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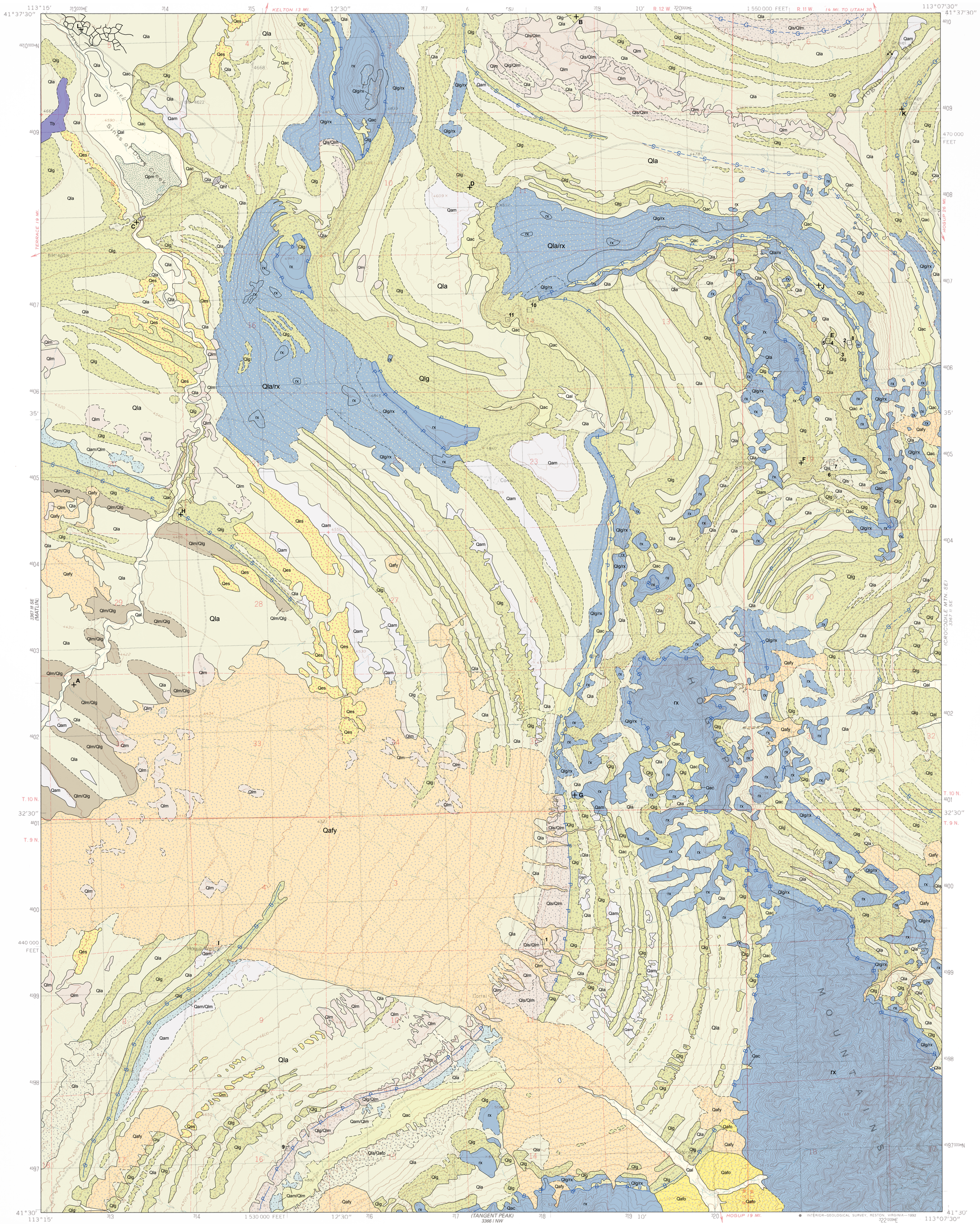
Plate 1
Utah Geological Survey Miscellaneous Publication 15-2DM
Geologic Map of Unconsolidated Deposits in the Hogup Bar Quadrangle



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SCALE 1:24,000

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1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

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CONTOUR INTERVAL 20 FEET

MAP LOCATION

GEOLOGIC MAP OF UNCONSOLIDATED DEPOSITS IN THE HOGUP BAR QUADRANGLE, BOX ELDER COUNTY, UTAH

by

Daren T. Nelson and Paul W. Jewell

2015

University of Utah, Department of Geology and Geophysics
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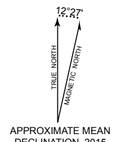

APPROXIMATE MEAN DECLINATION, 2015

1	2	3
4		5
6	7	8

1. Russian Knoll
2. Peplin Flats
3. Crocodile Mtn. NE
4. Matlin
5. Crocodile Mtn. SE
6. Sheep Mtn.
7. Tangent Peak
8. Dolphin Island West

ADJOINING 7.5' QUADRANGLE NAMES

Base from USGS Hogup Bar 7.5' Quadrangle (1991)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Project Manager: Donald L. Clark
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SCALE: 1:24,000

Cover photo: *The Hogup west embayment viewed from the Provo shoreline, looking to the east. Lake Bonneville-age sediments dominate the landscape. These small hills on the north side of the Hogup Mountains were once tombolos that were connected to the mountains by a series of transgressive-age bars. The transgressive-age sediments can be seen throughout the image; however, the Bonneville shoreline is the uppermost shoreline in the picture, and the Provo shoreline can be seen at the base of the landscape.*

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GEOLOGIC MAP OF UNCONSOLIDATED DEPOSITS IN THE HOGUP BAR QUADRANGLE, BOX ELDER COUNTY, UTAH

by Daren T. Nelson and Paul W. Jewell

INTRODUCTION

Location and Geographic Setting

The Hogup Bar quadrangle is in the northwestern portion of the Bonneville basin, a sub-basin of the Basin and Range Province. The quadrangle is near the northwestern shores of Great Salt Lake approximately 15 miles (24 km) southeast of Park Valley, Utah, and about 87 miles (140 km) northwest of Salt Lake City, Utah. Key geographic features include the northern Hogup Mountains and northeastern part of the Great Salt Lake Desert. Hogup Bar is located in the northeast corner of the quadrangle, and extends between the Hogup Mountains and Crocodile Mountain.

Hydrologic features in the quadrangle include multiple ephemeral gullies that drain either into internal closed basins, such as the West Desert or Dove Creek sub-basins, or directly into Great Salt Lake. The two largest ephemeral streams within the quadrangle are Dove Creek, located in the northwestern corner of the quadrangle, and an unnamed drainage emanating from Big Pass in the Hogup Mountains, southeastern corner of the map.

Scope of Work

Geologic mapping of the Hogup Bar quadrangle was completed as part of a Ph.D. dissertation at the University of Utah (Nelson, 2012). This mapping was instigated to better understand the development of transgressive shorelines in Lake Bonneville that developed during the late Pleistocene. The region was mapped directly on orthophotographs acquired from the Utah Automated Geographic Reference Center (AGRC) at 1:10,000 scale. The mapping was then transferred using ArcGIS to the 1991, 1:24,000-scale, Hogup Bar topographic map base. In addition, 5-meter digital elevation data (2005) were used. Fieldwork for mapping of the quadrangle was completed during the summers of 2008 and 2009. All coordinates in the document are reported in the North American Datum of 1927.

Previous Geologic Studies

Stifel (1964) mapped the bedrock and surficial geology of the Terrace and Hogup Mountains, including the Hogup Bar quadrangle, at a scale of 1:63,360. Doelling (1980) subsequently mapped the geology of Box Elder County at a scale of 1:125,000. Intermediate-scale mapping in the area is currently being conducted by the U.S. Geological Survey (USGS) and the Utah Geological Survey (UGS) (Miller and Felger, in preparation; Miller and others, 2012). Detailed mapping (1:24,000 scale) in the area is by Cavas (2003) in the adjacent Matlin quadrangle, and McCarthy and Miller (2002) and Miller and McCarthy (2002) mapped the Terrace Mountain East and West quadrangles west of the study area.

GEOLOGIC OVERVIEW

General Quaternary Geology

There are several aspects of Quaternary geology in the quadrangle, but our focus is on the Lake Bonneville deposits. The Bonneville basin is a terminal structural basin in which the saline Great Salt Lake resides. The excellent geological record within the basin indicates that the Great Salt Lake is a remnant of a series of large pluvial lake systems that have occupied the basin since the middle Pleistocene (Scott and others, 1983; McCoy, 1987; Oviatt and others, 1999; Balch and others, 2005; Benson and others, 2011). Lake Bonneville was the most extensive and recent of these lake cycles. The initial rise of Lake Bonneville was ~26,000 ^{14}C yr B.P., the lake reached its maximum extent ~15,000 ^{14}C yr B.P., and it lowered to its modern lake level ~11,500 ^{14}C yr B.P. (Oviatt, 1997; Godsey and others, 2011; Miller and others, 2013). Lake Bonneville had four major periods when significant shorelines developed, known from oldest to youngest as the Stansbury, Bonneville, Provo, and Gilbert shorelines (figure 1).

Late Pleistocene Shorelines

Within the Hogup Bar quadrangle, all four major shorelines of the Lake Bonneville lake cycle (Stansbury, Bonneville, Provo, and Gilbert) are exhibited; however, there are also more than 35 additional distinct shorelines that formed at various elevations during the transgressive and regressive phases of the lake cycle. The lake was a closed basin during its trans-

gressive and regressive phases; however, it was hydrographically open during the development of most of the Bonneville and Provo shorelines (figure 1). Each of the four main shorelines is not a distinct shoreline at a specific altitude, but can be best represented as a zone of shorelines within an altitudinal and chronological range (table 1). Therefore, even though there are numerous individual shorelines in the quadrangle, in order to simplify the map, only the upper shoreline of each of the four main shorelines is mapped. Other regressive and transgressive shorelines can be inferred in the map area by the relative gravel deposits that are mapped. However, from the map it is difficult to infer if these gravel deposits are transgressive or regressive shorelines without the stratigraphic context described herein. As a general rule, most transgressive shorelines exhibit a more subdued topography and have fine-grained marls overlapping the gravels; whereas the regressive features tend to have more distinct expressions.

Transgressive-Phase Shorelines

Transgressive shorelines – shorelines deposited during the transgressive phase of the Lake Bonneville cycle but not directly related to the position/altitude of the four major shorelines. These shorelines can be subdivided by their relative position/altitude, relative age, and stratigraphic relationships as pre- or post-Stansbury or intermediate shorelines. Pre-Stansbury shorelines are below the altitude of the Stansbury shorezone and are denoted by multiple gravel (Qlg) beach ridges or berms partially buried by lacustrine marl (Qlm). Dove Creek incised prominent deposits associated with these shorelines (UTM Zone 12, 312738 E, 4602595 N – Site A), and smaller ephemeral streams expose these shorelines near Peplin Flats (UTM Zone 12, 318754 E, 4610178 N – Site B). Post-Stansbury shorelines consist of gravel and sand (Qlg) deposits that comprise multiple shorelines between the altitude of the Stansbury shorezone and the Provo shorezone. Many transgressive shorelines are partially buried by Qlm or Qla (lacustrine and alluvial, undivided) deposits. The most distinctive post-Stansbury shorelines can be seen as multiple substantial beach ridges near Dove Creek (UTM Zone 12, 313602 E, 4607929 N – Site C) and in the northern portion of the quadrangle near Peplin Flats (UTM Zone 12, 317470 E, 4608233 N – Site D). Intermediate shorelines consist of both constructional gravel and sand (Qlg) deposits and erosional landforms between the altitude of the Provo and Bonneville shorezones (Gilbert, 1890). Gastropod samples from a transgressive-age sand below a Provo-age erosional platform to the northwest of Big Pass (Sample 1, table 2) suggest that the intermediate shorelines started to form ~19,000 ^{14}C B.P. Within the study area, evidence for at least three oscillatory events during the development of the intermediate shorelines exists on the eastern flanks of the northern Hogup Mountains (UTM Zone 12, 321566 E, 4606347 N – Site E) (Nelson, 2012). Gastropod samples collected from intermediate deposits have reported ages from 16,500 to 19,000 ^{14}C B.P. (Samples 1 through 9, table 2) (Nelson, 2012). The most prominent localities where these shorelines are preserved are within an embayment south of Hogup spit (UTM Zone 12, 321223 E, 4604945 N – Site F, see figure 2) and northwest of Big Pass (UTM Zone 12, 318499 E, 4601173 N – Site G, see figure 3).

Stansbury shorelines – shorelines exhibited as wave-cut (or wave-built) platforms or as multiple gravel (Qlg) beach ridges and berms, partially buried by lacustrine marls (Qlm). Stansbury landforms are best represented as a zone of shorelines rather than as a single shoreline at a distinct altitude. Shorelines within this zone (table 1) consist of both erosional and depositional landforms deposited during a large oscillation (150 feet [45 m]) of the water level (Currey and others, 1983; Currey and Oviatt, 1985; Oviatt, 1987; Oviatt and others, 1990; Oviatt, 1991; Patrickson and others, 2010). The constructional landforms consist of carbonate-encrusted sand deposits (Qls), tufa-encrusted gravels (beachrock), tufa mounds, and charophyte debris that are partially buried by fine-grained lacustrine marls (Qlm) deposited during the transgression of the lake. The most prominent localities where these shorelines are preserved are where Dove Creek dissects the shorezone (UTM Zone 12, 314025 E, 4604534 N – Site H) and near Hogup Well (UTM Zone 12, 314303 E, 4599487 N – Site I).

Open-Basin-Phase Shorelines

Bonneville shorelines – gravel and sand (Qlg) deposits make up multiple depositional and erosional shorelines. Bonneville-age lacustrine landforms include spits, beach ridge complexes, wave-cut platforms, and tombolos (table 1). The altitudinal range of the Bonneville shorezone is ~33 feet (10 m) (Gilbert, 1890; Nelson, 2012). The most prominent Bonneville-age feature within the quadrangle is a substantial spit in the northern Hogup Mountains informally referred to by the authors as the Hogup spit (UTM Zone 12, 318499 E, 4601173 N – Site F, see figure 2).

Provo shorelines – gravel and sand (Qlg) deposits overlying marl (Qlm) deposits and comprising multiple depositional shorelines and erosional platforms (table 1). Geomorphic features associated with the Provo shorezone include multiple spits, beach ridges, wave-cut platforms, and tombolos. The Provo shorezone consists of multiple shorelines within an altitudinal range of ~80 feet (25 m) (Godsey and others, 2005; Godsey and others, 2011; Miller and others, 2013). Provo-age lacustrine sediments tend to be finer grained than Bonneville-age lacustrine sediments. Provo-age sediments were derived from reworked lacustrine source material, whereas Bonneville-age sediments were usually derived from reworked colluvial and/or alluvial deposits. Tufa

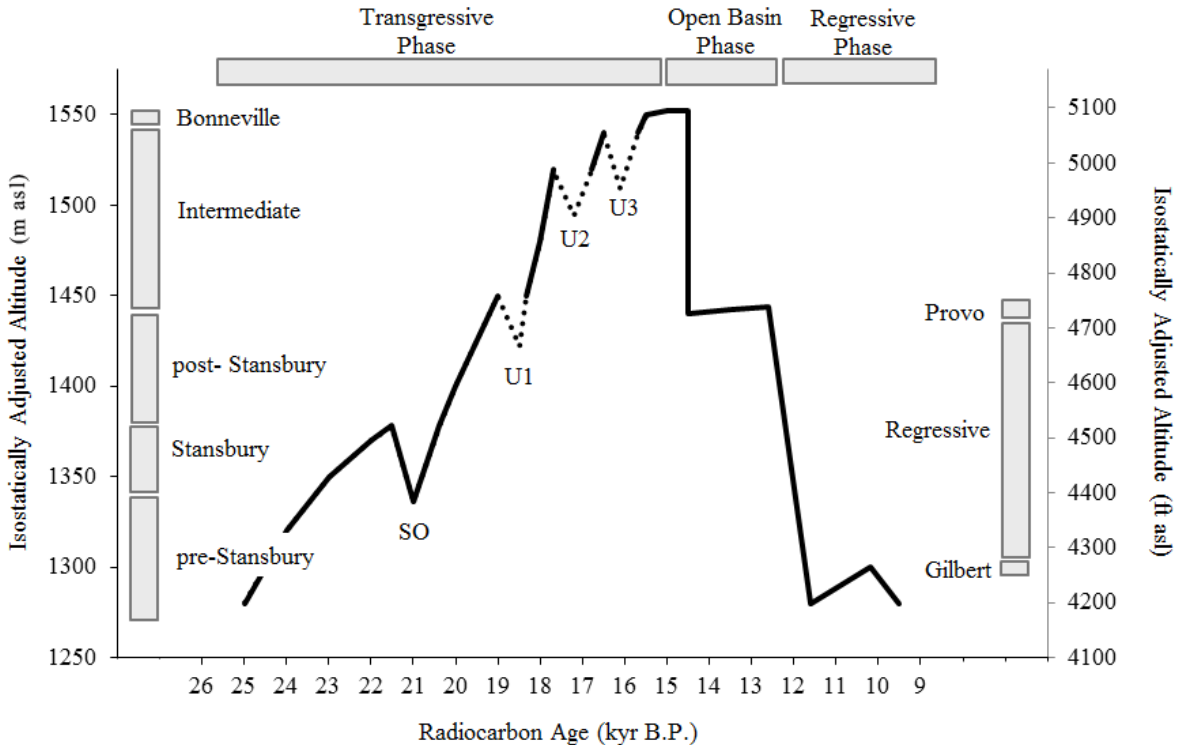

Figure 1. *Lake Bonneville hydrograph modified from Oviatt (1997), Godsey and others (2011), and Miller and others (2013). Altitudes are adjusted for effects of differential isostatic rebound in the basin (Oviatt and others, 1992). Amplitude limits of lake-stage fluctuations associated with the U1, U2, and U3 oscillations are approximate and are shown here schematically. The temporal range of the transgressive, regressive, and open phases of the lake cycle are shown in the horizontal bars, whereas the altitudinal range of each of the groups of shorelines are shown in the vertical bars.*

Table 1. *Estimated ages and altitudinal ranges of the four major shorezones associated with the Lake Bonneville lake cycle within the Hogup Bar quadrangle.*

Lake Cycle and Phase	Shorezone (map symbol)	Estimated ^{14}C Age B.P.	Estimated Years B.P.[1]	Local Altitude (ft asl)	Isostatically Adjusted Altitude[2] (ft asl)
Lake Bonneville					
Transgressive	Stansbury (S)	22,000–20,000[3]	26,200–24,100	4,462–4,610	4,393–4,521
Open Basin	Bonneville (B)	15,300–14,500[4]	18,600–17,700	5,243–5,276	5,069–5,092
	Provo (P)	14,500–12,600[5]	17,700–15,000	4,783–4,865	4,672–4,741
Regressive	Gilbert (G)	11,000–10,000[6]	12,800–11,400	4,281–4,298	4,236–4,252

[1]Calibrated ages shown here have been estimated by using Intcal13 (Reimer and others, 2013) and are reported as the peak values within the calibrated age ranges.

[2]Shoreline altitudes are adjusted by using the methodology of Oviatt and others (1992).

[3]Oviatt and others (1990) and Patrickson and others (2010)

[4]Oviatt and others (1992) and Oviatt (1997)

[5]Godsey and others (2011) and Miller and others (2013) revised the timing of the occupation of the Provo shoreline and subsequent regression.

[6]Oviatt and others (2005)

Table 2. *Radiocarbon ages of samples from the Hogup Bar quadrangle.*

Map No.	Lab Number[1]	UTM E[2]	UTM N[2]	Altitude[3]	Method[4]	Material	Age (^{14}C yr B.P.)	Calibrated Age (years BP)[5]	Depositional Setting	Reference
1	Beta-57132	318073	4599462	~4,816 (4,705)	Rad.	mollusk shells	18,990 ± 190	23,500 22,300	Top of gravel underlying fine sand	Sack, 1999
2	Beta-307248	321814	4606312	4,937 (4,816)	AMS	*Stagnicola*	18,510 ± 70	22,600 22,200	Fine sand above beach gravels that gradates into a sandy marl	Nelson, 2012
3	Beta-307247	321696	4606222	4,977 (4,849)	AMS	*Stagnicola*	18,240 ± 70	22,300 21,900	Fine sand above beach gravels that gradates into a sandy marl	Nelson, 2012
4	Beta-307251	321560	4606349	5,007 (4,875)	AMS	*Stagnicola*	17,210 ± 70	21,000 20,500	Fine sand above silt/sand-rich marls underlying beach gravels	Nelson, 2012
5	Beta-307250	321560	4606349	5,003 (4,872)	AMS	*Stagnicola*	16,930 ± 60	20,600 20,200	Fine sand above beach gravels that gradates into a sandy marl	Nelson, 2012
6	Beta-246724	321591	4604775	4,960 (4,836)	AMS	*Stagnicola*	16,910 ± 80	20,600 20,100	Within slightly cemented intermediate gravel beach ridge	Nelson, 2012
7	Beta-246723	321571	4604929	5,105 (4,964)	AMS	*Stagnicola*	16,770 ± 70	20,500 20,000	Fine sand lagoon deposit behind intermediate gravel beach ridge	Nelson, 2012
8	Beta-307249	321814	4606312	4,944 (4,823)	AMS	*Stagnicola*	16,480 ± 70	20,100 19,600	Fine sand above clay/silt-rich marls underlying beach gravels	Nelson, 2012
9	Beta-246725	315069	4597162	4,823 (4,715)	AMS	*Stagnicola*	16,280 ± 60	19,900 19,500	Gravel beach ridge – reverse grading deposit from coarse gravels and sand overlying finer sands	Nelson, 2012
10	Beta-169097	318119	4606806	4,813 (4,705)	AMS	*Stagnicola*	12,430 ± 50	14,900 14,200	Fine sand overlain by sandy gravel in embayment between spit & main Provo Shoreline	Godsey and others, 2005
11	Beta-169098	317862	4606689	4,806 (4,701)	AMS	*Stagnicola*	11,910 ± 50	13,800 – 13,600 13,940 – 13,910	Fine sand grading upward into sandy gravel at toe of spit, lies on top of gravel bench	Godsey and others, 2005

[1]Lab numbers from Beta Analytic Lab, Miami, Florida.

[2]North American Datum of 1927 (NAD27), Zone 12.

[3]Altitude in feet above sea level, values in parentheses are adjusted for isostatic rebound (Oviatt and others, 1992)

[4]AMS (Accelerator Mass Spectrometry) and Rad (Radiometric).

[5]Calibrated ages shown here have been estimated by using Intcal13 (Reimer and other, 2013) and are the maximum and minimum ages of the sample to two sigma rounded to 100 years.

Figure 2. *The embayment south of the Hogup spit (informal name by authors, see Site F on plate 1). The Provo erosional platform is cut into transgressive beach ridges and the Bonneville-age spit overlaps the intermediate transgressive features. Photo taken from (UTM Zone 12, 320012 E, 4604293 N) looking to the northeast. Scale bar indicates height of Hogup spit (203 feet [62 m]).*

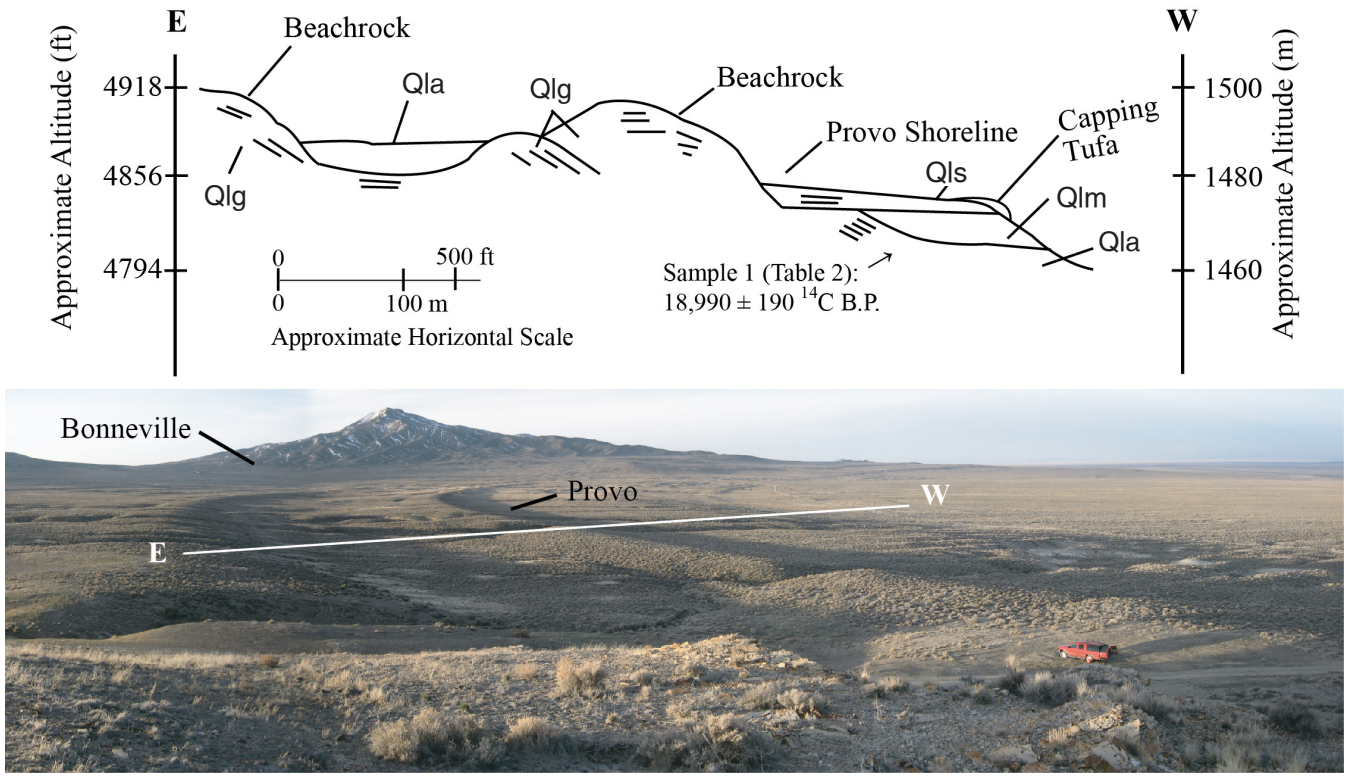

Figure 3. *Photo and east-west profile showing relationship between intermediate beach ridges and Provo erosional platform cut into the gravel barrier deposits northwest of Big Pass. Beachrock are calcium-carbonate-cemented gravels found on transgressive beach barriers, and capping tufa deposits are found on thin gravels of the Provo erosional platform. Radiocarbon Sample 1 (table 2) was obtained from a gastropod sample collected from transgressive off-shore lacustrine sands (unit* Qls/Qlm*). Photo taken from UTM Zone 12, 318452 E, 4601173 N looking to the south; the mouth of Big Pass is seen in left side of the background and is about 3 miles (5 km) away. Note red truck for scale.*

deposits are prevalent in the Provo shorezone. Two gastropod samples (Samples 10 and 11, table 2) collected from the lowest Provo-age deposits have ages of 11,910 and 12,430 ^{14}C B.P. (Godsey and others, 2005). The most prominent Provo features in the quadrangle are large wave-cut platforms excavated on the northern and northeastern slopes of northern Hogup Mountains (UTM Zone 12, 321480 E, 4606994 N – Site J).

Regressive-Phase Shorelines

Regressive shorelines – gravel and sand (Qlg) deposits that overlie fine-grained lacustrine marl and silt (Qlm), transgressive gravel and sand (Qlg), and sand (Qls) deposits. Shorelines that are representative of the regressive phase of the lake cycle are rare and most deposits related to these features are less than 5 feet (1.5 m) thick.

Gilbert shorelines – gravel and sand (Qlg) deposits making up two small beach berms, on the flanks of an older feature known as the Hogup Bar, in the northeastern portion of the quadrangle (UTM Zone 12, 322496 E, 4609007 N – Site K). The small berms are near the altitudinal extent of other Gilbert-age deposits in the basin (Currey, 1982) and do not have overlying marl deposits. We suggest that these features are landforms related to the Gilbert-age lake; however, there is no radiometric dating to support this interpretation (table 1).

Giant Desiccation Cracks

In the Dove Creek area (UTM Zone 12, 313017 E, 4610177 N – Site L), giant desiccation cracks are present within the fine alluvial and playa deposits (figure 4). There are also multiple areas of giant desiccation cracks in similar deposits to the northwest of the quadrangle in the Russian Knoll 7.5′ quadrangle. Similar structures identified as giant desiccation cracks are also found in many other playas around the Great Basin (see, for example, Neal and others, 1968; Harris, 2004; Lund and others, 2005) and are thought to be the result of the dewatering of clay-rich sediment during arid conditions. The desiccation cracks exhibit a polygonal pattern with a range of diameters from ~80 to 395 feet (~25–120 m). Cracks were mapped from 1:10,000-scale aerial photographs since they are difficult to discern in the field. Following the opening of these desiccation cracks, eolian and alluvial sediments filled the voids, trapping sediments that may have higher capillarity and provide more moisture for vegetation (Stifel, 1964). Therefore, these features are more noticeable from aerial photographs due to the change in vegetation and soil type.

Bedrock Stratigraphy and Geologic Structures

Sedimentary rocks of the Permian-Pennsylvanian Oquirrh basin are the predominate bedrock units in the quadrangle (Stifel, 1964; Doelling, 1980; Miller and others, 2012). The most abundant bedrock units in the quadrangle are Lower Permian in age including an interbedded sandstone and limestone unit of the Oquirrh Group and an overlying sandstone and dolomite unit. Other bedrock units in the quadrangle are the Permian Murdock Mountain Formation and undivided Permian-Pennsylvanian Oquirrh Group strata (Miller and others, 2012). Most of the Permian-age bedrock is thicker than in other areas in the Oquirrh basin and may represent a depositional low in the basin (Doelling, 1980). Deformation of the strata in the Hogup Mountains occurred during compression related to the Sevier Orogeny during the Jurassic to Late Cretaceous (DeCelles, 2004), and subsequent Tertiary extension (Miller and Felger, in preparation; Miller and others, 2012).

The area has undergone extensive Basin and Range extensional faulting from the Miocene to present. Normal faults bound each side of the Hogup Mountains; it is poorly understood when these faults last ruptured (Black and Hecker, 1999a; 1999b). The Big Pass fault is a significant normal fault that displaces Miocene Salt Lake Formation against Permian bedrock south of the quadrangle (Miller and Felger, in preparation; Miller and others, 2012).

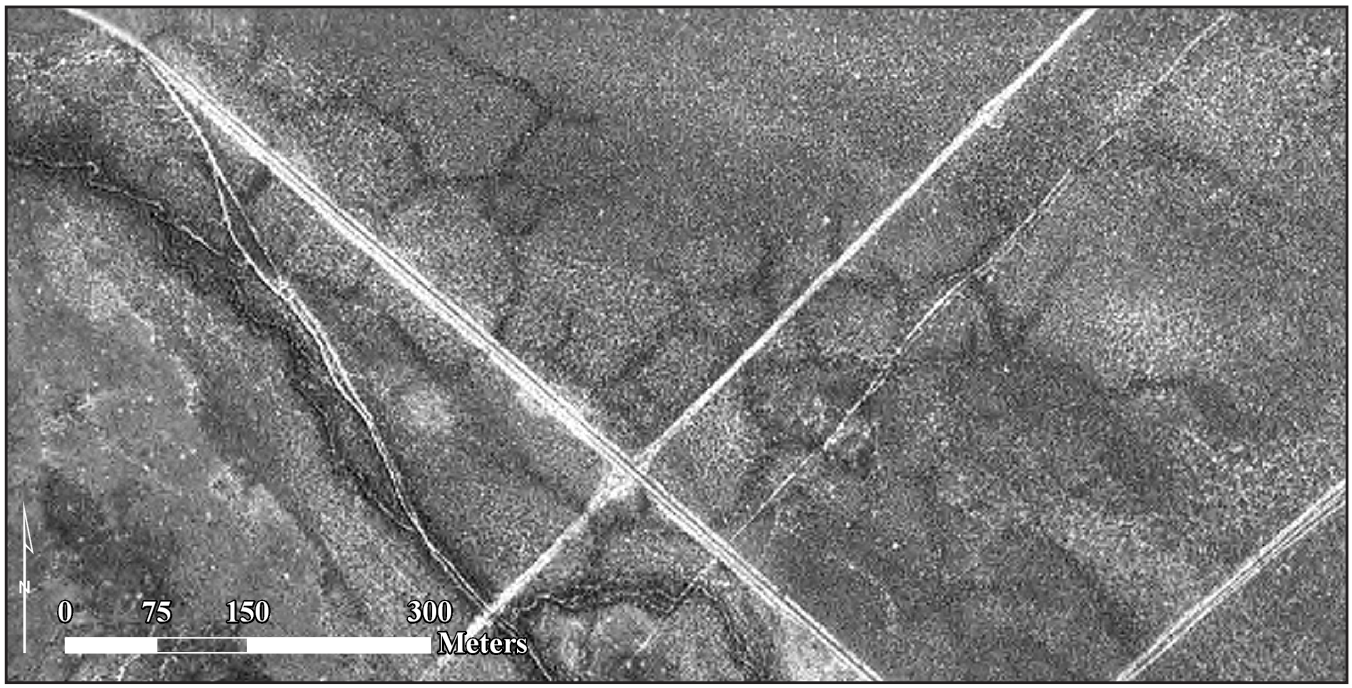

Figure 4. *Interpreted desiccation cracks (dark bands) along Dove Creek (UTM Zone 12, 313017 E, 4610177 N – Site L). Aerial photograph is a digital orthophoto quadrangle (1997).*

DESCRIPTION OF MAP UNITS

QUATERNARY SURFICIAL DEPOSITS

Alluvial deposits

Qal **Alluvium** (Holocene) – Moderately sorted, pebbles to cobbles within a matrix of sand, and silt deposited in active alluvial channels, floodplains, and minor terraces. These deposits are primarily located in the Dove Creek and Big Pass drainages. Other smaller gullies also have unit Qal, but are not significant enough to be mapped at this scale. Maximum thickness of the deposits is less than 10 feet (3 m).

Qafy **Younger alluvial-fan deposits** (Holocene) – Post-Bonneville fans with poorly to moderately sorted, subangular to rounded pebbles to cobbles within a matrix of sand, silt, and clay. Fan deposits below the Bonneville shorelines consist of reworked Lake Bonneville gravels and sands (Qlg), marls (Qlm), and sands (Qls) that were deposited by ephemeral flooding. Alluvial-fan deposits originating from above the Bonneville shorelines are coarser (cobbles to pebbles) and clasts are more angular due to the local erosion of the bedrock sources of the clasts. Deposits are thicker and coarser (pebble – cobble) in the headland portion of the fans and are thinner and finer grained (granules – medium pebbles) in the more distal portion of the fan slope. Expected maximum thickness of the deposits is less than 40 feet (12 m).

Qafo **Older alluvial-fan deposits** (upper to middle? Pleistocene) – Pre-Bonneville or Bonneville-age fans that are poorly to moderately sorted, subangular to rounded pebbles to cobbles within a matrix of sand, silt, and clay. The lack of stratigraphic and geochronological evidence for the age of these sediments makes it uncertain if they were actively deposited during the occupation of Lake Bonneville. Deposits are thicker and coarser (pebble – cobble) in the headland portion of the fans and are thinner and finer-grained (granules – medium pebbles) in the more distal portion of the fan slope. Expected maximum thickness of the deposits is less than 100 feet (30 m).

Qam **Alluvial Mud** (Holocene) – Mud to sandy mud that has been reworked from fine-grained lacustrine deposits related to Lake Bonneville. These deposits are primarily deposited behind relict gravel beach ridges related to Lake Bonneville or within other topographic depressions. Lacustrine fine grained deposits (Qlm) may also underlie the deposits. Thickness of the deposits is variable but the maximum thickness is less than 10 feet (3 m).

Lacustrine deposits

Qlg **Lacustrine gravel and sand** (upper Pleistocene) – moderately- to well-sorted, clast-supported pebbles and cobbles within a matrix of coarse to fine sand. Gravel clasts are subangular to subrounded due to the proximity of bedrock sources or reworking of local alluvial fans or older lacustrine deposits. Gravel deposits were deposited during both transgressive and regressive phases of the Lake Bonneville cycle. Well-sorted, low-angle (5–10°) finer-grained gravel beds represent shallow, lower-energy beach environments; coarser, moderately-sorted pebbles and cobbles in higher-angle (10–15°) beds were deposited in higher-energy gravel beach ridges, beaches, or spits. Gravel beach ridges deposited during the transgressive phase of the lake cycle have high levels of calcareous-cemented gravel beds (beachrock) that dip basinward ~5–15°. Gravel deposited during the Provo and regressive phase of the lake cycle contains well-sorted, finer-grained pebbles in finer-grained sand matrices compared to gravel deposits of the Bonneville and transgressive phase of the lake cycle. Stansbury-age gravel deposits contain a high level of calcareous cement and remnants of capping tufa mounds are found in float and outcrop. Tufa deposits are prevalent on many gravel and sand (Qlg) deposits near the Provo shorezone but are not found on regressive-phase deposits. Thickness of the deposits ranges from 1 to 3 feet (~1 m) up to 230 feet (70 m).

Qls **Lacustrine sand and silt** (upper Pleistocene) – moderately- to well-sorted silt and fine- to medium-grained sand that is subrounded to rounded. Lacustrine sand deposits are interpreted as lagoonal sand or offshore sand deposits. They are rarely significant enough to be mapped or are extensively reworked by eolian processes and mapped as eolian sand (Qes); however, some significant lacustrine sand deposits are found in protected localities near the Hogup spit (informal name by authors, UTM Zone 12, 318499 E, 4601173 N – Site G) and southwest of the Hogup Well (UTM Zone 12, 315133 E, 4599466 N – Site I). The lacustrine sand southwest of the Hogup Well is carbonate-coated sand offshore from the Stansbury shorezone (Miller and others, 2012). Estimated thicknesses of the deposits are less than 33 feet (<10 m).

Qlm **Lacustrine marl** (upper Pleistocene) – Calcareous, very fine grained, white to grey lacustrine silt and clay (marl). Marl contains various sedimentary structures and characteristics dependent on their location. A full section of the unit transitions from lower laminated calcareous-rich sand, silt, and marl upward into a dense, white blocky marl topped by a clastic-rich marl deposit. Ostracodes are found

throughout the deposit; however, the lower laminated section is notably rich in ostracodes and has very shallow ripple laminations. Marl laminations become thicker and denser up section. The blocky, dense marl contains multiple dropstones within the section, and is interpreted as the deepest deposits of the Bonneville-age sediments. Dropstones are isolated clasts of gravel transported by ice rafting, and are imbedded in the fine-grained lacustrine marls. The dropstones consist of rocks from local sources (i.e., chert, limestone, and basalt) or rocks from the Raft River Mountains to the north (Neoproterozoic quartzites and orthoquartzites with green, creamish-white, or pink hues). The blocky marl is bounded at its upper surface by a sandier unit with a layer rich in ostracodes. This layer is interpreted as representing deposition during the Bonneville flood and called the Bonneville flood marker (BFM). Locally, the layer exhibits a rusty coloration possibly due to the oxidation of the coarser sediments as ground water preferentially flowed through the layer. Rip-up clasts (1 to 2 inches [2–4 cm] in diameter) are present in the layer, and are interpreted as pieces of marl that were reworked and deposited. Upsection of the BFM, marl is more clastic-rich. Qlm deposits related to the regressive phase of the lake cycle are generally thick and exhibit multiple sand layers interbedded with calcareous silt and marl. Some of these interbedded sand and silt layers contain flame structures and ripple marks. Full sections of the marl can be seen in the valley incised by Dove Creek near the Stansbury shorezone (UTM Zone 12, 314025 E, 4604534 N – Site H), and behind a substantial gravel beach ridge of the Stansbury shorezone near Hogup Well (UTM Zone 12, 314303 E, 4599487 N – Site I). Many of the marl deposits have been eroded away by alluvial processes and some of the upper marl deposits may be slightly reworked alluvial muds. Thickness of unit Qlm ranges from 3 to 30 feet (1–10 m).

Eolian deposits

Qes **Eolian sand and silt** (Holocene) – Moderately- to well-sorted, fine- to medium-grained sand and some silt; sand is usually subrounded to rounded. Eolian deposits originate from lacustrine depositional settings and follow the trace of shorelines as coppice-dune deposits (Oviatt, 1991). In deeper layers of the sand deposits, whole gastropods are common, and graded beds are present. Gastropods are abundant in finer-grained sand deposits and are especially abundant in eolian sand derived from Provo-age deposits. Estimated thickness of the deposits are less than 33 feet (<10 m).

Playa deposits

Qpm **Playa mud** (Holocene) – Thin clay, mud, and evaporites associated with playa and spring deposits at the Sinks of Dove Creek (near Site C). Thickness of the deposits is less than 6 feet (<2 m).

Mixed-environment deposits

Qac **Alluvium and colluvium** (Holocene) – Moderately- to poorly-sorted cobbles to pebbles that are subrounded to angular. Even though alluvial and colluvial deposits are mixed, one process usually dominates the other. Colluvium-dominated deposits are usually near cliffs or other steep slopes associated with relict wave-cut platforms and are poorly sorted, angular gravel (pebble to cobble size [4–256 mm]) with minor portions of eolian sand and silt. Alluvium is dominant in small ephemeral gullies or at the base of gravel landforms, such as spits or beach ridges. Alluvial-dominated deposits are moderately sorted, subangular to subrounded pebbles to cobbles with a higher percentage of silt and sand. Estimated maximum thickness of the deposits is less than 20 feet (<6 m).

Qla **Lacustrine and alluvial deposits, undivided** (Holocene to upper Pleistocene) – Mixed alluvial and lacustrine deposits of marl, silt, sand, and gravel. These deposits include pre-Bonneville alluvial deposits that were reworked or etched by lacustrine processes during the occupation of Lake Bonneville, or lacustrine and alluvial deposits that cannot readily be distinguished at the scale of the map. Deposits vary in thickness and are estimated to be no thicker than 6 to 12 feet (2–4 m).

Human-derived deposits

Qhf **Fill** (Historical) – Significant deposits of fill used to provide berms for the Transcontinental Railroad, in the northwestern corner of the quadrangle; thickness of the deposits range from 2 to 20 feet (1–6 m).

Stacked-unit deposits

Qla/rx **Lacustrine and alluvial deposits over undivided bedrock** (Holocene to upper Pleistocene over Permian-Pennsylvanian) – A thin veneer of undifferentiated lacustrine gravels, sands, silts, and marls overlying bedrock. Finer-grained deposits are often slightly reworked by alluvial processes. Thickness of the cover (Qla) deposits varies from less than 3 to 9 feet (<1–3 m).

Qlg/rx **Lacustrine gravel and sand over undivided bedrock** (upper Pleistocene over Permian-Pennsylvanian) – Abraded bedrock platform surfaces with thin

veneers of lacustrine gravel and sand. Lacustrine clasts are usually subangular to subrounded due to their proximity to the bedrock sources. Capping tufa mounds and tufa-encrusted gravels are at the basinward edge of the platform. Cover (Qlg) deposits are from less than 3 to 9 feet (<1–3 m) thick.

Qla/Qafo

Lacustrine and alluvial deposits over older alluvial-fan deposits (Holocene to upper Pleistocene over upper to middle? Pleistocene) – A thin veneer of undifferentiated lacustrine gravels, sands, silts, and marls overlying pre-Bonneville or Bonneville-age fans. The fans are moderately sorted, sub-angular to rounded pebbles to cobbles within a matrix of sand, silt, and clay. These fan deposits were extensively incised and reworked by wave action into multiple gravel (Qlg) beach ridges during the occupation of the Provo shorelines and the transgression to the Bonneville shoreline. Expected maximum thickness of the deposits is less than 100 feet (30 m).

Qlm/Qlg

Lacustrine marl over gravel (upper Pleistocene over upper Pleistocene) – Thin veneer of lacustrine marl overlying gravel beach ridges and berms. Lacustrine marls (Qlm) associated with these deposits are generally less than 3 feet (1 m) thick, and Qlg deposits can be 6 to 20 feet (2–6 m) thick.

Qlg/Qlm

Lacustrine gravel and sand over marl (upper Pleistocene over upper Pleistocene) – Well- to moderately sorted, clast-supported gravels within a fine- to medium-grained sand matrix overlying marl. Gravel and sand (Qlg) deposits are associated with the Provo and regressive shorelines whereas the marls are a combination of transgressive and regressive phase deposits. Gravel and sand (Qlg) deposits range from 2 to 6 feet (<2 m) thick and Qlm deposits can be up to 25 feet (8 m) thick.

Qls/Qlm

Lacustrine sand and silt over marl (upper Pleistocene over upper Pleistocene) – Moderately- to well-sorted, fine- to medium-grained sand overlying marl. This sand is interpreted as either offshore sand or very shallow beach deposits. In low-lying deposits below the Provo shoreline, very thin sand deposits were mapped as unit Qlg/Qlm if there was enough of a gravel component (<15% gravel). Thicknesses of the deposits vary from 6 to 14 feet (~2–4 m) near the Provo shorezone and less than 3 feet (<1 m) in regressive shorelines below the Provo shorezone.

Qam/Qlm

Alluvial mud over marl (Holocene over upper Pleistocene) – These stacked units are designated in areas where significant marl units are found underlying Qam deposits. Qam deposits are less than 10 feet (3 m) thick and Qlm deposits can be up to 25 feet (8 m) thick.

BEDROCK UNITS

Tb **Tertiary basalt** (Pliocene to Miocene) – A single grey to black aphanitic basalt flow crops out in the Dove Creek area (UTM Zone 12, 313017 E, 4610177 N). Dove Creek has dissected the larger northern portion of the basalt flow from the smaller southern lobe. The southern portion of the flow is topped by a thin layer of lacustrine marl and silt/sand, and reworked eolian sands. This flow has not been dated, but basalt flows in this area have K-Ar ages from 3.2 to 9.6 Ma (Miller and others, 1995; Miller and others, 2012).

rx **Pre-Quaternary bedrock** – Bedrock in the quadrangle is dominated by undivided Permian to Pennsylvanian strata consisting of rhythmically layered sandstone and chert-rich carbonate rock. It may also include Tertiary rocks that are not well exposed. The bedrock has been previously mapped in more detail; the interested reader can see Stifel (1964), Doelling (1980), and Miller and others (2012) for a more detailed description regarding these units.

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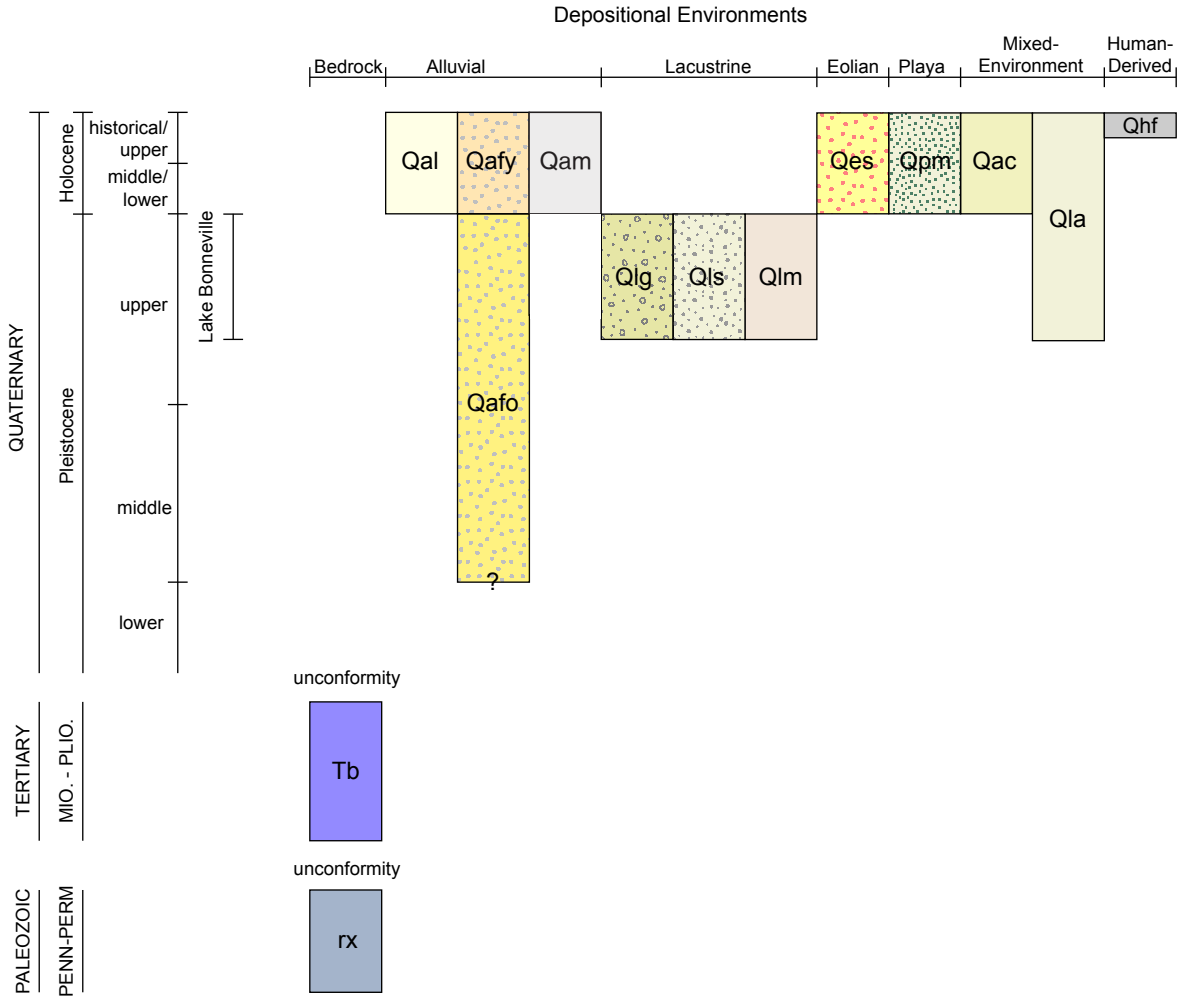
CORRELATION OF MAP UNITS



GEOLOGIC SYMBOLS

+	Site locations (discussed in text)
□	Radiocarbon sample location and number
⚔	Sand and gravel pit
⊙	Water well
——— – – – –	Contact - Dashed where approximately located
——— B – – –	Shorelines of the Bonneville lake cycle - Mapped at the wave-cut bench of erosional shorelines or at the crest of the constructional landforms. Dashed where approximately located. Label designates the specific named shoreline (i.e., B - Bonneville, P - Provo, S - Stansbury, or G - Gilbert).
	Interpreted desiccation cracks