p. 1869–1887.

Richmond, G.M., 1964, Glaciation of Little Cottonwood and Bells Canyons, Wasatch Mountains, Utah: U.S. Geological Survey Professional Paper 454-D, 41 p., 2 plates, scale 1:24,000.

Schwartz, D.P., and Lund, W.R., 1988, Paleoseismicity and earthquake recurrence at Little Cottonwood Canyon, Wasatch fault zone, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert—Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 82–85.

Scott, W.E., 1988a, temporal relations of lacustrine and glacial events at Little Cottonwood and Bells Canyons, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert—Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological Survey Miscellaneous Publication 88-1, p. 78–81.

Scott, W.E., 1988b, Deposits of the last two deep-lake cycles at Point of the Mountain, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert—Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological Survey Miscellaneous Publication 88-1, p. 86–88.

Scott, W.E., 1988c, Transgressive and high-shore deposits of the Bonneville lake cycle near North Salt Lake, Utah, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert—Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological Survey Miscellaneous Publication 88-1, p. 38–42.

Scott, W.E., McCoy, W.D., Shroba, R.R., and Rubin, M., 1983, Reinterpretation of the exposed record of the last two cycles of Lake Bonneville, western United States: Quaternary Research, v. 20, p. 261–285.

Scott, W.E., and Shroba, R.R., 1985, Surficial geologic map of an area along the Wasatch fault zone in the Salt Lake Valley, Utah: U.S. Geological Survey Open-File Report 85-448, 18 p., 2 plates, scale 1:24,000.

Shroba, R.R., 1984, Soil properties and loess mantles as age indicators for Holocene deposits in alpine and semiarid regions of Colorado and Utah: Geological Society of America Abstracts with Programs, v. 16, no. 4, p. 255.

Smith, R.B., and Arabasz, W.J., 1991, Seismicity of the Intermountain seismic belt, *in* Slemmons, D.B., Engdahl, E.R., Zoback, M.D., Zoback, M.L., and Blackwell, D., editors, Neotectonics of North America: Geological Society of America, Decade of North American Geology Map Volume 1, p. 185–228.

Solomon, B.J., Storey, N., Wong, I., Silva, W., Gregor, N., Wright, D., and McDonald, G., 2004, Earthquake-hazards scenario for a M 7 earthquake on the Salt Lake City segment of the Wasatch fault zone, Utah: Utah Geological Survey Special Study 111DM, 59 p., scale 1:250,000.

Spencer, C.J., Hoiland, C.W., Harris, R.A., Link, P.K., and Balgord, E.A., 2012, Constraining the timing and provenance of the Neoproterozoic Little Willow and Big Cottonwood Formations, Utah—expanding the sedimentary record for early rifting of Rodinia: Precambrian Research, v. 204–205, p. 57–65.

Swan, F.H., III, Hanson, K.L., Schwartz, D.P., and Knuepfer, K.L., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Little Cottonwood site, Utah: U.S. Geological Survey Open-File Report 81-450, 30 p. (also *in* Bowman, S.D., and Lund, W.R., 2013, Compilation of U.S. Geological Survey National Earthquake Hazards Reduction Program Final Technical Reports for Utah: Utah Geological Survey Miscellaneous Publication 13-3, 9 p. + 56 reports, DVD).

USDA Agricultural Stabilization and Conservation Service, 1937, Aerial photography, Project AAL frames 1-6 to 19, and 1-63 to 78 dated 9-19-1937, frames 4-19 to 31, 4-42 to 55, and 4-93 to 94, dated 9-21-1937, black and white, approximate scale 1:20,000.

USDA Agricultural Stabilization and Conservation Service, 1958, Aerial photography, Project AAL frames 12V-88 to 106, 12V-120 to 139, 16V-5 to 18, and 16V-35 to 54, dated 5-27-1958, frames 21V-9 to 23, and 21V-104 to 110, dated 5-29-1958, frames 32V-2 to 6 dated 9-6-1958, and frames 35V-88 to 94 dated 10-15-1958, black and white, scale 1:10,000.

USDA National Agriculture Imagery Program (NAIP), 2009, Digital aerial stereo-photography, image size 12 microns or 2117 pixels per inch, 3-band natural color, scale 1:40,000.

Utah Automated Geographic Reference Center (UAGRC), State Geographic Information Database, 2006, 2-meter lidar elevation data: Online, http://gis.utah.gov/data/elevation-terrain-data/2-meter-lidar/, accessed February 2015.

Utah Automated Geographic Reference Center (UAGRC), State Geographic Information Database, 2012, 6-inch high resolution orthophotography (HRO): Online, http://gis.utah.gov/data/aerial-photography/2012-hro-6-inch-color-orthophotography/, accessed February 2015.

Utah Automated Geographic Reference Center (UAGRC), State Geographic Information Database, 2013–2014, 0.5-meter Wasatch Front lidar elevation data: Online, http://gis.utah.gov/data/elevation-terrain-data/2013-2014-lidar/, accessed February 2015.

Utah Geological Survey (UGS), undated, Deep-basin-structure data: Online, https://geology.utah.gov/about-us/geologic-programs/geologic-hazards-program/for-consultants-and-design-professionals/community-velocity-model-cvm-and-other-geophysical-data/deep-basin-structure-data/, accessed September 2015.

Van Horn, R., 1972, Surficial geologic map of the Sugar House quadrangle, Salt Lake County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-766-A, 1 plate, scale 1:24,000.

Van Horn, R., 1975, Unevaluated reconnaissance geologic maps of Salt Lake and Davis Counties, west of the Wasatch Front, Utah: U.S. Geological Survey Open-File Report 75-616, 29 plates, scale 1:48,000.

Vogel, T.A., Cambray, F.W., Feher, L., Constenius, K.N., and the WIB research team, 1997, Petrochemistry and emplacement history of the Wasatch igneous belt, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah: Society of Economic Geologists Guidebook Series, v. 29, p. 35–46.

Vogel, T.A., Cambray, F.W., and Constenius, K.N., 2001, Origin and emplacement of igneous rocks in the central Wasatch Mountains, Utah: Rocky Mountain Geology, v. 36, no. 2, p. 119–162.

Wallace, J., and Lowe, M., 2009, Ground-water quality classification for the principal basin-fill aquifer, Salt Lake Valley, Salt Lake County, Utah: Utah Geological Survey Open-File Report 560, 80 p., 3 plates, scale1:75,000.

Willis, G.C., 1999, The Utah thrust system—an overview, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 1–9.

Wohlers, A. and Baumgartner, L.P., 2013, Melt infiltration into quartzite during partial melting in the Little Cottonwood contact aureole (UT, USA)—implication for xenocryst formation: Journal of Metamorphic Geology, v. 31, issue 3, p. 301–312.

Woodward, L., Harvey, J.L., Donaldson, K.M., Shiozaki, J.J., Leishman, G.W., and Broderick, J.H., 1974, Soil survey of Salt Lake area, Utah: U.S. Department of Agriculture, Soil Conservation Service, 132 p., 58 plates.

Working Group on Utah Earthquake Probabilities (WGUEP), 2016, Earthquake probabilities for the Wasatch Front region in Utah, Idaho, and Wyoming: Utah Geological Survey Miscellaneous Publication 16-3, 164 p., 5 appendices.

Zoback, M.L., 1983, Structure and Cenozoic tectonism along the Wasatch fault zone, Utah, *in* Miller, D.M., Todd, V.R., and Howard, K.A., editors, Tectonic and stratigraphic studies in the eastern Great Basin: Geological Society of America Memoir 157, p. 3–27.

Table 1. Ages of major shoreline occupations of Lake Bonneville, Gilbert episode, and Great Salt Lake with shoreline elevations in the Draper 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	Not recognized[3]
	Bonneville (B) flood	~15,000[4]	~18,000	5180–5280 (1580–1610)
Overflowing phase	Provo (P)	15,000–12,600[5]	18,000–15,000	4780–4850 (1460–1480)
Regressive phase	Regressive shorelines (r)	12,600–11,500[5]	15,000–13,000	4440–4780 (1350–1460)
Gilbert episode	Gilbert (G)	10,000[6]	11,500	Not present[7]
Great Salt Lake	early Holocene highstand	9700–9400[8]	11,000–10,500	Not present[7]
	late Holocene highstand	4200–2100[9]	5000–2000	Not present[7]
	Historical highstand		late 1860s to early 1870s and 1986–87[10]	Not present[7]

[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] The Stansbury shoreline formed at elevations of about 4440 to 4450 feet (1350–1360 m), which are found in the northwest corner of the Draper quadrangle, but the shoreline was either weakly developed or poorly preserved and cannot be identified.

[4] 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)

[5] Godsey and others (2005b, 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 (2005b) 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.

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

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

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

[9] Miller and others (2005)

[10] Arnow and Stephens (1990)

Table 2. *Relative position and height of stream-terrace deposits ($Qat_{1\text{-}17}$) above the Little Cottonwood Creek active stream channel.*

Terrace Number	Height above channel	
	Feet	Meters
Qat_1 (youngest)	15–20	5–6
Qat_2 to Qat_{11}	20 to 120	5 to 40
Qat_{12}	<150	<45
Qat_{13} to Qat_{17} (oldest)	<240	<70

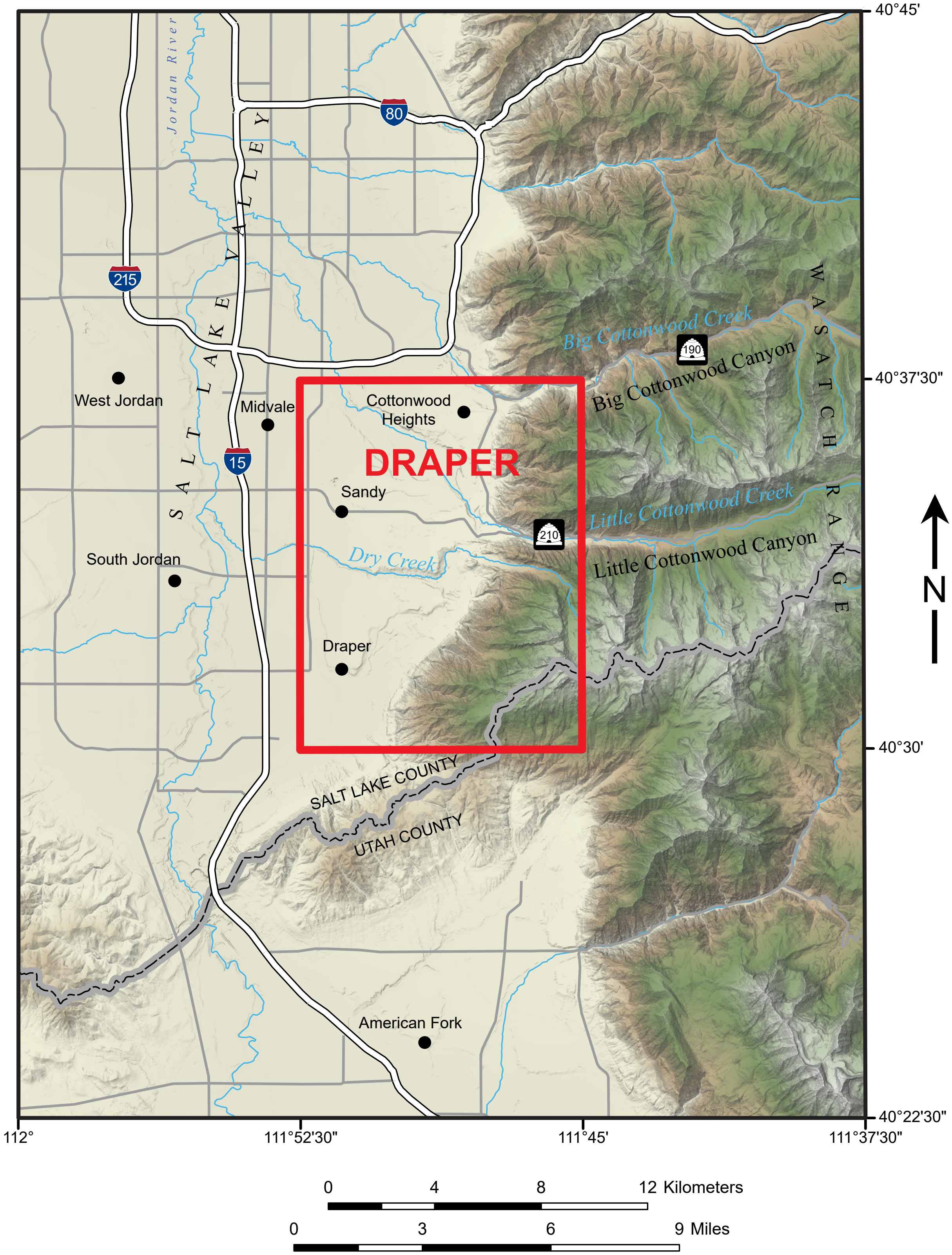


Figure 1. *Map showing the primary geographic features in the vicinity of the Draper 7.5′ quadrangle.*

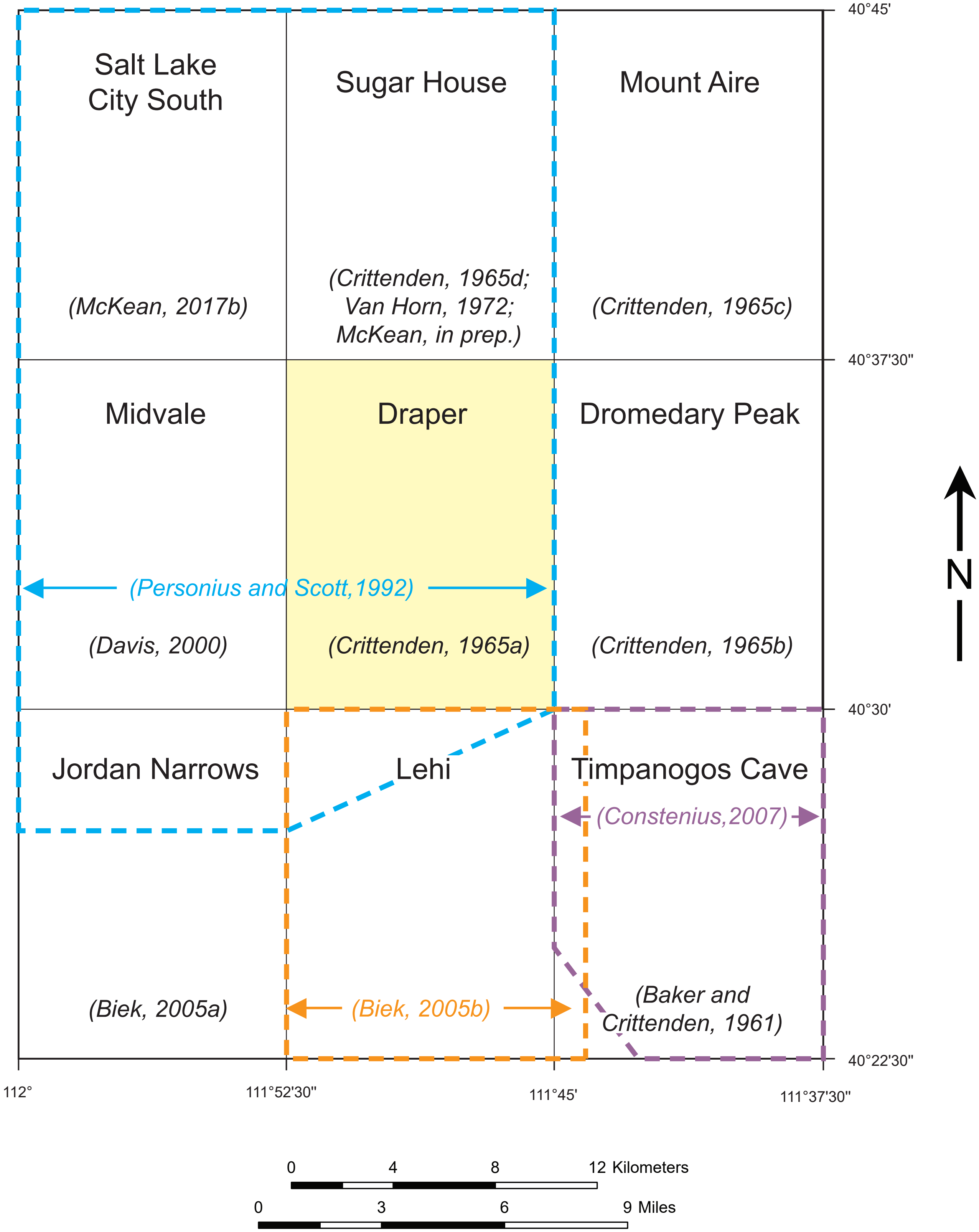


Figure 2. *Index map showing selected geologic maps available for the Draper and surrounding 7.5′ quadrangles.*

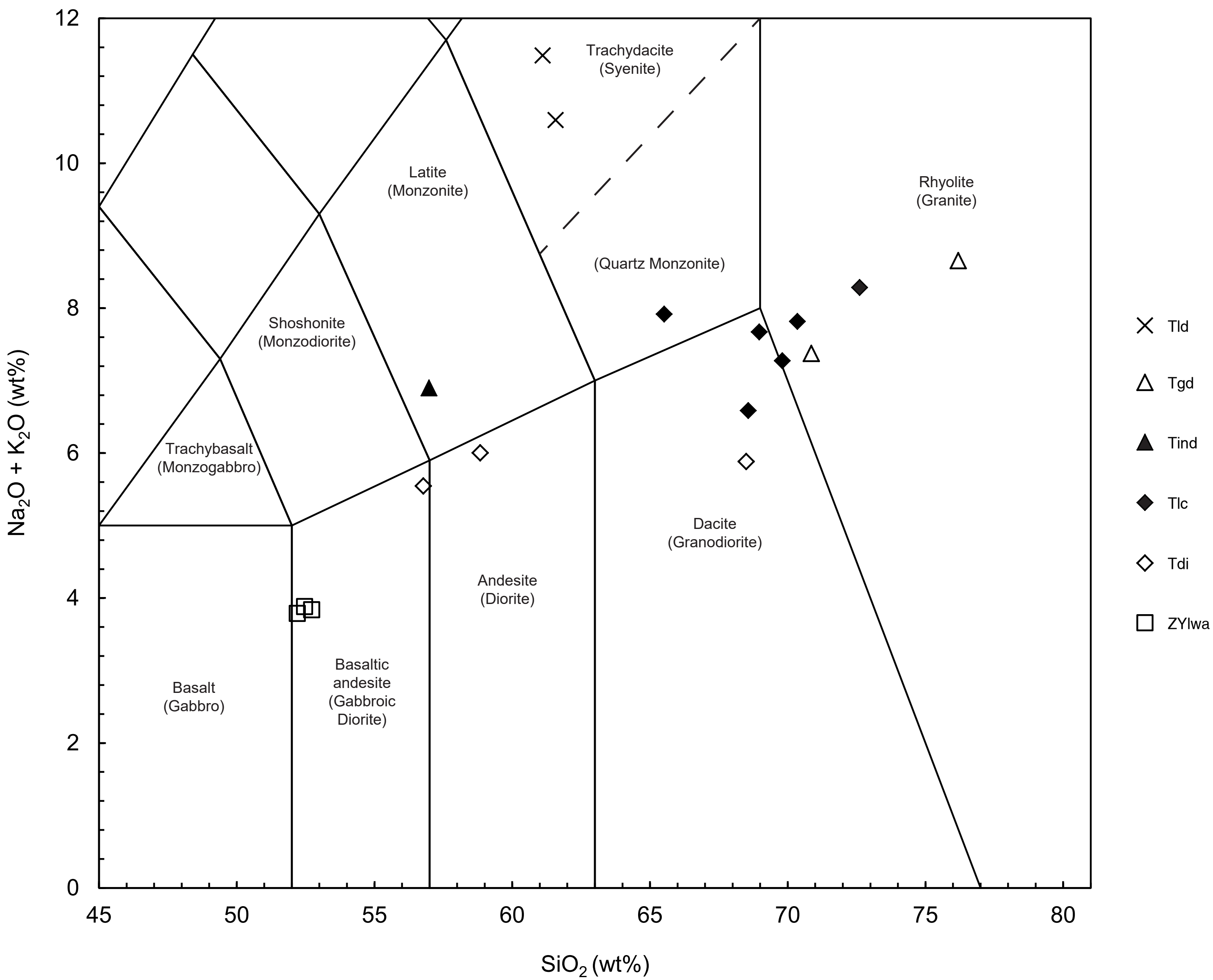


Figure 3. *Total alkali-silica classification for igneous rocks of the Draper 7.5-minute quadrangle (values have been normalized to 100% on a volatile-free basis), classificat on diagram from LeBas and others (1986), with plutonic (holocrystalline) names from Middlemost (1994) in parentheses. See McKean (2017c) for whole-rock geochemical data. Rocks (with map unit symbol in parentheses) are lamprophyric dikes (*Tld*), granite dikes (*Tgd*), intermediate dike (*Tind*), Little Cottonwood stock (*Tlc*), diorite (*Tdi*); and Little Willow Formation amphibolite (*ZYlwa*).*

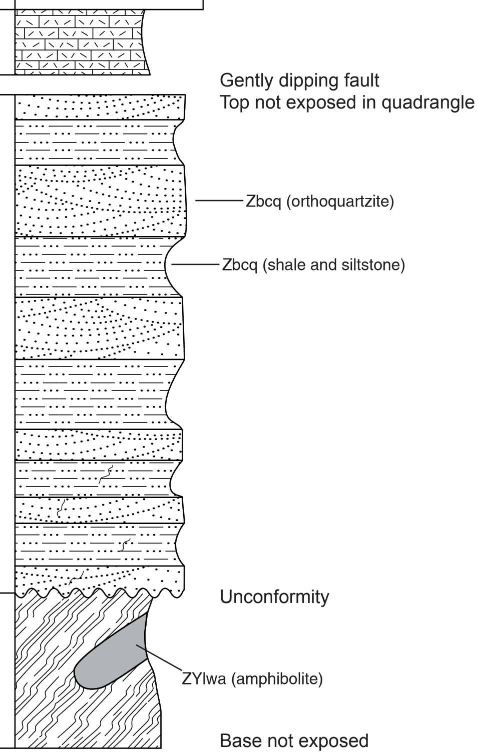
GEOLOGIC SYMBOLS

?	Contact – Dashed where very approximately located, queried where uncertain
	Scratch contact – Separates undivided Big Cottonwood Formation from its subdivisions
	Fault – Sense of offset not known or complex; dashed where approximately located; dotted where concealed (and approximately located)
?	Normal fault – Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; arrows on cross section indicate direction of relative movement, queried where uncertain
	Gently dipping fault – Dashed because approximately located, solid half-oval on hanging wall
?	Thrust fault – Dashed where approximately located; sawteeth on upper plate; queried where location speculative; arrows on cross section indicate direction of relative movement
	Joint
	Major shorelines of the Bonneville lake cycle. 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
B	Bonneville highstand shoreline of Lake Bonneville
t	Transgressive shorelines of Lake Bonneville (present above the Provo shoreline and below the Bonneville shoreline)
P	Provo shoreline of Lake Bonneville
r	Regressive shorelines of Lake Bonneville (present below the Provo shoreline) – Dashed where approximately located
	Crest of lacustrine barrier bar or spit
	Glacial moraine crest, symmetrical
	Glacial moraine crest, asymmetrical, tick marks are on the steep side
	Glacial moraine crest, symmetry uncertain
	Glacial arete, knife-edge ridge
	Cirque head wall
	Landslide scarp – Hachures on downdropped side; dotted where obscured by later construction
A — A'	Line of cross section

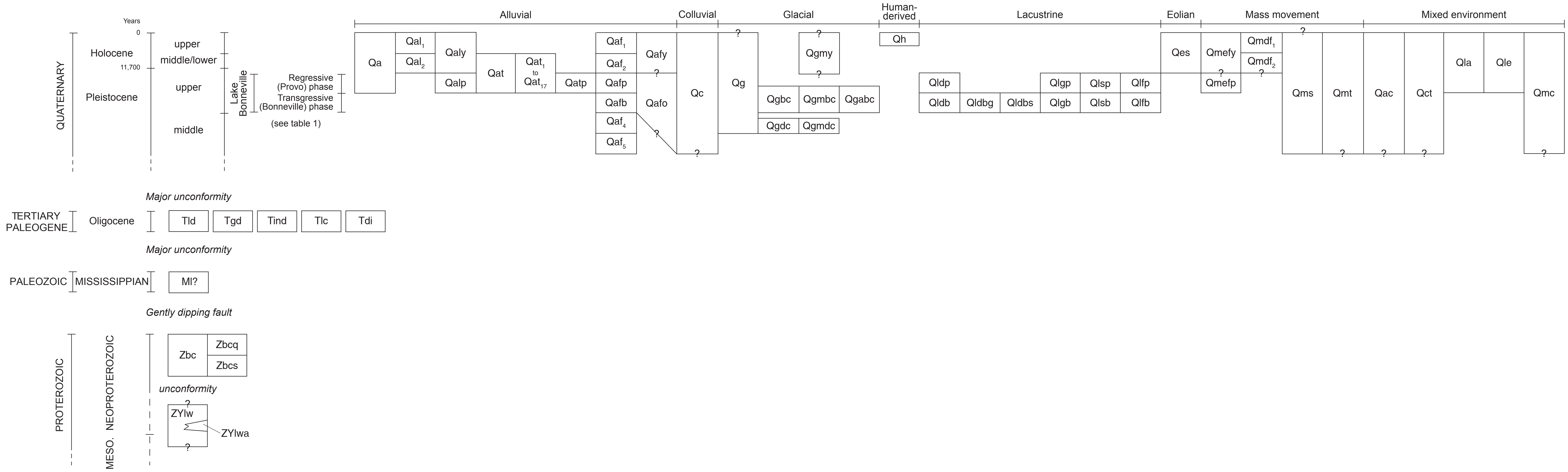
	Structural measurements – red symbols and dips are from Crittenden (1965a)
65 65	Strike and dip of inclined bedding
85 85	Strike and dip of overturned bedding
	Strike of vertical bedding
45 45	Strike and dip of metamorphic foliation
	Spring
	Quarry
	Adit
	Prospect
	Shaft
	Sand and gravel pit
DP2014-52	Rock sample location and number
Qg/Tlc	Stacked unit – Denotes thin cover of first unit overlying second unit
DG	Trench sites for paleoseismic investigations: DG - Dry Gulch (Black and others, 1996); LCC - Little Cottonwood Canyon (Swan and others, 1981; McCalpin, 2002); SFDC - South Fork Dry Creek (Schwartz and Lund, 1988; Black and others, 1996); CC - Corner Canyon (Hiscock and DuRoss, 2016)

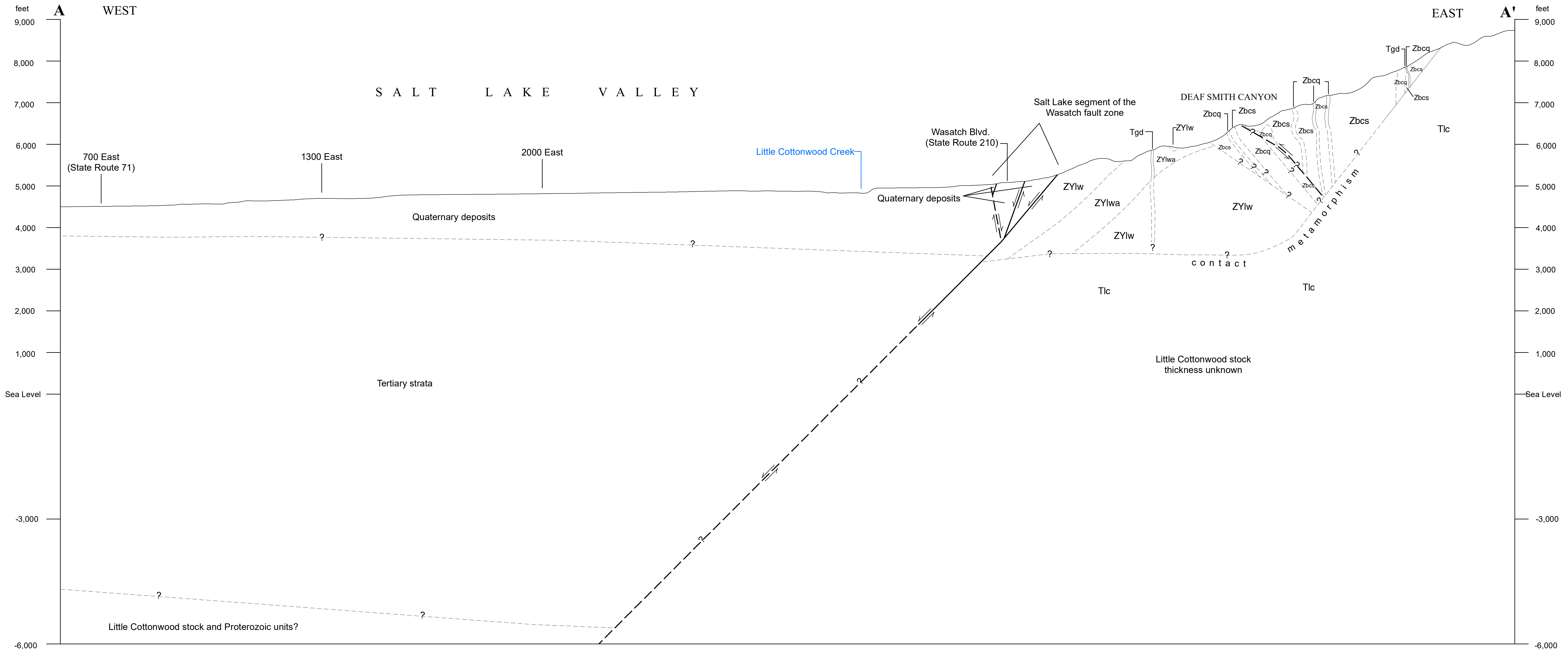
LITHOLOGIC COLUMN

AGE		FORMATION	MAP UNIT SYMBOL		THICK-NESS Feet (Meters)	LITHOLOGY
Pz	MISS.	Limestone	Ml?		<50 (<15)	
PROTEROZOIC	NEOPROTEROZOIC	Big Cottonwood Formation	Zbc	Zbcq Zbcs	7000+ (2100+) exposed in quadrangle	
	—?— MESO. ?	Little Willow Formation	ZYlw ZYlwa		6500+ (2000+) exposed in quadrangle	



CORRELATION OF GEOLOGIC UNITS





Thin surficial deposits omitted for clarity

Modified from Cook and Berg (1961), Arnow and Mattick (1968), Arnow and others (1970), Mattick (1970), Bashore (1982), Meiiji Resource Consultants (1983), Zoback (1983), Case (1985), and Radkins and others (1989)