INTERIM GEOLOGIC MAP OF THE NORTH OGDEN QUADRANGLE, WEBER AND BOX ELDER COUNTIES, UTAH

by

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Disclaimer

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INTRODUCTION

The North Ogden 7.5' quadrangle is in the eastern Basin and Range Province in the northern Wasatch Range, Utah. The Wasatch Range forms a high ridge between Ogden Valley to the east and the Great Salt Lake Valley to the west. Ben Lomond and Willard Peak (just north of the quadrangle) form the prominent ridge north of North Ogden Canyon. South of North Ogden Canyon, Lewis Peak is the highest point on the ridge that continues south to Ogden Canyon. Ogden Canyon bisects the southeast corner of the quadrangle. In the northeast part of the quadrangle, the North Fork of the Ogden River flows south toward Pineview Reservoir in the adjoining Huntsville quadrangle. Several smaller ephemeral and perennial streams are present in the quadrangle. Most of the Wasatch Range within the quadrangle is within the Uinta-Wasatch-Cache National Forest. The west part of the quadrangle includes parts of the cities of North Ogden, Ogden, Harrisville, Pleasant View, and the Business Depot Ogden, an industrial park situated in northwest Ogden. The east part of the quadrangle in Ogden Valley includes part of the community of Liberty. This new map provides geologic data for a variety of derivative uses. The Utah Geological Survey (UGS) Geologic Hazards Mapping Initiative (Christenson and Ashland, 2007; Castleton and McKean, 2012) will use this mapping to identify and delineate potential geologic hazards for UGS geologic hazard maps of the quadrangle.

The surficial geology of the North Ogden quadrangle consists primarily of alluvial, lacustrine colluvial, mass-movement, glacial, and marsh deposits. The bedrock in the Wasatch Range is bounded by the north part of the Weber segment and southern part of the Brigham City segment of the Wasatch fault zone. The Wasatch fault zone is a Quaternary active fault zone with documented Holocene activity (Personius, 1990; Machette et al., 1992; Nelson and Personius, 1993; Nelson et al., 2006; DuRoss et al., 2009, 2012, 2016). The southeast part of the Pleasant View salient is in the northwestern part of the quadrangle. The salient is the boundary between two segments of the Wasatch fault zone, the Weber segment to the south and the Brigham City segment to the north. Ogden Valley is bounded by Quaternary-active normal faults. The Ogden Valley North Fork fault and Ogden Valley Southwestern Margin fault bounds the west side of the Ogden Valley and are present in the quadrangle. On the east side of the Ogden Valley, east of the study area, is the Ogden Valley Northeastern Margin fault. A series of large earthquake-induced lateral spread and flow failures caused by prehistoric earthquake ground shaking cover much of the west side of the quadrangle valley floor (Harty and Lowe, 2003).

The bedrock geology of the North Ogden quadrangle includes Tertiary tuffaceous deposits, Paleozoic and Neoproterozoic sedimentary rocks, and Paleoproterozoic to Mesoproterozoic metamorphic rocks. The Paleozoic to Mesoproterozoic rocks are cut and folded by the Willard and Ogden thrust faults of the Cretaceous–Eocene Sevier orogeny (Crittenden, 1972; Yonkee et al., 1989; Evans and Neves, 1992; Yonkee, 1992; DeCelles, 2004; Yonkee, 2005; Yonkee et al., 2013; Yonkee and Weil, 2015; Yonkee et al., 2019). Eastward tilting and broad folding of the Willard and Ogden thrust zones, and hanging wall and footwall rocks, are due to development of the Wasatch anticlinorium (stacked thrust splays) along which pulses of uplift occurred between 90 and 50 Ma (Cretaceous and Tertiary) (Yonkee and Weil, 2011). The Willard thrust places Neoproterozoic to Mesoproterozoic bedrock over Paleozoic bedrock. The Ogden thrust places Cambrian Tintic Quartzite over Middle to Late Cambrian bedrock. To the south of the quadrangle the Ogden thrust branches into a floor and roof thrust system, which brackets a lozenge of Paleoproterozoic Farmington Canyon Complex (Crittenden and Sorensen, 1985b; Yonkee and Lowe, 2004).

PREVIOUS WORK

Previous geologic maps of various age, scale, and purpose cover part of the North Ogden quadrangle (Figure 1). The bedrock geology of the quadrangle was previously mapped at 1:24,000 scale by Crittenden and Sorensen (1985b). The surficial geology was mapped as part of a regional surficial geologic map by Miller (1980) at 1:100,000 scale and parts of the quadrangle were covered by surficial and Wasatch fault zone geologic mapping by Personius (1990) and Nelson and Personius (1993) at 1:50,000 and 1:10,000 scale, respectively. Harty and Lowe (2003) mapped and described the liquefaction-induced landslides (lateral-spread and flow failures) in the western part of the quadrangle. Most recently Coogan and King (2016) mapped the area at 1:62,500 scale as part of the Ogden 30′ x 60′ quadrangle. McDonald et al. (2020) mapped the surface fault ruptures of the Brigham City and Weber segments of the Wasatch fault zone. We incorporated and revised the previous surficial, bedrock, and fault-scarp mapping for this project.

METHODS

Mapping of surficial deposits is based on age and depositional environment or origin (Doelling and Willis, 1995). The letters of the map units indicate (1) age (e.g., Q = Quaternary), (2) depositional environment or origin determined from landform morphology, bedding, or other distinctive characteristics of the deposits, (3) grain size(s), and (4) age as related to the phases of Lake Bonneville. For example, unit Qal_1 is a Quaternary surficial deposit of alluvial origin (al), and the number one indicates it is young and potentially historically active. Numbering of alluvial terrace deposits is the exception and does not relate to Lake Bonneville deposits. The letters "y" and "o" in place of a subscript indicate deposits younger and older than Lake Bonneville (uppermost Pleistocene), respectively. Unit numbers indicate relative age with "1" being the youngest and increasing with age.

Mapping for the project was done using stereographic pairs of aerial photographs, including black-and-white aerial photographs at an approximate scale of 1:20,000 from the U.S. Department of Agriculture (USDA) Agricultural Adjustment Administration (1937); 1:20,000 scale USDA Production and Marketing Administration (1953) photographs; and USDA Agricultural Commodity Stabilization Service (1958) photographs at a scale of 1:10,000. Black-and-white oblique aerial photography was also used at various scales from 1:12,000 to 1:5000 from the Woodward-Lundgren & Associates Wasatch fault investigation (Cluff et al., 1970, compiled in Bowman et al., 2015). Natural color aerial photographs were used at a scale of 1:12,000 from the USDA U.S. Forest Service (1980). Natural color, digital aerial photographs from the USDA National Agriculture Imagery Program (NAIP) (2009) were used in digital stereo software. Contacts were revised using 2018 NAIP imagery, Hexagon, and Google orthophotographs (Utah Geospatial Resource Center [UGRC], 2018b, 2018c, 2021a, 2021b), and lidar from various collection years (Ogden City, 2009; UGRC, 2006, 2011, 2013–2014, 2018a). The geologic map was made by transferring geology from the aerial photographs to a geographic information system (GIS) database in ArcGIS for a target scale of 1:24,000 using 1990s digital orthophoto quadrangles (DOQ) (UGRC, 1990s) and 2018 NAIP orthophotographs (UGRC, 2018b). Field data were collected using an iPad and ArcGIS Collector and Field Maps applications in 2021 and 2022. Field mapping of Quaternary deposits of Ogden Valley by McDonald occurred between 2001–2004 and 2021–2022. Field mapping by other authors was completed in 2021–2024.

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial Deposits

Qal_1 **Level-1 stream and floodplain deposits** (Late Holocene) – Poorly to moderately sorted pebble and cobble gravel, locally contains boulders, with a matrix of sand and silt; contains thin discontinuous sand lenses; subangular to subrounded clasts; thin to medium bedded with planar bedding and cross-bedding; mapped in channels and active floodplains of North Fork of Ogden River, Mill Creek, and other small creeks and on terraces less than 10 feet (9 m) above active stream channels; inset into Lake Bonneville deposits; equivalent to the younger part of young stream and floodplain deposits (Qaly), but differentiated because active channels and bar-and-swale geomorphology of Qal_1 visible on historical aerial photos (USDA, 1937, 1958); some stream deposits are human-modified (channelized, including channel embankments), but are too small to map separately as Qh; mapped as stacked unit with Qh in the Business Depot Ogden industrial area where concealed by fill and disturbed land; estimated thickness less than 15 feet (5 m).

Qal_2 **Level-2 stream and floodplain deposits** (Middle Holocene to Late Pleistocene) – Poorly to moderately sorted silt, sand, and cobble gravel, locally contains boulders, with a matrix of sand and silt; subangular to rounded clasts; thin to medium bedded with planar bedding and cross-bedding; forms terraces that are 10 to 30 feet (3–9 m) above adjacent channels and floodplains of North Fork of Ogden River, Ogden River, Mill Creek, and other small creeks; inset into Lake Bonneville deposits; equivalent to the older part of Qaly, but differentiated from level-1 stream deposits (Qal_1) where characterized by subdued bar-and-swale topography and incised by Qal_1 deposits; mapped as stacked unit with Qh in the Business Depot Ogden industrial area where concealed by fill and disturbed land; thickness generally less than 15 feet (5 m).

Qaly **Young stream and floodplain deposits** (Holocene to Late Pleistocene) – Poorly to moderately sorted pebble and cobble gravel, locally contains boulders, with a matrix of sand and silt; subangular to subrounded clasts; thin to medium bedded with planar bedding and cross-bedding; mapped in channels and active floodplains of North Fork of Ogden River, Ogden River, and other small creeks; includes small alluvial-fan and colluvial deposits; inset into Lake Bonneville deposits; mapped where Qal_1 and Qal_2 deposits cannot be mapped separately due to lack of bars and swales and because individual deposits are too small to show separately at map scale; postdates regression of Lake Bonneville from the Provo and lower shorelines; some stream deposits on the North Ogden liquefaction-induced landslide complex (Qml_2) appear to have a chaotic and disrupted flow path, likely the result of the streams establishing drainages across a hummocky surface, but some of the alluvial deposits could include liquefaction-induced flow-failure landslide deposits (unit Qml_2) that traveled down the alluvial channels or include reworked Qml_2; mapped as stacked unit with Qh in the Business Depot Ogden industrial area where concealed by fill and disturbed land; thickness variable, probably less than 15 feet (5 m).

Qao **Older alluvial deposits** (Middle to Early Pleistocene?) – Poorly to moderately sorted, pebble and cobble gravel, locally contains boulders, with a matrix of sand and silt; contains thin sand lenses; subangular to rounded clasts; thin to thick bedded with planar bedding and cross-bedding; mapped along North Fork of Ogden River where the deposits form a veneer over a bedrock ridge of Norwood Formation (Tn) 80 to 140 feet (25–43 m) above the active drainage; estimated thickness is 5 to 30 feet (1.5–9 m).

Qat_2 **Level-2 stream-terrace deposits** (Late Pleistocene) – Poorly to moderately sorted, pebble and cobble gravel, locally contains boulders, with a matrix of sand and silt; contains thin sand lenses; subangular to rounded clasts; thin to thick bedded with planar bedding and cross-bedding; mapped along North Fork of Ogden River, Ogden River, and Mill Creek where the deposits are 15 to 35 feet (5–11 m) above the drainage; Qat_2 terraces above the North Fork of Ogden River may grade to or below the Bonneville shoreline in Ogden Valley; in Ogden Valley and adjoining areas Qat_1 and Qat_3 stream-terrace deposits are present, but are not present in this quadrangle; numbered subscripts are relative to each other and do not indicate a specific age related to Lake Bonneville; estimated thickness is 5 to 30 feet (1.5–9 m).

Qat_4 **Level-4 stream-terrace deposits** (Late Pleistocene) – Poorly to moderately sorted, pebble and cobble gravel, locally contains boulders, with a matrix of sand and silt; contains thin sand lenses; subangular to rounded clasts; thin to thick bedded with planar bedding and cross-bedding; mapped along North Fork of Ogden River where the deposits are 30 to 80 feet (9–25 m) above the drainage; terraces above the North Fork of Ogden River appear graded to a level above the Bonneville shoreline in Ogden Valley; Qat_3 in Ogden Valley to the east are 35 to 45 feet (11–14 m) above the drainage, but Qat_1 and Qat_3 are not present in this quadrangle; numbered subscripts are relative to each other and do not indicate a specific age related to Lake Bonneville; estimated thickness is 5 to 30 feet (1.5–9 m).

Qaf_1 **Level-1 alluvial-fan deposits** (Late Holocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay, distal parts of this unit are finer-grained; angular to subrounded clasts; weakly to non-stratified; deposited by debris flows, debris floods, sheet floods, snow avalanches, and perennial and intermittent streams at the mouth of canyons and incised drainages; forms fans, locally with distinct levees, and channels at mouths of mountain-front canyons; equivalent to the younger part of young alluvial-fan deposits (Qafy) but mapped where active fans can be shown separately, younger than Qaf_2 based on incision into older unit; thickness variable, greater than 30 feet (9+ m).

Qaf_2 **Level-2 alluvial-fan deposits** (Middle Holocene to Late Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay, which becomes finer-grained away from source; clasts angular to subrounded; weakly to non-stratified; deposited by debris flows, debris floods, sheet floods, snow avalanches, and perennial and intermittent streams at the mouth of canyons and incised drainages; equivalent to the older part of young alluvial-fan deposits (Qafy) but mapped separately where incised by younger streams; thickness variable, greater than 30 feet (9+ m).

Qafy **Young alluvial-fan deposits** (Holocene to Late Pleistocene?) – Poorly to moderately sorted, pebble to cobble gravel with boulders near bedrock exposures, with a matrix of sand, silt, and minor clay, which becomes finer-grained away from source; clasts angular to subrounded; weakly to non-stratified; deposited by debris flows, debris floods, sheet floods, snow avalanches, and perennial and intermittent streams at the mouth of canyons and incised drainages; includes both ages of younger alluvial-fan deposits (Qaf_1 and Qaf_2) across large alluvial slopes where individual fan surfaces cannot be differentiated consistently; where possible, adjacent alluvial fans are mapped separately with a contact between them; locally may include some undifferentiated thin Bonneville transgressive deposits or pre-Bonneville alluvial-fan deposits; postdates Lake Bonneville highstand (Table 1), may coincide with the youngest part of the regression of Lake Bonneville; Lake Bonneville shorelines are not present on these alluvial fans; thickness variable, greater than 30 feet (9+ m).

Qafp **Alluvial-fan deposits related to Provo shoreline and regressive phase of Lake Bonneville** (Late Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock exposures, in a matrix of sand, silt, and minor clay; clasts angular to subrounded, well rounded where derived from Lake Bonneville gravel; weakly to non-stratified; deposited by debris flows, debris floods, sheet floods, and streams near the Provo shoreline; mapped only on the west side of the Wasatch Range where alluvial fans are graded to near Provo shoreline or regressive shorelines of Lake Bonneville; correlative with Lake Bonneville overflowing and regressive phase alluvial-fan deposits (afp, af_3) of other maps in adjacent areas (Nelson and Personius, 1993; (Qaf_3 in Harty et al., 2012); incised by younger alluvial deposits (Qal_1, Qafy); exposed thickness less than 30 feet (9 m).

Qafb, Qafb?

Alluvial-fan deposits related to Bonneville shoreline and transgressive phase of Lake Bonneville (Late Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel with boulders near bedrock exposures, in a matrix of sand, silt, and minor clay; clasts angular to subrounded but well rounded where derived from Lake Bonneville gravel; deposited principally by debris flows, debris floods, sheet floods, and streams; incised by younger alluvial fans (Qaf_1, Qaf_2, Qafy) and grades to near and slightly below the elevation of the Bonneville shoreline; mapped in the northwest corner of the quadrangle where it is correlative with Lake Bonneville transgressive phase alluvial-fan deposits (afb and af_3) of other maps in adjacent areas (Nelson and Personius, 1993) and in Ogden Valley along the North Fork of Ogden River; differentiated from Qafp by relation to the Bonneville shoreline; in Ogden Canyon mapped as queried where alluvial fan is above the Provo but below the Bonneville shoreline, may represent transgressive alluvial-fan deposits; thickness less than 30 feet (9 m).

Qaf_4 **Level-4 alluvial-fan deposits** (Late to Middle Pleistocene?) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, in a matrix of sand, silt, and clay; clasts angular to subrounded; weakly to non-stratified; includes fan remnants near Long Bench (see Plate 1, sections 16, 17, 20, and 21, T. 7 N., R. 1 W., Salt Lake Base Line and Meridian [SLBLM]) and the Pleasant View salient where QTaf is incised by Qaf_4, and Qaf_4 is incised by younger fans (Qafy); unit lacks recycled Bonneville lacustrine clasts (Personius, 1990) and lacks fan morphology in fan-axis-perpendicular lidar profiles; deposits of the same age likely underlie Lake Bonneville deposits and are probably gradational into lacustrine deposits of the older Little Valley or Pokes Point lake cycles, which are not exposed; Little Valley lake cycle reached maximum water depth at about 138,000 ^{14}C yr B.P. (McCalpin, 1986), with a highstand elevation of about 4920 feet (1500 m) (Scott et al., 1983) or 5000 feet (~1525 m) (Scott, 1988); the Pokes Point lake cycle highstand is at an elevation of 4685 feet (1428 m) in Little Valley in the Promontory Range (McCoy, 1987), and ages range from more than ~271 ka (^{230}Th corrected age, Balch et al., 2005) to MIS 12 or about 430 ka (Oviatt et al., 1999); thickness variable from several feet up to several tens of feet.

Qafo **Older alluvial-fan deposits** (Late to Middle Pleistocene?) – Poorly sorted, clast to matrix supported pebble to cobble gravel with boulders, with a matrix of sand, silt, and clay; clasts are angular to well rounded; weakly to non-stratified; forms dissected, isolated alluvial deposits that predate Lake Bonneville; thin to thick planar beds, mapped on Pleasant View salient and in Ogden Valley where fans deposits older than Lake Bonneville cannot be differentiated; incised by Qafy; thickness variable from several feet up to several tens of feet thick.

Colluvial Deposits

Qc **Colluvial deposits** (Holocene to Middle Pleistocene?) – Poorly to moderately sorted, clay- to boulder-size, locally derived sediment; generally poorly stratified; deposited by slope wash and soil creep on steep slopes and in shallow depressions; may include landslide, rockfall, debris flow, and alluvial-fan deposits that are too small to map separately; most bedrock is covered by at least a thin veneer of colluvium, but only the larger, thicker (> 3 feet [1 m]) deposits are mapped; thickness between 3 and 15 feet (1–5 m).

Deltaic Deposits

Qdp **Deltaic deposits related to Provo shoreline and regressive phase of Lake Bonneville** (Late Pleistocene) – Moderately to well-sorted pebble to cobble gravel, sand, silt, and minor clay; subrounded to rounded clasts; contains thin discontinuous sand lenses deposited as thin to thick parallel and cross-bedded foresets, locally includes topset beds; mapped on the south edge of the quadrangle where deltaic deposits were sourced from the mouth of Ogden Canyon (in the Ogden quadrangle); correlative with Qd_3 deltaic deposits in the Ogden quadrangle to the south (Yonkee and Lowe, 2004); deposited into Lake Bonneville during the overflowing and regressive phase at and below the Provo shoreline (Table 1); exposed thickness more than 100 feet (30 m).

Glacial Deposits

Glacial deposits mapped in the North Ogden quadrangle are assumed to correlate with the Pinedale and Bull Lake glaciations. No ages of the glacial deposits from the North Ogden quadrangle are available and cross-cutting relationships are uncertain; therefore, the deposits are mapped as undivided with respect to age.

The Pinedale glaciation is roughly correlative in age to Marine Oxygen Isotope Stage (MIS) 2 (14 to 29 ka; data from Lisiecki and Raymo, 2005). In the Wasatch Range, maximum ice extent during the Pinedale glaciation occurred about 20 to 21 ka (Laabs and Munroe, 2016; Quirk et al., 2018, 2020) with deglaciation and minor moraine-building pauses lasting through about 13 ka (Laabs et al., 2011; Laabs and Munroe, 2016; Quirk et al., 2018). These ages coincide well with ages of the Pinedale glaciation in the Wind River and Teton Ranges (about 13 to 30 ka; Gosse et al., 1995; Phillips et al., 1997; Pierce et al., 2018 and references therein). Recalculated and new ^{10}Be ages from Big Cottonwood, Little Cottonwood, American Fork, and Bells Canyons show glaciers readvanced around 17.5 ka to near the maximum positions and retreated to approximately half of their maximum lengths around 15 ka, followed by rapid deglaciation that coincided with the beginning of the regressive phase of Lake Bonneville around 14.8 ka (Quirk et al., 2018, 2020).

The Bull Lake glaciation is roughly correlative in age to MIS 6 (130 to 191 ka; data from Lisiecki and Raymo, 2005). Bull Lake glacial deposits are typically higher on ridges and farther away from cirques, suggesting larger ice volumes during this glacial cycle than the Pinedale. However, many of the Bull Lake glacial features were obliterated by the younger Pinedale glaciation. Minimal chronology data exist for the Bull Lake glaciation in the Wasatch Range. Quirk et al. (2018) reported a ^{10}Be exposure age of 132.2 ± 5.9 ka from a striated bedrock surface in Big Cottonwood Canyon and interpreted this as a minimum age for the onset of Bull Lake deglaciation. In the Wind River and Teton Ranges Gosse and Phillips (2001), Sharp et al. (2003), and Pierce et al. (2018, and references therein) suggest a Bull Lake glacial maximum of about 140 to 160 ka.

Qg **Glacial deposits, undivided** (Late to Middle Pleistocene?) – Unsorted, non-stratified boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subrounded; may include mass-movement and colluvial deposits too small to show at map scale; mapped east of Ben Lomond where moraine and till deposits are intermixed and indivisible at map scale; may include Pinedale and/or Bull Lake-age deposits (see age discussion above); estimated thickness 30 feet (9+ m) or more.

Qgm **Glacial moraines, undivided** (Late to Middle Pleistocene?) – Unsorted, non-stratified boulder, cobble, and pebble gravel with a matrix of sand and silt; clasts subangular to subrounded; may include mass-movement and colluvial deposits too small to show at map scale; mapped east of Ben Lomond where distinct end, lateral, and recessional moraine deposits are discernable; may include Pinedale and/or Bull Lake-age deposits (see age discussion above); exposed thickness 0 to 150 feet (0–45 m).

Qga **Glacial outwash** (Late to Middle Pleistocene?) – Poorly to moderately sorted, clast-supported cobble and pebble gravel, locally contains boulders, 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 along the North Fork of Ogden River below large lateral and end moraines out of Cutler Creek drainage (primarily in neighboring Mantua quadrangle) and likely Cold Canyon; incised by younger alluvial streams (Qaly) and terraces (Qat_4); may include Pinedale and/or Bull Lake-age deposits (see age discussion above); exposed thickness up to 150 feet (45 m).

Qgao **Older glacial outwash** (Middle Pleistocene?) – Poorly to moderately sorted, clast-supported cobble and pebble gravel, locally contains boulders, with a minor matrix of sand and silt; clasts subangular to rounded; thin to thick parallel bedding and cross-bedding; forms dissected, stranded outwash deposits that are offset by the Ogden Valley North Fork fault; deposited by glacial meltwater streams along the North Fork Ogden River below large lateral and end moraines out of Cutler Creek drainage (primarily in neighboring Mantua quadrangle) and likely Cold Canyon; incised by younger alluvial streams (Qaly) and terraces (Qat_4); may include Bull Lake-age (see age discussion above) or older glacial deposits; exposed thickness up to 100 feet (3045 m).

Human-Derived

Qh **Fill and disturbed land** (historical) – Undifferentiated artificial (human-made) fill and disturbed land related to construction, water storage and debris flood control structures, and aggregate mining operations (commonly in Lake Bonneville deposits); extents are based on lidar data (Ogden City, 2009; UGRC, 2006, 2011, 2013–2014, 2018a) and aerial imagery (UGRC, 2018b, 2018c, 2021a, 2021b); only larger areas of disturbed land are mapped; mapped as a stacked unit over young alluvium in the Business Depot Ogden industrial area in southwest part of the quadrangle; deposits of unmapped fill and disturbed lands are present in most developed areas and contain changing mix of cuts and fills; smaller ponds are not mapped due to map scale limitations; thickness variable and unknown.

Lacustrine Deposits

Undivided deposits of Bonneville lake cycle:

Qlf **Lacustrine fine-grained deposits of Lake Bonneville** (Late Pleistocene) – Moderately sorted silt, clay, and very fine to medium-grained sand; laminated to thin bedded; deposited in shallow to moderately deep water of Lake Bonneville; located in the southwest part of the quadrangle; grades upslope into lacustrine and deltaic deposits (Qldp); includes transgressive, overflowing, and regressive phase Bonneville deposits; estimated thickness less than 15 feet (5 m).

Ql **Lacustrine deposits of Lake Bonnevill**e (Late Pleistocene) – Moderately sorted, subrounded to rounded, fine to coarse sand, silt, and clay with pebbly gravel; locally includes beds of gravel and sand; limited to exposures in bluffs along the North Ogden liquefaction-induced lateral-spread and flow failure head scarp; may include pre-Bonneville deposits; exposed thickness less than 100 feet (30 m).

Deposits related to the Provo shoreline and regressive phase of Lake Bonneville: Mapped near and below the Provo shoreline, which is about 4820–4880 feet (1469–1591 m) in elevation in the North Ogden quadrangle (Table 1).

Qldp **Deltaic deposits** (Late Pleistocene) – Moderately to well-sorted, pebble and cobble gravel with a matrix of sand and silt; clasts subrounded to rounded; locally includes thin beds of silt and sandy silt; mapped near the mouth of North Ogden Canyon and Ogden Canyon (in the adjoining Ogden quadrangle); exposed thickness less than 80 feet (25 m).

Qlgp **Lacustrine gravel and sand** (Late 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 lenses of silt and sandy silt; thin to thick planar beds and cross-beds; typically deposited below wave-cut benches close to the Provo and regressive shorelines in shallow water as nearshore linear beaches and/or offshore gravel bars; locally deposits form veneers over shallow bedrock; commonly interbedded with or laterally gradational into lacustrine sand and silt (Qlsp); exposed thickness less than 40 feet (12 m).

Qlsp **Lacustrine sand and silt** (Late Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; thin to thick bedded; commonly has ripple marks and scour features; deposited in relatively shallow water nearshore areas, laterally gradational with gravel and sand deposits (Qlgp) and downslope from deltaic deposits (Qldp); exposed thickness less than 40 feet (12 m).

Deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville: Mapped between the Bonneville and Provo shorelines. The Bonneville shoreline is at elevations between 5180–5220 feet (1578–1591 m) in the North Ogden quadrangle (Table 1).

Qlgb **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, clast-supported pebble to cobble gravel 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; bedding is planar and cross-bedded; deposited between the Bonneville and Provo shorelines as gravel bars and nearshore deposits; locally deposits form veneers over shallow bedrock; commonly interbedded with or laterally gradational into lacustrine sand and silt (Qlsb); estimated thickness is less than 40 feet (12 m).

Qlsb **Lacustrine sand and silt** (Late Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; thin to thick bedded; sedimentary structures includes ripples marks and scour features; mapped below prominent Bonneville shorelines below Long Bench and on the Pleasant View salient; deposited in relatively shallow water nearshore, laterally gradational with transgressive gravel and sand (Qlgb); at Long Bench, sand and silt deposits overlie coarser-grained beach gravel (Qlgb), indicating deposition in a transgressing lake; thickness is less than 40 feet (12 m).

Mass-Movement Deposits

Qml_2 **North Ogden liquefaction-induced landslide deposits** (Holocene? to Late Pleistocene) – Poorly sorted silt, fine sand, and minor gravel deposited by liquefaction-induced landslides (lateral-spread and flow failure) triggered by strong earthquake ground motion; grain size varies with the nature of source material; characterized by lineaments, hummocks, grabens, depressions, and scarps; lateral spreads slide on a basal detachment on slopes between 0.1% and 5%; in slumps and rotated blocks; pre-existing bedding is usually preserved, but can be chaotic in orientation; flow-failures occur where slopes exceed 5%; refer to Harty and Lowe (2003, and references therein) for more details on the various types of earthquake-induced liquefaction and ground failure features; see age discussion in paragraph below; mapped as a stacked unit where Qafy partially conceals the landslide deposits close to landslide scarps; thickness highly variable, likely up to several tens of feet thick.

During Harty and Lowe's (2003) investigation of the North Ogden liquefaction-induced landslide complex they excavated two trenches on the lateral spread. At their Lomond View Park trench (see Plate 1, NE1/4 section 29, T. 7 N., R. 1 W., SLBLM) of the main scarp of the landslide complex, they found the scarp of landslide consisted of a eroded free face buried by alluvial-fan deposits with no colluvial wedge or landslide deposit. Based on the stratigraphy and morphology of the scarp they concluded that the landslide was produced by a liquefaction-induced flow failure. The Harrisville trench (see Plate 1, NW1/4 section 5, T. 6 N., R. 1 W., SLBLM) investigated a landslide hummock and the surrounding area. The result was the identification of buried soil, blocks of soil and sediment, contorted bedding, sand injection deposits, and sand-filled fractures. They interpreted these features to represent deformation of Lake Bonneville deposits from liquefaction, lateral spread, and flow failure. Within the landslide complex, they identified one lateral spread and flow failure that post-dated Lake Bonneville at 7860 cal yr B.P., a second flow-failure event about 3390 cal yr B.P., and at least one liquefaction event that formed sand injections sometime after 3390 cal yr B.P.. Harty and Lowe (2003) attributed the liquefaction-induced flow failures, lateral spreading, and liquefaction events to multiple large earthquakes in the area. They also indicated that conditions exist for potential future liquefaction events including lateral spreading and/or flow failure during moderate to large earthquakes.

Qms **Landslide deposits** (historical? to Middle Pleistocene?) – Poorly sorted clay- to boulder-size material in slides and slumps; composition varies with the source material; characterized by hummocky topography, main and internal scarps, toe thrusts, back-rotated blocks, and chaotic bedding in displaced bedrock; mapped in multiple areas in the quadrangle and sourced from older mass-movement deposits or mass-movement-prone surficial deposits and/or bedrock (see units: Qg, Qgm, Qago, Qmso, Qlgp, Qdp, Qml_2, QTaf, Ꞓt, Qms, Qmso, Ꞓn, Ꞓo, Ꞓm, Ꞓt, Zpm, Zpg, Zpd, Xfcg, and YXfp); in highly vegetated areas, lidar-derived elevation models were used to distinguish individual landslides in larger landslide complexes based on geomorphology and cross-cutting relationships; the North Ogden rockslide (section 22, T. 7 N., R. 1 W., SLBLM) is mostly composed of Tintic Quartzite (Ꞓt), see Nelson and Personius (1993) for further discussion of this large and unique landslide; where possible adjacent landslides are mapped separately with a contact between them; 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); age and stability determinations require detailed geotechnical investigations; many small or thin landslides may be present throughout the quadrangle but are not mapped due to map scale; thickness highly variable, can be up to several hundred feet thick.

Qmsy **Younger landslide deposits** (historical? to Middle Pleistocene?) – Poorly sorted clay- to boulder-size material in slides and slumps; composition varies with the source material; characterized by hummocky topography, main and internal scarps, toe thrusts, back-rotated blocks, and chaotic bedding in displaced bedrock; mapped in multiple areas in the quadrangle and sourced from older mass-movement deposits or mass-movement-prone surficial deposits and/or bedrock (see units: Qms, Qmso, Ꞓn, Ꞓo, Ꞓm, Zpm, Zpg, Zpd); in highly vegetated areas lidar-derived elevation models were used to distinguish individual landslides in larger landslide complexes by geomorphology and cross-cutting relationships; 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); age and stability determinations require detailed geotechnical investigations; many small or thin landslides may be present throughout the quadrangle but are not mapped due to map scale; thickness highly variable, likely up to several tens of feet thick.

Qmso **Older landslide deposits** (Pleistocene?) – Poorly sorted clay- to boulder-size material, colluvium, and brecciated bedrock; characterized by subdued eroded scarps with benches and steps in topography reminiscent of eroded slide blocks or back-rotated surfaces; much of the hummocky surface and identifiable features have been removed by erosion or filled by other types of deposition; mapped in multiple areas in the quadrangle and sourced from mass-movement-prone bedrock (see units: Ꞓo, Ꞓm, Zpm, Zpg, and Zpd); in highly vegetated areas lidar-derived elevation models were used to distinguish individual landslides in the complex by geomorphology and cross-cutting relationships; where possible adjacent landslides are mapped separately with a contact between them; landslides with subdued morphology (suggesting that they are older, weathered, and have not moved recently) may continue to have slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); age and stability determinations require detailed geotechnical investigations; thickness variable, can be up to several hundred feet thick.

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

Mixed-Environment Deposits

Qac **Alluvial and colluvial deposits** (Holocene to Middle Pleistocene?) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder size, locally derived sediment; rounded to angular clasts; mapped where alluvium and colluvium grade into one another or are intermixed and cannot be shown separately; mapped at the base of steep slopes in the Wasatch Range and in small drainages where alluvium and colluvium from the sides of the drainage are intermixed; small, unmapped deposits are likely present in most small drainages; thickness less than 15 feet (5 m).

Qaco **Older alluvial and colluvial deposits** (Late to Middle? Pleistocene) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment; rounded to angular clasts; forms incised surfaces as much as several tens of feet above modern drainages; mapped on range front drainages where incised alluvium and colluvium grade into one another or are intermixed and cannot be shown separately at map scale; thickness less than 30 feet (9 m).

Qafdb **Alluvial-fan and delta deposits, undivided, related to Bonneville shoreline and transgressive phase of Lake Bonneville** (Late Pleistocene) – Poorly to moderately sorted cobbly gravel in a matrix of sand, silt, and clay; angular to subrounded clasts; moderately to well bedded; typically consists of well-sorted, finer-grained deltaic deposits over coarser-grained, poorly sorted alluvium and glacial outwash; deposited upstream from and into Lake Bonneville as the lake transgressed to the Bonneville shoreline; mapped where a distinct contact between alluvial and deltaic facies is not apparent in Ogden Valley; 10 to 50 feet (3–15 m) thick.

Qam **Alluvial and marsh deposits** (Holocene) – Moderately to well-sorted sand, silt, clay, and organic-rich sediment associated with springs, ponds, seeps, wetlands and alluvial channels; locally contains peat deposits; commonly wet, but seasonally dry; mapped on North Ogden liquefaction-induced landslide complex where hummocky lateral-spread topography caused alluvial streams to pond and develop wetlands, some of the alluvial deposits could be far traveled flow-failure deposits or alluvium reworking flow-failure deposits (see Qml_2); distinguished from alluvial units (Qal_1, Qaly) by wetland-like vegetation on older aerial photographs; estimated thickness less than 15 feet (5 m).

Qct **Colluvial and talus deposits** (Holocene to Middle Pleistocene?) – Very poorly sorted, gravel-size angular debris with a finer-grained matrix; composed of slope wash, soil creep, and rockfall deposits that are mixed and grade into one another; typically distinguished from talus (Qmt) due to the presence of vegetation and lower angle slopes; typically deposited at the base of steep slopes in the Wasatch Range; 0 to 30 feet (0–9 m) thick.

Qla **Lacustrine and alluvial deposits** (Holocene to Late Pleistocene) – Poorly to moderately sorted clay, silt, sand, and gravel; subangular to rounded clasts; moderately to well bedded; mapped where alluvial streams and fans interfinger, rework, and incorporate Lake Bonneville-age deposits; 1 to 10 feet (0.3–3 m) thick.

Qmc **Mass-movement and colluvial deposits** (Holocene to Middle Pleistocene?) – Poorly sorted to unsorted clay- to boulder-size material; mixed landslide, slump, slope wash, and soil creep deposits that grade into one another; typically has a slightly hummocky appearance on lidar-derived elevation models; lacks clear landslide scarps and lateral margins; age and stability determinations require detailed geotechnical investigations; thickness 0 to 30 feet (0–9 m).

Stacked-Unit Deposits

The term "stacked" means a thin covering of one unit over the other. The symbology shows the overlying map unit (listed first) then a slash, then the underlying unit. See individual map unit descriptions for more information regarding materials.

Qafy/Qml$_2$

Younger alluvial-fan deposits over liquefaction-induced landslide deposits (Holocene to Late Pleistocene over Holocene to Late Pleistocene) – Alluvial-fan deposits are poorly to moderately sorted, pebble to cobble gravel with boulders near bedrock exposures; matrix of sand, silt, and minor clay; over liquefaction-induced flow-failure and lateral-spread deposits that consist of poorly sorted silt, fine sand, and minor gravel in displaced or redeposited sediment; alluvial-fan deposits are likely less than 15 feet (5 m) thick; thickness of landslides highly variable, likely up to several tens of feet thick.

Qlgp/€t

Lacustrine gravel and sand related to the Provo shoreline and regressive phase of Lake Bonneville over Tintic Quartzite (Late Pleistocene over Middle to Early Cambrian?) – Veneer of lacustrine deposits that are moderately to well-sorted, subrounded to rounded pebble to cobble gravel with a matrix of sand and pebbly sand over bedrock (€t); mapped in one location south of Garner Canyon; lacustrine deposit thickness 0 to 30 feet (0–9 m).

Qlgp/Xfc

Lacustrine gravel and sand related to the Provo shoreline and regressive phase of Lake Bonneville over Farmington Canyon Complex, undivided (Late Pleistocene over Paleoproterozoic) – Veneer of lacustrine deposits that are moderately to well-sorted, subrounded to rounded pebble to cobble gravel with a matrix of sand and pebbly sand over bedrock (Xfc); mapped in two locations near Jumpoff Canyon; lacustrine deposit thickness 0 to 30 feet (0–9 m).

Qlgb/Xfc

Lacustrine gravel and sand related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Farmington Canyon Complex, undivided (Late Pleistocene over Paleoproterozoic) – Veneer of lacustrine deposits that are moderately to well-sorted, subrounded to rounded pebble to cobble gravel with a matrix of sand and pebbly sand over bedrock (Xfc); lacustrine deposit thickness 0 to 30 feet (0–9 m).

Qafdb/Qga

Alluvial-fan and delta deposits related to Bonneville shoreline and transgressive phase of Lake Bonneville over younger glacial outwash (Late Pleistocene over Late to Middle Pleistocene?) – Alluvial-fan and delta deposits that are poorly to moderately sorted cobble gravel in a matrix of sand, silt, and clay over glacial outwash that is poorly to moderately sorted, clast-supported cobble and pebble gravel, locally contains boulders, with a minor matrix of sand and silt; mapped in North Fork of Ogden Valley; alluvial and delta deposits about 10 feet (3 m) thick; the glacial outwash is likely thicker than 20 feet (6 m).

Qct/Qam

Colluvial and talus deposits over alluvial and marsh deposits (Holocene to Middle Pleistocene? over Holocene) – Rockfall deposits composed of very poorly sorted, gravel- to boulder-size angular to subangular debris sourced from the Tintic Quartzite over alluvial and marsh deposits that consist of moderately to well-sorted sand, silt, clay, and organic-rich sediment associated with springs, ponds, seeps, wetlands and alluvial channels; mapped at one location south of Garner Canyon (Ogden Nature Center North); thickness of the rockfall deposits between 0 and 10 feet (0–3 m); alluvial and marsh deposits likely less than 15 feet (5 m) thick.

Qct/Qml$_2$

Colluvial and talus deposits over liquefaction-induced landslide deposits (Holocene to Middle Pleistocene? over Holocene to Late Pleistocene) – Rockfall deposits composed of very poorly sorted, gravel- to boulder-size, angular to subangular debris sourced from the Tintic Quartzite over liquefaction-induced flow failure and lateral-spread deposits that consist of poorly sorted silt, fine sand, and minor gravel in displaced or redeposited sediment; mapped in two location south of Garner Canyon (Ogden Nature Center North); thickness of the rockfall deposits between 0 and 10 feet (0–3 m); thickness of landslides highly variable.

Qct/Qlgp

Colluvial and talus deposits over lacustrine gravel and sand related to the Provo shoreline and regressive phase of Lake Bonneville (Holocene to Middle Pleistocene? over Late Pleistocene) – Rockfall deposits composed of very poorly sorted, gravel- to boulder-size, angular to subangular debris sourced from the Tintic Quartzite over lacustrine deposits that consist of moderately to well-sorted pebble to cobble gravel with a matrix of sand and pebbly sand, subrounded to rounded, and clast-supported; mapped in two location south of Garner Canyon (Ogden Nature Center North); thickness of the rockfall deposits between 0 and 10 feet (0–3 m); lacustrine deposits likely less than 30 feet (10 m).

Qh/Qal_1

Fill and disturbed land over level-1 stream and floodplain deposits (historical over Late Holocene) – Undifferentiated earth fill and disturbed land associated with the Business Depot Ogden industrial area that conceals alluvial deposits that consist of poorly to moderately sorted pebble and cobble gravel, with a matrix of sand and silt; thickness of fill and disturbed land highly variable; mapped at the Business Depot Ogden industrial area; alluvial deposits estimated thickness less than 15 feet (5 m).

Qh/Qal_2

Fill and disturbed land over level-2 stream deposits (historical over Middle Holocene to Late Pleistocene) – Undifferentiated earth fill and disturbed land associated with the Business Depot Ogden industrial area that conceals alluvial deposits that consist of poorly to moderately sorted pebble and cobble gravel, with a matrix of sand and silt; thickness of fill and disturbed land highly variable; mapped at the Business Depot Ogden industrial area; alluvial deposits estimated thickness less than 15 feet (5 m).

Qh/Qaly

Fill and disturbed land over young stream deposits (historical over Holocene to Late Pleistocene) – Undifferentiated earth fill and disturbed land associated with the Business Depot Ogden industrial area that conceals alluvial deposits that consist of poorly to moderately sorted pebble and cobble gravel, with a matrix of sand and silt; mapped at the Business Depot Ogden industrial area; thickness of fill and disturbed land highly variable; alluvial deposits estimated thickness less than 15 feet (5 m).

QUATERNARY-PLIOCENE (TERTIARY)

QTaf **Quaternary-Pliocene alluvial-fan deposits** (Middle Pleistocene to Pliocene?) – Poorly sorted, pebble to cobble gravel, locally contains boulders, in a matrix of sand, silt, and clay; mapped above the Bonneville shoreline on the Pleasant View salient; makes up most of the upper surface of Long Bench; the remnant deposits lack fan morphology; cut by normal faults of the Wasatch fault zone (see Personius, 1990; Nelson and Personius, 1993; Harty et al., 2012); unit correlates with the Qaf_5 unit of Personius (1990) and QTaf of Harty et al. (2012); thickness likely less than 200 feet (60 m).

Major unconformity

PALEOGENE (TERTIARY)

Tsl **Salt Lake Formation** (Miocene) – Light-gray to light-brown, altered tuff (claystone), tuffaceous siltstone, sandstone, and conglomerate; locally light red or green; mapped on margins of Ogden Valley where it forms colluvium-covered slopes; prone to landslides and slumps; unconformably overlies older bedrock, base not exposed in quadrangle; previously mapped as Norwood Formation, new preliminary research suggest much of the Norwood Formation in Ogden Valley is actually Salt Lake Formation with detrital zircon ages of 8–10 Ma (Cornwall et al., 2025; Mayfield et al., 2025); exposed thickness in quadrangle approximately 0 to 200 feet (0–60 m); in Huntsville quadrangle 0 to 1500+

feet (0–450+ m) (Sorenson and Crittenden, 1979); Coogan and King (2016) estimated the thickness in western Ogden Valley to be 2000 feet (600 m).

Major unconformity

WILLARD THRUST HANGING WALL

NEOPROTEROZOIC

Zcc **Caddy Canyon Quartzite of Brigham Group** (Neoproterozoic) –Variable colored, vitreous well-cemented sandstone (commonly referred to as an orthoquartzite) that is white, pale yellowish brown, pale olive, greenish gray, dark gray, and grayish purple; fine to medium grained, moderate to well sorted; low- to high-angle cross-bedding, with medium to thick beds; includes minor interbedded argillite layers and pebble conglomerate lenses; ledge forming; mapped in Ogden Valley in a poorly exposed isolated knob in Flat Canyon; the upper and lower contacts are not exposed in the quadrangle, elsewhere the base of the Caddy Canyon Quartzite and Papoose Creek Formation is gradational and placed where interbedded argillite beds diminish and quartzite beds dominate (McKean et al., 2018); prior mapping in the area may include the Papoose Creek Formation within the Caddy Canyon Quartzite and/or Kelly Canyon Formation (Coogan and King, 2016), may be present within the Kelly Canyon Formation; age-based stratigraphic position relative to radiometric ages from overlying Browns Hole Formation (Sorenson and Crittenden, 1979; Provow et al., 2021) and underlying Perry Canyon Formation (Balgord et al., 2013); incomplete thickness of about 150 to 250 feet (~45–75 m) exposed in the quadrangle; total thickness is 1000 to 1600 feet (300–500 m) in the adjacent Mantua quadrangle (Crittenden and Sorenson, 1985a) and 1500 to 2000 feet (460–600 m) in the Huntsville quadrangle (Sorenson and Crittenden, 1979).

Zkc **Kelley Canyon Formation** (Neoproterozoic) – Gray to olive-gray weathering, slope-forming argillite, slate, and phyllite with minor layers of fine-grained quartzite; micaceous to graphitic; alternating yellowish-gray to greenish-gray silt and dark-gray to olive-gray fine grained laminations; mapped in Ogden Valley in one outcrop in Flat Canyon, upper and lower contacts are not exposed in the quadrangle; elsewhere the base of the Kelley Canyon Formation is mapped where argillite is dominant above quartzite beds of the Maple Canyon Formation (not exposed in the quadrangle) (McKean et al., 2018); Papoose Creek Formation may be present in the Caddy Canyon Quartzite and/or Kelly Canyon Formation in this area (Coogan and King, 2016); age-based stratigraphic position relative to radiometric ages from overlying Browns Hole Formation (Sorenson and Crittenden, 1979; Provow et al., 2021) and underlying Perry Canyon Formation (Balgord et al., 2013); incomplete thickness of about 200 feet (70 m) exposed in the quadrangle; Crittenden and Sorenson (1985a) report a thickness of 600 feet (180 m) in the Mantua quadrangle; Sorenson and Crittenden (1979) report 2000 feet (600 m) in the Huntsville quadrangle; Coogan and King (2016) report 1000 feet (300 m) in the Mantua quadrangle.

Perry Canyon Formation – Regionally divided into seven informal members by Balgord et al. (2013), from top to bottom: (1) graywacke, (2) diamictite, (3) mafic volcanic and intrusive rocks (greenstone), (4) slate, (5) pebbly slate, (6) quartzite-grit, and (7) arkosic grit. In the following descriptions, the prefix "meta," which signifies their metamorphic grade of greenschist facies, has been omitted for simplicity. The informal members present in the North Ogden quadrangle are, from top to bottom: (1) altered diorite, (2) graywacke and mudstone, (3) diamictite, and (4) greenstone pillow basalt. Due to the interbedding and poor exposure, the graywacke and mudstone units of Crittenden and Sorenson (1985b) are combined in this report. Euhedral zircon grains from volcaniclastic rocks to the northwest in the Willard quadrangle yielded U-Pb maximum depositional age of 667 ± 5 Ma for the graywacke member (sample 38EAB09 in Balgord et al., 2013), and a maximum depositional age of 703 ± 6 Ma for the diamictite member (sample 36EAB09) (Balgord et al., 2013).

Zpi **Altered diorite** (Neoproterozoic) – Greenish-gray altered diorite; phenocrysts include plagioclase, chlorite, actinolite, altered carbonate, epidote, and other mafic minerals; mapped north of North Ogden Canyon, near North Ogden Peak, and in North Fork Park where it forms knobs of boulders, talus, and deeply weathered outcrops; intrudes as dikes through the Perry Canyon Formation diamictite, greenstone pillow basalt, and undivided graywacke and mudstone; up to 780 feet (240 m) wide.

Zpgm **Graywacke and mudstone** (Neoproterozoic) – Interlayered olive-gray to medium-gray feldspathic to lithic wacke, dark yellowish-brown to olive-gray argillite, dark gray pebbly slate, schistose slate, and mudstone; moderately to poorly sorted; locally contains isolated lenses of diamictite; graywacke and argillite form normally graded beds interpreted to be turbidites (Balgord et al., 2013); graywacke contains subangular to subrounded grains of quartz, feldspar, and volcanic lithics in a micaceous, altered matrix; pyrite cubes up to 0.5 inch (1 cm) are widespread and typically altered; mudstone and pebbly slate contain subangular to subrounded grains of quartz in the fine-grained matrix; cleavage is best developed in argillite; forms ledges and slopes and is prone to slope failure; lower contact is mapped above the diamictite but also may interfinger with the greenstone pillow basalt member; may also represent the units below the diamictite such as the slate, pebbly slate, quartzite-grit, and arkosic grit members of Balgord et al. (2013); estimated thickness is 800 to 1000 feet (250–300 m) thick, potentially exaggerated by folding and faulting; in the Willard quadrangle the graywacke member thickness is ~650 feet (~200 m) (McKean et al., 2018).

Zpd **Diamictite** (Neoproterozoic) – Dark gray diamictite with minor interbedded argillite, feldspathic to lithic wacke, and conglomerate; diamictite contains subrounded to subangular pebbles to boulders of granite, gneiss, quartzite, volcanic rocks (including trachyte, rhyolite, and basalt), and sedimentary rocks; matrix is micaceous and sandy (Balgord et al., 2013, see Figures 6 and 11); diamictite is typically unstratified, but locally displays sandy wisps and crude layering defined by clast-rich zones; interpreted as glacio-marine deposits (Balgord et al., 2013); forms rocky ledges and slopes partly covered by unmapped colluvium; prone to slope failure; lower contact is only visible in a few locations above the Willard thrust fault where it is marked by the greenstone member or unconformable contact with the Facer Formation; estimated thickness in the quadrangle where present is approximately 200 to 400 feet (60–120 m); regional thicknesses variable with a thickness of approximately 1000 feet (~300 m) in the Willard quadrangle (McKean et al., 2018) and on Fremont Island (Balgord et al., 2013); only 200 to 400 feet (60–120 m) thick in the Ogden 30′ x 60′ quadrangle (Coogan and King, 2016); interpreted as correlative with diamictite of the Mineral Fork Formation exposed on Antelope Island in the footwall of the Willard thrust fault (Balgord et al., 2013) where it is 0 to 200 feet (0–60 m) thick (Doelling et al., 1990).

Zpgb **Greenstone pillow basalt** (Neoproterozoic) – Olive-gray to greenish-gray altered mafic igneous rocks; contains pillow basalts that have been altered, stretched, and sheared almost beyond recognition; fine-grained matrix composed mostly of chlorite, actinolite, epidote, and albite; thin section showed vesicles filled with quartz; forms slopes to ledges and is generally poorly exposed north of North Ogden Canyon; lower contact in the area is either (1) unconformable with the Facer Formation (in the Willard quadrangle, McKean et al., 2018), (2) conformable and/or interfingering with the diamictite (Zpd), graywacke and mudstone (Zpgm), or slate (in the Willard quadrangle, McKean et al., 2018) or (3) cut by the Willard thrust fault; in the map area estimated thickness is 100 to 200 feet (30–60 m); thickness in the Willard quadrangle is 0 to 100 feet (0–30 m) (McKean et al., 2018).

Major Unconformity

MESOPROTEROZOIC AND PALEOPROTEROZOIC

Facer Formation – As described by Crittenden and Sorensen (1980), the Facer Formation is a collection of greenschist to amphibolite facies metamorphic units including quartzite, pelitic schist and phyllite, quartz muscovite schist, amphibolite (meta-diorite), gneiss, (meta-) carbonate, (meta-) conglomerate, pegmatite, vein quartz, and minor fuchsite-bearing quartzite and quartz-hematite schist. Only the quartzite, phyllite, and meta-carbonate are found in the North Ogden quadrangle. To the north in the Mantua quadrangle, muscovite from a schist yielded a K-Ar age of 1342 ± 10 Ma and a Rb-Sr age of 1660 ± 50 Ma; muscovite from a pegmatite in the upper Facer Formation yielded a K-Ar age of 1357 ± 10 Ma and a Rb-Sr age of 1580 ± 50 Ma (Crittenden and Sorensen, 1980). Hornblende from meta-diorite that intrudes the gneiss in the Mantua quadrangle yielded a K-Ar age of 1681 ± 12 Ma (Crittenden and Sorensen, 1980). The wide age range between the K-Ar muscovite and hornblende ages may be due to a younger metamorphic/alteration event or may indicate that the schist and pegmatite are significantly younger than the meta-diorite and gneiss. To the northwest in the Willard quadrangle a ^{206}Pb/^{207}Pb age from zircons in a quartzite in the gneiss have a minimum age of 1582 ± 10 Ma and a population of Paleoproterozoic grains (~2000 to 2500 Ma) (sample 32EAB09 in Balgord, 2011). A pegmatite sample in gneiss in the Mantua quadrangle has similar age populations (sample 41EAB09 in Balgord, 2011). Further work is needed to better constrain the age, geologic history, correlation, and characteristics of the various units within the Facer Formation.

YXfp **Phyllite and quartzite of Facer Formation** (Mesoproterozoic and Paleoproterozoic) – Greenish-gray to dark-greenish-gray and maroon phyllite (meta-siltstone to mudstone), and light-gray to white quartzite; forms slopes; lower contact is truncated by the Willard thrust fault; age from Crittenden and Sorensen (1980), Balgord (2011), and McKean et al. (2018); incomplete thickness is approximately 100 to 300 feet (30–90 m), unit is commonly folded and faulted.

YXfl **Limestone of Facer Formation** (Mesoproterozoic and Paleoproterozoic) – Light-gray limestone (meta-carbonate); fine grained; forms ledges; interbedded in Facer Formation phyllite near Lewis Peak; age from Crittenden and Sorensen (1980), Balgord (2011), and McKean et al. (2018); incomplete thickness is 30 to 70 feet (9–20 m).

WILLARD THRUST FOOTWALL

PALEOZOIC

DEVONIAN

Db **Beirdneau Sandstone** (Late Devonian) – Yellow- to red- to light-gray sandy to silty dolomite and limestone, sandstone, shale, siltstone, and flat-pebble conglomerate; dolomite and limestone are thin to medium bedded with well-rounded quartz grains in medium-size beds; the sandstone is orange-gray, thin to medium bedded, fine to medium grained, and moderate to well sorted; shale is red to yellow; siltstone is variably calcareous to dolomitic, with mud cracks and soft sediment deformation features; forms ledges and slopes; mapped in Goodale Creek, a tributary of Ogden Canyon; lower contact marked by a transition from sandy dolomite to ledge-forming dolomites of Hyrum Dolomite; top not exposed in the quadrangle; Late Devonian age from Williams (1971); estimated thickness 250 to 300 feet (75–90 m), thickness varies due to faulting and folding; Yonkee and Lowe (2004) reported 170 to 330 feet (50–100 m) thick in the Ogden quadrangle; 250 to 300 feet (75–90 m) thick in the Huntsville quadrangle (Sorenson and Crittenden, 1979).

Dh **Hyrum Dolomite** (Late and Middle Devonian) – Medium- to dark-gray dolomite and minor silty limestone; medium to thick bedded; fine to medium grained; some layers contain light-gray, slightly silty laminations; locally contains calcite-filled vugs and chert nodules; forms ledges; mapped in Ogden Canyon and between Dry Canyon and Goodale Creek drainage; lower contact with Water Canyon Formation placed at change to sandy dolomite; Late and Middle Devonian age from Williams (1948, 1971); estimated thickness 200 to 250 feet (30–75 m), varies due to faulting and folding; in the adjacent Ogden quadrangle Yonkee and Lowe (2004) reported a thickness of 130–260 feet (40–80 m); in the Huntsville quadrangle Sorenson and Crittenden (1979) reported a thickness of 350 feet (107 m).

Dwc **Water Canyon Formation** (Early Devonian) – Light- to yellow-gray, sandy to silty dolomite; thin- to medium-bedded; slope forming; mapped in Ogden Canyon and between Dry Canyon and Goodale Creek drainage; lower contact unconformable and mapped at change from well-layered dolomite (Dwc) to massive dolomite of Fish Haven Dolomite; Laketown Dolomite and Silurian strata missing due to Stansbury uplift; Early Devonian age (Williams, 1948; Taylor, 1963; Williams and Taylor, 1964; Oviatt, 1986); estimated thickness 30 to 100 feet (9–30 m), varies due to faulting and folding; thickness 30 to 100 feet (9–30 m) in Ogden Canyon (Yonkee and Lowe, 2004); 90 feet (27 m) in Huntsville quadrangle (Sorenson and Crittenden, 1979).

Unconformity (Disconformity related to the Stansbury uplift; see Rigby, 1959; Rigby and Clark, 1962; Morris and Lovering, 1961; Tooker, 1999)

ORDOVICIAN

Ofh **Fish Haven Dolomite** (Late Ordovician) – Medium- to dark-gray dolomite, medium to thick bedded; fossil corals, crinoids, and twiggy bodies; forms cliffs; mapped in Ogden Canyon and between Dry Canyon and Goodale Creek drainage; lower contact is an unconformity with Garden City Formation that is mapped at change from well-bedded lighter dolomite to more massive darker dolomite; regionally the Swan Peak Quartzite underlies this unit but is missing due to unconformity related to the Ordovician Tooele arch; Late Ordovician age (Williams, 1948; Gelnett, 1958; Budge, 1972; Budge and Sheehan, 1980); estimated thickness 200 to 250 feet (60–80 m), varies due to faulting and folding; 130–260 feet thick (40–80 m) in Ogden quadrangle (Yonkee and Lowe, 2004); 200 to 225 feet thick (60–69 m) in the Huntsville quadrangle (Sorenson and Crittenden, 1979).

Unconformity (Disconformity related to the Tooele arch; see Hintze, 1959; Morris and Lovering, 1961, and references therein; Ethington et al., 2016)

Ogc, Ogc?

Garden City Formation (Early Ordovician) – Tan to light-gray, silty dolomite, dolomite, silty limestone and siltstone, thin to thick bedded; fossils of crinoids, brachiopods, and gastropods; forms slopes and ledges; mapped in Ogden Canyon and between Dry Canyon and Goodale Creek drainage; lower contact with St. Charles Formation is gradational and is placed above the massive dolomite; queried where unit identification uncertain; Early Ordovician age (Ross, 1951; Taylor et al., 1981; Oviatt, 1986); estimated thickness 200 to 400 feet (60–120 m), varies due to faulting and folding; in the Ogden quadrangle Yonkee and Lowe (2004) report a thickness of 200 to 400 feet (60–120 m); 200 to 250 feet (60–75 m) thick in Huntsville quadrangle (Sorenson and Crittenden, 1979).

ORDOVICIAN-CAMBRIAN

O€sd **Dolomite member of St. Charles Formation** (Early Ordovician and Late Cambrian) – Light- to dark-gray dolomite; thick bedded; brachiopod fossils near base (lower 50 feet [15 m], Crittenden and Sorensen, 1985a); forms cliffs; mapped in and north of Ogden Canyon; regional age earliest Ordovician and Late Cambrian (Taylor et al., 1981); lower contact conformable with Worm Creek Quartzite Member; estimated thickness 200 to 600 feet (60–185 m), thickness varies due to faulting and folding; in the Ogden quadrangle Yonkee and Lowe (2004) report a thickness of 500 to 720 feet (150–220 m); 500 to 725 feet thick (150–245 m) in the Huntsville quadrangle (Sorenson and Crittenden, 1979).

CAMBRIAN

€sw, €sw?

Worm Creek Quartzite Member of St. Charles Formation (Late Cambrian) – Light-gray to light-brown calcareous sandstone and sandy dolomite; well sorted, thin bedded; well-rounded grains; mapped in and north of Ogden Canyon to Coldwater Canyon; lower contact placed at mottled dolomite of the Nounan Formation; unit often missing due to thrust faulting but could also be undifferentiated from Nounan Formation due to lack of exposures; queried where unit identification uncertain; Late Cambrian age (Oviatt, 1986); estimated thickness 20 to 30 feet (6–10 m); 20 feet thick (6 m) in the Huntsville quadrangle (Sorenson and Crittenden, 1979).

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Nounan Formation (Late Cambrian) – Light- to dark-gray dolomite and minor silty dolomite, mottled with shale; locally includes twiggy bodies; forms cliffs; queried where unit designation uncertain and could be dolomitized Maxfield Limestone; lower contact with Bloomington Formation is conformable and mapped at appearance of shaley limestone; Late Cambrian age (Williams, 1948; Maxey, 1958; Oviatt, 1986); estimated thickness 500 to 750 feet (150–230 m), unit is often overturned and thickened by folding and faulting; in the Ogden quadrangle the thickness is 500 to 720 feet (150–220 m) (Yonkee and Lowe, 2004); 500 to 800 feet (150–245 m) in the Huntsville quadrangle (Sorenson and Crittenden, 1979).

€boc, €boc?

Calls Fort Shale Member of Bloomington Formation (Middle Cambrian) – Olive-green to light-brown shaley limestone, shale, ribbon limestone with abundant orange-weathering silty ribbons, oncolitic limestone, oolitic limestone, and flat-pebble conglomerate; forms slopes and ledges; lower contact with Maxfield is conformable; queried where unit identification uncertain; Rigo (1968) reported *Eldoradia* sp. trilobite fossil, indicating a late Middle-Cambrian age; estimated thickness 80 to 200 feet (25–60 m), varies due to faulting and folding; in the Ogden quadrangle thickness is 100 to 200 feet (30–60 m) (Yonkee and Lowe, 2004); 75 to 300 feet (23–90 m) thick in Huntsville quadrangle, lower plate of Willard thrust (Sorenson and Crittenden, 1979).

€mo **Maxfield Limestone and Ophir Formation, undivided** (Middle Cambrian) – Argillaceous limestone and dolomite with interlayered shale; undivided Maxfield Limestone and limestone of the Ophir Formation; mapped in the Ben Lomond and Johnson Draw areas where the units are faulted, sheared, and difficult to differentiate; see unit descriptions for full description and thickness of each unit.

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Maxfield Limestone (Middle Cambrian) – Argillaceous limestone and dolomite with interlayered shale, ribbon limestone, oncolitic limestone, and oolitic limestone; forms slopes and ledges; Yonkee and Lowe (2004) mapped three informal members in the Ogden quadrangle, which are identifiable here but not mappable; descriptions for each member are: (1) upper limestone and dolomite member is light- to dark-gray dolomite, oolitic dolomite, and minor limestone; medium to thick bedded; twiggy bodies (that could represent burrows), cliff former; gray boundstone near the top; lower part, light- to medium-gray oolitic limestone, limestone with yellow weathering silty ribbons, and minor dolomite, dark-gray cherty dolomite; forms ledges; (2) middle argillaceous limestone member is brown to orange-gray, interlayered argillaceous limestone, shale, ribbon limestone, oncolitic limestone, oolitic limestone and flat pebble conglomerate; forms slopes to ledges; (3) lower limestone member is light- to medium-gray, ribbon limestone with abundant orange-weathering silty ribbons and minor oolitic limestone; thin to medium bedded; thin argillaceous limestone near middle of member separates upper and lower ledges; lower contact with the Ophir Shale is conformable and gradational and placed at the base of the lowest Maxfield limestone beds; Middle Cambrian age from Morris and Lovering (1961), Hintze (1962), and *Ehmaniella* sp. and *Glossopleura* sp. trilobites in Ogden Canyon (Rigo, 1968); queried where uncertain; estimated thickness 600 to 1000 feet (180–300 m), varies due to folding and faulting; 600 to 100 feet (180–300 m) thick in the Ogden quadrangle; 950 feet (290 m) thick in the Huntsville quadrangle.

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Ophir Formation (Middle Cambrian) – Upper and lower olive-green shale with a middle light-medium-gray limestone; upper olive-green shale intervals contain silty micaceous shale with some thin silty limestone beds; middle argillaceous limestone is thin to medium bedded with orange-gray silty ribbons that forms a thin distinct ridge between the two shale intervals; lower olive-green shale is silty to micaceous with some thin fine-grained sandstone near the base; forms slopes; lower contact is gradational with the thick-bedded sandstone of the Tintic Quartzite; age from Morris and Lovering (1961), Hintze (1962), and Middle Cambrian *Ehmaniella* sp. and *Glossopleura* sp. trilobites in Ogden Canyon (Rigo, 1968); queried where designation uncertain and could be Maxfield Limestone; estimated thickness is 100 to 700 feet (30–200 m), in the Ogden quadrangle thickness is 300 to 700 feet (90–200 m) (Yonkee and Lowe, 2004); unit has been thinned and thickened by faulting and folding in both quadrangles.

Ꞓt **Tintic Quartzite** (Middle to Early Cambrian?) – White- to light-pink on fresh surfaces, weathers dark-yellowish-orange, quartzose to subarkosic, well-cemented sandstone (commonly referred to as an orthoquartzite) that is fine to medium grained, thick bedded, moderately sorted, with common cross-beds; small beds of conglomerate composed of subrounded to angular quartz-pebble clasts; basal part of the formation contains green to purple to light brown arkosic sandstone, quartz-pebble conglomerate, and micaceous siltstone; lower contact is unconformable and represents a long-lived paleo surface that locally includes grus developed on the top of the underlying Farmington Canyon Complex; forms cliffs and ledges; trace fossils in the upper part of the formation in the Ogden Canyon area include *Skolithos* tubes and *Plagiogmus* traces that indicate Middle Cambrian age (Peterson and Clark, 1974); estimated thickness in the quadrangle is 1100 to 1500 feet (335–450 m); in the Ogden quadrangle the thickness is 1300 to 1500 feet (400–450 m) (Yonkee and Lowe, 2004).

Major unconformity

PALEOPROTEROZOIC

Farmington Canyon Complex – Bryant (1988) divided metamorphic and intrusive igneous rocks of the complex into seven units, (1) quartz-monzonite gneiss, (2) migmatite, (3) schist and gneiss, (4) quartzite, gneiss, and schist (5) amphibolite, (6) pegmatite, and (7) mica-rich schist. Yonkee and Lowe (2004) divided these rocks in the Ogden quadrangle into units that included granitic gneiss, migmatitic gneiss, quartz-rich gneiss, biotite-rich schist, amphibolite, and pegmatite. Only three units are present in the North Ogden quadrangle: granitic gneiss, amphibolite, and pegmatite. The Farmington Canyon Complex is Paleoproterozoic based on geochronologic data from nearby areas. Barnett et al. (1993) reported $^{207}Pb/^{206}Pb$ monazite metamorphic ages from gneisses that ranged from 1640 to 1720 Ma. Nelson et al. (2002, 2011) reported a mean monzonite microprobe age of 1705 ± 90 Ma from a gneiss. Mueller et al. (2011) reported a $^{207}Pb/^{206}Pb$ age of 2450 Ma for zircon in gneiss in the Bountiful Peak quadrangle and an aggregate mean U-Pb age of 1674 ± 12 Ma for metamorphic zircon overgrowths. Yonkee et al. (2024) reported igneous zircon $^{207}Pb/^{206}Pb$ ages of 2450 and 2460 Ma for granitic gneiss bodies on Antelope Island and in the Ogden 7.5-minute quadrangle, respectively, an igneous zircon $^{207}Pb/^{206}Pb$ age of 1660 Ma for a late stage pegmatitic granite body on Antelope Island, a wide range of detrital (inherited) zircon grain $^{207}Pb/^{206}Pb$ ages ranging from Archean to ca. 2000

Ma for quartz-rich and layered gneiss samples on Antelope Island, and $^{207}Pb/^{206}Pb$ age ages spanning about 1600 to 1800 Ma for metamorphic zircon rims in gneiss samples from Antelope Island.

Xfc **Farmington Canyon Complex, undivided** (Paleoproterozoic) – Undivided pegmatite, plagioclase hornblende amphibolite, and granitic gneiss; shown on cross sections and mapped as a stacked unit where covered by talus and colluvium (Qct/Xfc); thickness is unknown.

Xfcp **Pegmatite of Farmington Canyon Complex** (Paleoproterozoic) – White to light-gray pegmatite veins and dikes; composed of very coarse grained quartz, potassium feldspar, plagioclase and biotite; intrudes the granitic gneiss; forms ledges; mapped only in one location north of the Pleasant View salient (NW1/4 section 8, T. 7 N., R. 1 W., SLBLM); smaller veins and dikes not shown due to map scale; up to several tens of feet (~10 m) wide.

Xfca **Amphibolite of Farmington Canyon Complex** (Paleoproterozoic) – Medium- to dark greenish-gray amphibolite pods and dikes composed of fine- to coarse-grained hornblende and plagioclase; forms ledges to slopes; intrudes granitic gneiss; smaller veins and dikes not shown due to map scale; veins and dikes are feet to up to several tens of feet (~10 m) wide.

Xfcg **Granitic gneiss of Farmington Canyon Complex** (Paleoproterozoic) – Gray, medium- to coarse-grained orthogneiss composed of quartz, plagioclase, potassium feldspar, hornblende and minor biotite; numerous faults with small offsets in the gneiss not shown due to map scale; forms rugged cliffs; mapped along the west edge of the Wasatch Range; thickness unknown.

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Table 1. *Ages of major shoreline occupations of Lake Bonneville and shoreline elevations in the North Ogden 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]
	Transgressive shorelines (t)	20,000–15,000[4]	24,000–18,000	4880–5180 (1487–1578)
	Bonneville (B) flood	~15,000[5]	~18,000	5180–5220 (1578–1591)
Overflowing phase	Provo (P)	15,000–12,600[6]	18,000–15,000	4820–4880 (1469–1487)
Regressive phase	Regressive shorelines (r)	12,600–11,500[6]	15,000–13,000	4440–4780 (1353–1457)

[1] Radiocarbon ages (^{14}C yr B.P.) must be calibrated to compare to calendar years, or calibrated years before present (cal yr B.P.), meaning years before 1950. All calibrations made using OxCal ^{14}C calibration and analysis software (version 4.4; Bronk Ramsey, 2009; using the IntCal20 calibration curve of Reimer et al., 2020), rounded to the nearest 500 years.

[2] Oviatt et al. (1990).

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

[4] Oldest and youngest age from the youngest Stansbury shoreline and oldest Bonneville shoreline, respectively (see references 2 and 4)

[5] 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).

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