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11°16'
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2019

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET

UTAH
QUADRANGLE LOCATION

INTERIM GEOLOGIC MAP OF THE BOUNTIFUL PEAK QUADRANGLE, DAVIS AND MORGAN COUNTIES, UTAH

by
Zachary W. Anderson

2019

Base from USGS US Topo Bountiful Peak 7.5' Quadrangle (2017)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1983
Geology mapped in 2017–2018

Program Manager: Grant C. Willis
Project Manager: Jon K. King
GIS and Cartography: Zachary W. Anderson and Rosemary Fasselin

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1	2	3
4		5
6	7	8

1. Kaysville
2. Peterson
3. Morgan
4. Farmington
5. Porterville
6. Salt Lake City North
7. Fort Douglas
8. Mountain Dell

ADJOINING 7.5' QUADRANGLE NAMES

LIST OF MAP UNITS

QUATERNARY-TERTIARY DEPOSITS

- Qh — Fill and disturbed land
- Qal — Stream alluvium
- Qaf1 — Youngest alluvial-fan deposits
- Qafy — Younger alluvial-fan deposits
- Qafp — Alluvial-fan deposits related to regressive phase of Bonneville lake cycle
- Qafb? — Alluvial-fan deposits related to Bonneville shoreline occupation?
- Qlsp — Lacustrine sand and silt of regressive phase of Bonneville lake cycle
- Qldp — Deltaic deposits related to regressive phase of Bonneville lake cycle
- Qlsb — Lacustrine sand and silt of transgressive phase of Bonneville lake cycle
- Qlgb — Lacustrine gravel and sand of transgressive phase of Bonneville lake cycle
- Qlf — Lacustrine silt and clay of Lake Bonneville
- Qls — Lacustrine sand and silt of Lake Bonneville
- Qlg — Lacustrine gravel and sand of Lake Bonneville
- Qg — Glacial deposits,undivided
- Qgp — Glacial deposits, Pinedale age
- Qgmp — Glacial moraines, Pinedale age
- Qgb — Glacial deposits, Bull Lake age
- Qgmb — Glacial moraines, Bull Lake age
- Qgo — Glacial deposits, older
- Qmsh — Landslide deposits, historical movement
- Qms — Landslide deposits
- Qms?(Tw) — Landslide deposits(?) derived from Wasatch Formation
- Qmso — Landslide deposits, older
- QTms?(Xfcgs) — Landslide blocks(?) of Farmington Canyon Complex gneiss and schist
- QTms?(Xfcp) — Landslide blocks(?) of Farmington Canyon Complex pegmatite, gneiss, and schist
- Qmt — Talus deposits
- Qc — Colluvial deposits
- Qct — Colluvial and talus deposits, undivided
- Qac — Alluvial and colluvial deposits, undivided
- Qmc — Mass-movement and colluvial deposits, undivided
- Qla — Lacustrine and alluvial deposits, undivided
- Qlm — Lacustrine and marsh deposits, undivided
- Qafp/Qmso — Alluvial-fan deposits of the regressive phase of Bonneville lake cycle over older landslide
- Qlsp/Qmso — Lacustrine sand and silt of regressive phase of Bonneville lake cycle over older landslide
- Qlgb/Qmso — Lacustrine gravel and sand of transgressive phase of Bonneville lake cycle over older landslide
- Qlsb/Qmso? — Lacustrine sand and silt of transgressive phase of Bonneville lake cycle over older landslide?
- Qls/Qmso — Lacustrine sand and silt of Lake Bonneville over older landslide

TERTIARY (NEOGENE) DEPOSITS

- Tg — Tertiary gravel

TERTIARY (PALEOGENE) ROCKS

- Tn — Norwood Formation
- Tw — Wasatch Formation
- Twc — Wasatch Formation, conglomerate and sandstone unit

CAMBRIAN ROCKS

- Ꞓsc — St. Charles Formation
- Ꞓn — Nounan Formation
- Ꞓbo — Bloomington Formation
- Ꞓmu — Maxfield Limestone, upper limestone unit
- Ꞓmm — Maxfield Limestone, middle mixed unit
- Ꞓml — Maxfield Limestone, lower limestone unit
- Ꞓo — Ophir Formation
- Ꞓt — Tintic Quartzite

PROTEROZOIC ROCKS

- Xfcgs — Farmington Canyon Complex, gneiss and schist
- Xfcq — Farmington Canyon Complex, quartzite, gneiss, and schist
- Xfcp — Farmington Canyon Complex, pegmatite, gneiss, and schist
- Xfca — Farmington Canyon Complex, amphibolite

See booklet for introductory text, map unit descriptions, acknowledgments, references, and table 1.

GEOLOGIC SYMBOLS

- Contact - Dashed where approximately located; dotted where concealed; queried where existence and/or location uncertainty is high
- Approximate location of pegmatite dikes, unit Xfcp
- Fault, unknown offset - Dashed where approximately located; dotted where concealed; queried where existence and/or location uncertainty is high
- Normal fault - Dashed where approximately located; dotted where concealed; queried where existence and/or location uncertainty is high; ball and bar on downthrown hanging wall; arrows on cross section show relative movement
- Lineament
- Headwall of glacial cirque
- Crest of glacial arete
- Crest of asymmetrical glacial moraines; ticks on steep side
- Crest of symmetrical glacial moraines
- Crest of glacial moraines with unknown symmetry
- Landslide scarp - Dashed where approximately located; ticks on down-dropped side

Lacustrine shorelines - Major shorelines of Lake Bonneville; mapped at the top of wave-cut bench; may coincide with geologic contacts

- B — Bonneville shoreline (highstand); dashed where approximately located; dotted where concealed
- t — Transgressive shoreline (present below the Bonneville shoreline and above the Provo shoreline); dashed where approximately located
- P — Provo shoreline; dashed where approximately located; dotted where concealed
- r — Regressive shoreline; dashed because approximately located (present below the Provo shoreline)
- S — Stansbury shoreline; dashed because approximately located
- Paleochannel margins in Qafp; dashed because approximately located; ticks point toward paleochannel
- Extent of abandoned gravel pits
- Water boundary
- A A′ — Cross section line
- Approximate schematic bedding or foliation on cross section

Data from this study

- 12 — Approximate strike and dip of inclined bedding
- 12 — Strike and dip of inclined bedding
- 12 — Strike and dip of metamorphic cleavage
- 12 — Dip and dip direction of fault
- 12 — Dip and dip direction of fault determined by 3-point problem
- 12 — Minor S-fold showing bearing and plunge of fold hinge
- 12 — Minor Z-fold showing bearing and plunge of fold hinge
- 12 — Strike and dip of inclined metamorphic foliation
- 12 — Bearing and plunge of mineral lineation
- Sinkhole
- Spring
- Adit (approximate locations from Gloyn and others, 1995)
- Prospect (approximate locations from Gloyn and others, 1995)

Data from Bryant, 1984, 1988

- 12 — Strike and dip of inclined beds
- 12 — Strike and dip of overturned beds
- Strike and dip of vertical beds
- 12 — Strike and dip of inclined cataclastic foliation and foliation in retrogressively metamorphosed rock
- 12 — Strike and dip of inclined foliation and compositional layering
- 12 — Strike and dip of inclined foliation
- Strike and dip of vertical foliation
- 12 — Bearing and plunge of mineral lineation
- Bearing of mineral lineation with horizontal plunge
- S — Microscopic sillimanite
- S — Megascopic sillimanite
- SM — Microscopic sillimanite and microcline
- SMM — Microscopic sillimanite, microcline, and muscovite

NOTE: A few bedrock attitude and mineral symbols from Bryant (1988) are shown on mapped Quaternary surficial units in which small bedrock outcrops are lumped into the unit. Where this occurs in Qms, Qmso, and Qmso?, the landslides incorporate large intact blocks of bedrock that Bryant (1988) may have considered "in place."

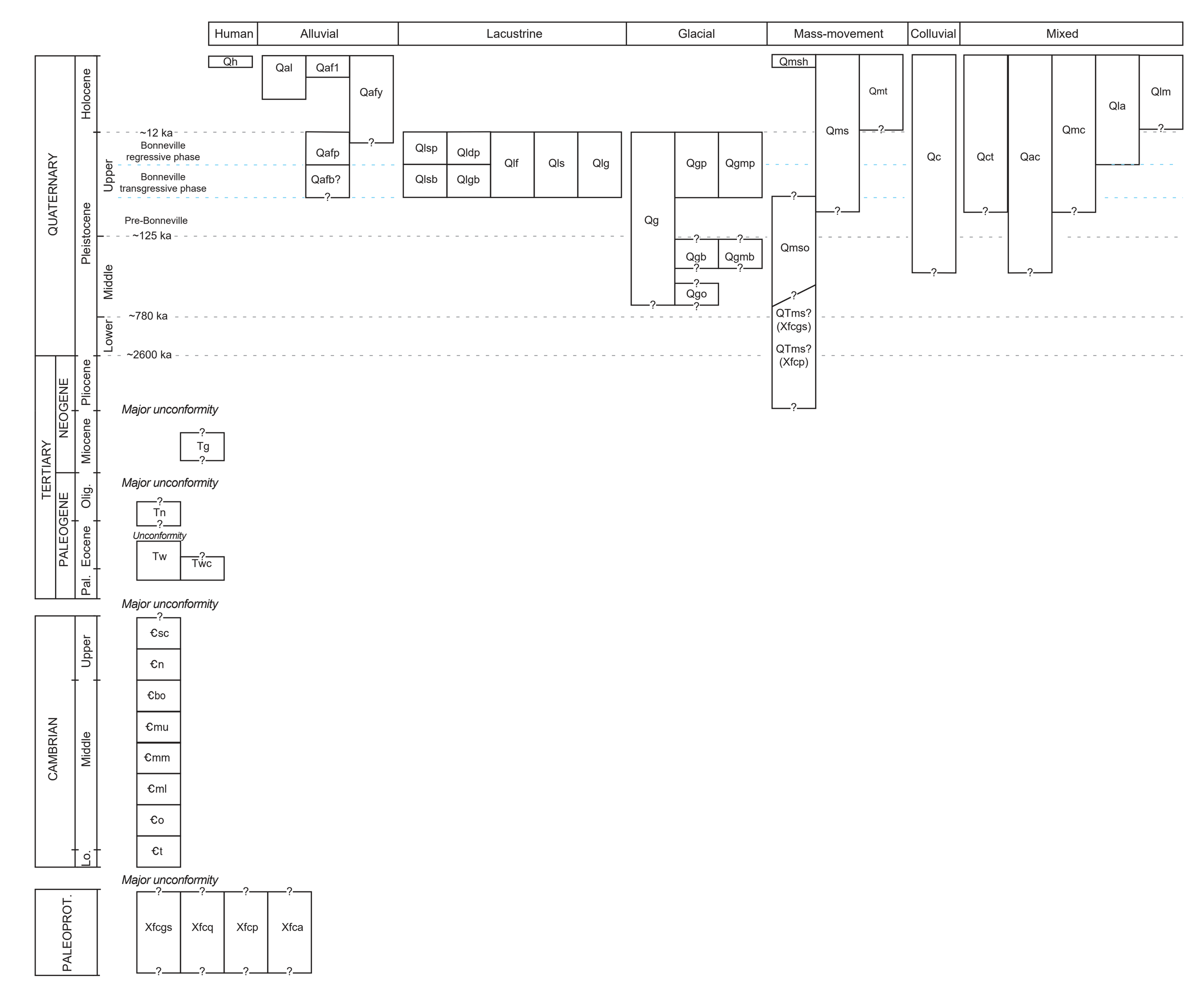
LITHOLOGIC COLUMN

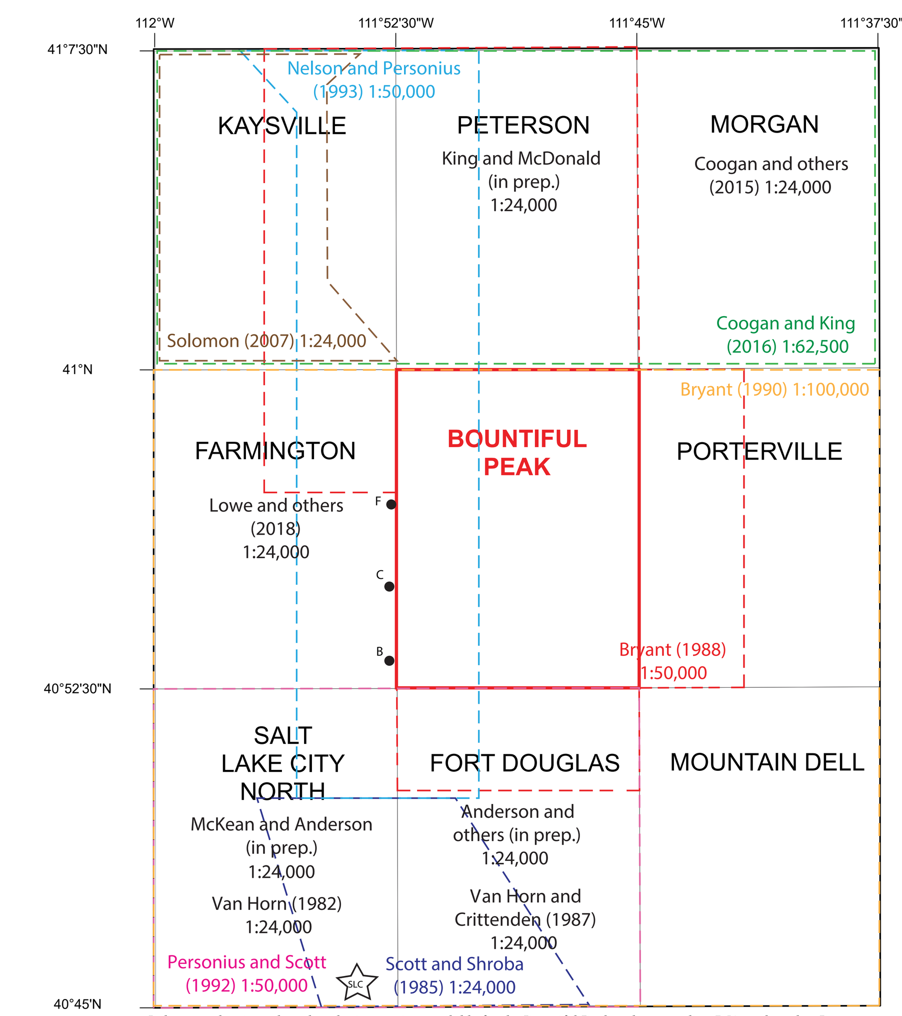
AGE			UNIT SYMBOL	GEOLOGIC UNIT	THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
QUAT.			Q various	Surficial deposits	0–160+	0–50+	
TERTIARY	NEOG.	Pl.	QTms?	Older landslide complexes	1200–2600?	360–790?	Large blocks(?) of Xfcgs and Xfcp Basal slide plane at indeterminant depth MAJOR UNCONFORMITY
TERTIARY	NEOG.	M.	Tg	Tertiary gravel	0–400?	0–120?	MAJOR UNCONFORMITY
TERTIARY	PALEOGENE	O.	Tn	Norwood Formation	250**	75**	Top not exposed in quadrangle Unconformity
TERTIARY	PALEOGENE	Paleoc. - Eoc.	Tw Tw?	Wasatch Formation	500–2300**	150–700**	
TERTIARY	PALEOGENE	Paleoc. - Eoc.	Twc Twc?	Wasatch Formation, conglomerate and sandsone unit	0–1500**	0–450**	MAJOR UNCONFORMITY
CAMBRIAN	Upper		Ꞓsc	St. Charles Formation	440–520**	130–160**	Top not exposed in quadrangle
CAMBRIAN	Upper		Ꞓn	Nounan Formation	550 – 650	160 – 180	
CAMBRIAN	Middle		Ꞓbo	Bloomington Formation	200–350*	60–110*	
CAMBRIAN	Middle	Maxfield Limestone	Ꞓmu	Upper limestone unit	250–280	75–85	
CAMBRIAN	Middle	Maxfield Limestone	Ꞓmm	Middle mixed unit	200–350*	60–110*	
CAMBRIAN	Middle	Maxfield Limestone	Ꞓml	Lower limestone unit	170–230	50–70	
CAMBRIAN	Middle		Ꞓo	Ophir Formation	300–380*	90–115*	
CAMBRIAN	Low.		Ꞓt	Tintic Quartzite	1500–1980?	450–600?	MAJOR UNCONFORMITY
PALEO-PROTEROZOIC			Xfcgs Xfcq Xfcp Xfca	Farmington Canyon Complex	indeterminant		1700± Ma Xfcq=quartzite, gneiss, and schist Xfcgs=gneiss and schist Xfca=amphibolite Xfcp=pegmatite, gneiss, and schist

Diagram is schematic - no fixed thickness scale

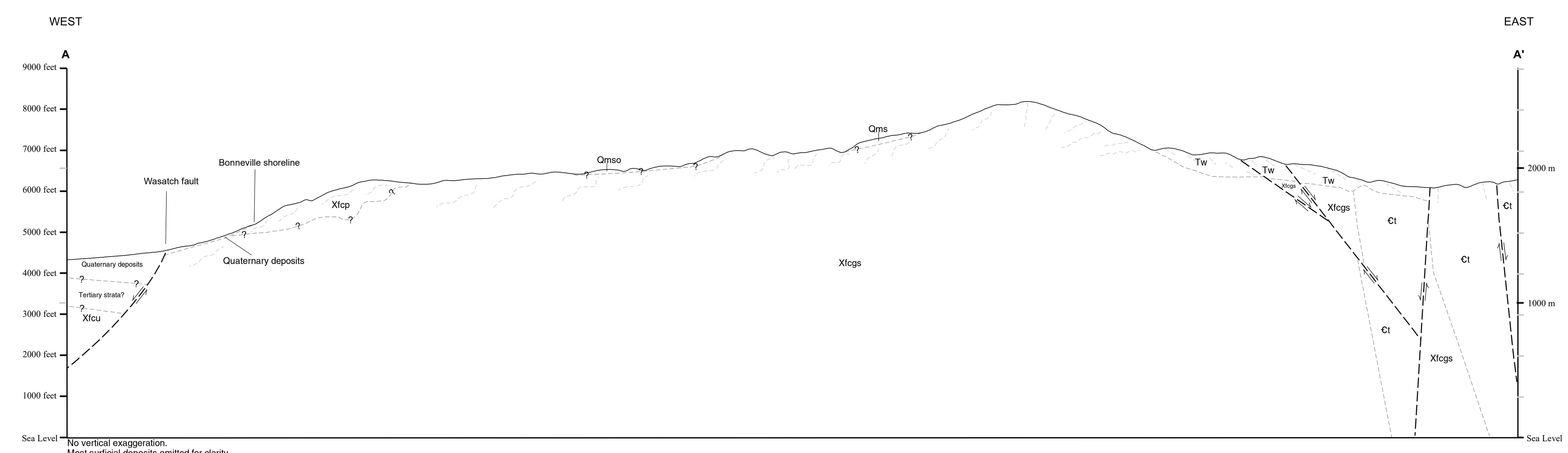
*Apparent thickness, deformed rocks
**Exposed thickness in quadrangle may not be complete. See description of map units for complete thickness in nearby areas.

CORRELATION OF MAP UNITS





Index map showing selected geologic mapping available for the Bountiful Peak and surrounding 7.5' quadrangles. Downtown Salt Lake City is marked by the black-outlined star. Black dots with B, C, and F show the city centers of Bountiful, Centerville, and Farmington, respectively.



No vertical exaggeration.
Most surficial deposits omitted for clarity.

INTERIM GEOLOGIC MAP OF THE BOUNTIFUL PEAK QUADRANGLE, DAVIS AND MORGAN COUNTIES, UTAH

by

Zachary W. Anderson

Suggested citation:

Anderson, Z.W., 2019, Interim geologic map of the Bountiful Peak quadrangle, Davis and Morgan Counties, Utah: Utah Geological Survey Open-File Report 703DM, 19 p., 1 plate, https://doi.org/10.34191/OFR-703DM.

Disclaimer

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number G17AC00226, 2017–18. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

OPEN-FILE REPORT 703DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2019

Blank pages are intentional for printing purposes.

INTRODUCTION

The Bountiful Peak 7.5′ quadrangle is in southern Davis and Morgan Counties (plate 1), just northeast of Salt Lake City, Utah. Parts of the cities of Bountiful, Centerville, and Farmington occupy the western part of the quadrangle in the valley and foothill areas. The central and eastern parts of the quadrangle are dominated by rural, rugged, and steep mountainous terrain of the northern Wasatch Range and Sessions Mountains.

The bedrock geology in the quadrangle includes Paleoproterozoic metamorphic rocks of the Farmington Canyon Complex (see Bryant, 1988), which has a complex history with peak metamorphism reaching amphibolite facies around 1700 Ma (Barnett and others, 1993; Nelson and others 2002, 2011; Yonkee and others, 2014). Most of these rocks have a retrograde metamorphic overprint from deformation during the Cretaceous to early Tertiary Sevier orogeny (Bryant, 1988; Yonkee, 1992; Yonkee and others, 1997; Yonkee and others, 2003; Yonkee and Lowe, 2004; Yonkee and Weil, 2011). The Proterozoic rocks are unconformably overlain by Cambrian sedimentary rocks that belong to the footwall strata of the Willard thrust sheet exposed to the north (Yonkee and Lowe, 2004; King and others, 2008; Coogan and King, 2016). Near the end of the Sevier orogeny, the map area was likely on the east flank of the Wasatch anticlinorium, a structural arch cored by the Ogden floor and roof thrusts (Yonkee and others, 1997; Yonkee and Weil, 2011). The map area is allochthonous to the Ogden floor thrust (Yonkee, 1992; Yonkee and others, 1997), and is likely autochthonous to the Ogden roof thrust, however a surface expression of the roof thrust has not been definitively mapped anywhere south of the Durst Mountain area in the Morgan quadrangle to the northeast (Coogan and others, 2015). In the Morgan quadrangle, Coogan and others (2015) showed the roof thrust in their cross section A-A′ as queried in the footwall block of the Morgan fault zone, a large, west-down normal fault on the east side of Morgan Valley. However, Yonkee (1992) showed the Ogden roof thrust extending above the Bountiful Peak quadrangle. Just east of the quadrangle in Hardscrabble Creek Bryant (1990, cross section C-C′) showed Farmington Canyon Complex rocks thrust over Cambrian strata, which may be a southern extension of the Ogden roof thrust (see also Yonkee, 1992, figures 2 and 10; Yonkee and others, 2003, figure 2).

The Proterozoic and Cambrian rocks are overlain by Tertiary terrestrial, syn- and post-orogenic clastic rocks that record a landscape and tectonic setting that changed from contraction dominated to extensional orogenic collapse (Constenius, 1996) and basin and range extension (Zoback, 1983). North-northeast-striking normal faults cut the Wasatch Formation (upper Paleocene to Eocene) in the eastern range crest in the quadrangle and are likely related to orogenic collapse of the Sevier fold-and-thrust belt (Constenius, 1996) and younger basin and range extension that started about 17 Ma (Parry and Bruhn, 1987). Large amounts of extension and basin formation in the area are indicated by over 6000 feet (1850 m) of Paleocene to Pleistocene sedimentary and volcaniclastic rocks deposited in Morgan Valley to the east (Coogan and others, 2015; cross section A-A′).

Deposits and shorelines of Lake Bonneville, a large late Pleistocene lake (table 1), are prominent within the quadrangle at and below about 5200 feet (1575 m) elevation. Lake Bonneville deposits were approximately time-equivalent to most glacial deposits in the higher elevations of the quadrangle. Older middle Pleistocene glacial deposits are also present in the quadrangle. Young alluvial fans and landslides derived mostly from Farmington Canyon Complex rocks that have been highly weathered and altered to clay minerals are also prominent features of this map.

This map is the first geologic map of the Bountiful Peak quadrangle published at 1:24,000 scale. The bedrock mapping, particularly of the Paleoproterozoic Farmington Canyon Complex, is primarily based on mapping by Bryant (1984, 1988, both 1:50,000 scale) but includes improved locations and identification of a few more pegmatite dikes and areas of pegmatite-rich rock (unit Xfcp). This new map shows the Cambrian Bloomington, Nounan, and St. Charles Formations, which were previously not recognized in this part of the Wasatch Range and were separated out of an overly thick Maxfield Limestone as mapped by Van Horn and Crittenden (1987) and Bryant (1984, 1988, 1990). This mapping also documents a unique cobble- to boulder-gravel deposit (unit Tg) that is present on the crest of the Wasatch Range and is here interpreted as a Miocene deposit, but was previously mapped as part of the Paleocene to Eocene Wasatch Formation (Bryant, 1984, 1988, 1990).

Geologic hazards are prominent features of this quadrangle. The communities of Bountiful, Centerville, and Farmington have experienced debris floods, flows, and landslides since the area was settled in the late 1800s (Woolley, 1946; Wieczorek and others, 1983). Lowe (1989a, 1989b, 1989c, 1990) mapped and described many slope failures and related geologic hazards in the quadrangle. This map improves the identification and delineation of Quaternary surficial deposits, primarily landslides, within the mountainous areas of the quadrangle by using slope and hill-shade images derived from lidar (light detection and ranging) data. Lowe (1989c) documented about 400 individual slope failures within the Davis County part of the map (approximately western 3/4 of map). This report documents over 700 individual mass-movement deposits within the quadrangle.

One of the main goals of this project was to improve the accuracy and precision of the mapping of the Quaternary deposits and the Wasatch fault zone. The urbanized valley part of the quadrangle that contains the Wasatch fault zone was previously mapped by Nelson and Personius (1993). I used their mapping as a guide but reinterpreted some of the Quaternary deposits and locations of strands of the Wasatch fault zone. The Wasatch fault zone is a major segmented normal fault zone that bounds the east side of the Basin and Range Province, and creates the stark topographic rise of the Wasatch Range in its footwall to the east and the relatively flat valley bottoms in its hanging wall to the west (Gilbert, 1928; Cluff and others, 1970; Machette and others, 1992). The western part of the quadrangle contains the southern part of the active Weber segment of the Wasatch fault zone that presents a significant earthquake hazard to the communities along the Wasatch front. Based on measured vertical displacements up to 13.8 feet (4.2 m), the Weber segment of the Wasatch fault is considered capable of producing earthquakes as large as magnitude 7.2 (Swan and others, 1980, 1981; Nelson, 1988; Foreman and others, 1991; McCalpin and others, 1994; DuRoss, 2008; DuRoss and others, 2009; DuRoss and others, 2016, and references therein). Large-magnitude earthquakes produce strong ground shaking, particularly in unconsolidated Lake Bonneville deposits, which can cause lateral spreads (see mapping in the adjacent Farmington quadrangle by Lowe and others, 2018), landslides, liquefaction, and rockfalls, all of which can cause severe damage to infrastructure and loss of property and life.

Mapping of surficial deposits and faults in the valley was primarily done using older black-and-white stereographic photographs from the U.S. Department of Agriculture (USDA) Stabilization and Conservation Service (1958) to limit obscuring human modification. Low-sun-angle, black-and-white oblique aerial photographs from the Woodward-Lundgren & Associates Wasatch fault investigation (Cluff and others, 1970, complied in Bowman and others, 2015) enhance small scarps, and slope-shade images of half-meter lidar data (Utah Automated Geographic Reference Center [UAGRC], 2013–2014) enhance terrain features. Mapping of the Wasatch fault zone from this study is also included in a new map of most segments of the Wasatch fault zone (McDonald and others, 2018).

MAP UNIT DESCRIPTIONS

QUATERNARY – TERTIARY

Human-derived deposits

Qh **Fill and disturbed land** (historical) – Undifferentiated artificial (human) fill and disturbed land related primarily to water storage and debris flood control structures; map outlines of this unit based on 2011 lidar data; only larger areas of disturbed land are mapped; unmapped fill and disturbed lands are present in most developed areas of Centerville and Bountiful and contain continually changing mix of cuts and fills; thickness unknown.

Alluvial Deposits

Qal **Stream alluvium** (Holocene) – Pebble and cobble gravel, locally bouldery, with matrix of sand, silt, and clay; locally stratified, thin to medium bedded with planar and cross-bedding; poorly to moderately sorted; clasts subangular to subrounded; typically clast supported; includes modern stream channel, active floodplain deposits, and minor stream terraces up to 6.5 feet (2 m) above active drainages; locally includes minor colluvial, debris-flow, and alluvial-fan deposits; mapped in valley bottom below the westernmost strand of the Wasatch fault zone where stream gradients decrease and main channels become less confined; estimated thickness less than 15 feet (5 m).

Qaf1 **Youngest alluvial-fan deposits** (upper Holocene) – Poorly to moderately sorted, pebbles to large boulders in matrix of sand, silt, and clay; clasts subangular to well rounded; typically matrix supported; unconsolidated; typically fan-shaped lobes of sediment deposited by debris flows and floods during heavy rain and runoff events; mapped at mouths of Centerville Canyon and Parrish Creek; on USDA (1958) aerial photographs they have a distinct rough texture, local levees and channels, and large boulders indicative of debris-flow deposits; equivalent to younger parts of Qafy some of which are mapped by Nelson and Personius (1993) as debris-flow deposits (their cd1 and cd2); estimated thickness is typically less than 30 feet (10 m).

Out of the 11 major canyons that drain the west side of the Wasatch Range in the quadrangle (from north to south: Mill Creek, Holbrook Canyon, Ward Canyon/Stone Creek, Centerville Canyon, Parrish Creek, Barnard Creek, Ford Canyon/Ricks Creek, Davis Creek, Steed Creek, Rudd Creek, and Farmington Canyon), all but Mill Creek, Centerville Canyon, and Barnard Creek have historical evidence of debris flows and floods that passed the mouths of the canyons and contributed sediment to active alluvial fans (Woolley, 1946; Wieczorek and others, 1983). It is uncertain if Holbrook and Ward Canyons had historical floods as Woolley (1946) reported a flood that left the highway (presumably US Hwy 89) under 2 feet of water and sediment near historic Perry Station in Bountiful, but did not specify which drainage the flood originated from. Although Mill Creek, Centerville Canyon, and Barnard Creek do not have historical evidence of debris floods, the USDA (1958) aerial photographs show evidence of likely pre-historical floods at the mouths of these canyons, and Miller (1980) mapped "Young fan alluvial deposits" (his map unit f) at the mouths of each of these canyons.

Qafy **Younger alluvial-fan deposits** (Holocene to upper? Pleistocene) – Poorly to moderately sorted, pebbles to large boulders in matrix of sand, silt, and clay; clasts subangular to well rounded; typically matrix supported; deposited by debris flows, debris floods, and streams at mouths of smaller drainages, where larger drainages enter valley bottom, and on benches of Bonneville and Provo shorelines; mostly postdate regression of Lake Bonneville from Provo and lower shorelines; includes both ages of younger alluvial-fan deposits (Qaf1 and Qaf2) and mapped where relative ages cannot be determined or separated at map scale; Qaf2 not mapped in this quadrangle due to lack of distinguishable deposits of this age but mapped in neighboring quadrangles of Farmington (Lowe and others, 2018), Fort Douglas (Anderson and others, in preparation), Salt Lake City North (McKean and Anderson, in preparation), and Kaysville (Solomon, 2007); all or parts of the fans are active and may impinge on or deflect active drainages; estimated thickness between 10 and 40 feet (3–12 m) thick, but could be locally thicker.

Qafp, Qafp?

Alluvial-fan deposits related to regressive phase of Bonneville lake cycle (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, locally bouldery, in matrix of sand, silt, and minor clay; typically matrix supported; clasts typically angular but well rounded where derived from Lake Bonneville deposits; poorly bedded but medium to very thick bedded where apparent; deposited by debris flows, debris floods, and streams at mouths of minor and major drainages below Bonneville shoreline; downslope portions may be gradational into regressive Lake Bonneville deltaic deposits, particularly at mouths of Mill Creek, Holbrook, and Ward Canyons; inactive and deeply incised by modern streams at mouths of major drainages; typically more incised and have less of an apparent fan morphology than Qafy where mapped at mouths of small drainages between Bonneville and Provo shorelines; queried south of Holbrook Canyon because age is uncertain (could be Qafy); exposed thickness less than 80 feet (25 m).

Qafb? **Alluvial-fan deposits related to Bonneville shoreline occupation?** (upper? Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel in matrix of sand, silt, and minor clay; clasts mostly subangular; typically matrix supported; deposited by debris flows and debris floods in small drainages on the mountain front above the Bonneville shoreline; toe or depositional surface of fan is graded to the Bonneville shoreline; deeply incised by modern drainages and have a smooth and rounded surface; queried because unit designation as alluvial and its relation to Bonneville shoreline are uncertain; exposed thickness less than 30 feet (10 m).

Lacustrine Deposits

Deposits related to the Provo shoreline and regressive phase of Lake Bonneville – Mapped only below the Provo shoreline at elevations of about 4820 to 4890 feet (1460–1481 m) in the Bountiful Peak quadrangle (table 1). Elevations of the shoreline vary, in part due to offset on the Wasatch fault zone.

Qlsp **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; commonly ripple laminated to very thick bedded with some planar bedding; mostly wavy to sub-horizontal bed sets with minor channel features; commonly interbedded with or laterally gradational into lacustrine gravel and sand (Qlg); exposed thickness less than 60 feet (20 m).

Qldp, Qldp?

Deltaic deposits (upper Pleistocene) – Moderately to well-sorted, pebble and cobble gravel in matrix of sand and silt; locally includes thin beds of silt and sandy silt; clasts subrounded to rounded; deposited as thin to thick planar and foreset beds; locally includes topset beds that may be alluvial; mapped at mouths of Mill Creek, Holbrook, and Ward Canyons as a deltaic complex related to lake regression from Provo shoreline; gradational and likely equivalent to alluvial-fan deposits related to regressive phase of Lake Bonneville (Qafp) mapped immediately upslope and approximately above Provo shoreline elevation of about 4850 feet (1470 m); mapped from aerial photographs and lidar

(USDA, 1958; Cluff and others, 1970, compiled in Bowman and other, 2015); queried where mapped near the Provo shoreline elevation and uncertain if unit is mostly subaqueous (Qldp) or mostly subaerial (Qafp); estimated thickness up to less than 120 feet (35 m).

Deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville – Mapped below the Bonneville shoreline and above the Provo shoreline. The Bonneville shoreline is at elevations from about 5160 to 5235 feet (1564–1586 m) in the Bountiful Peak quadrangle (table 1). Elevations of the shoreline vary, in part due to offset on the Wasatch fault zone.

Qlsb, Qlsb?

Lacustrine sand and silt (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; thin to very thick bedded with mostly wavy to sub-horizontal bed sets; commonly ripple laminated with some planar bedding and minor channel features; commonly interbedded with or laterally gradational into lacustrine gravel and sand (Qlgb); queried in Bountiful between Holbrook and Ward Canyons where unit designation is uncertain (could be Qldp); exposed thickness less than 75 feet (20 m).

Qlgb **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, clast- to matrix-supported, pebble to cobble gravel with boulders in places in matrix of sand and pebbly sand; locally planar and cross-bedded; locally interbedded with thin beds and lenses containing sand, silt, and clay; clasts commonly subrounded to rounded, but some deposits consist of poorly sorted, angular gravel derived from nearby bedrock outcrops; typically overlies bedrock near the foot of Wasatch Range, some small exposures of bedrock and older landslides (QTms?, Qmso) within this unit have been omitted because they are too small to show at map scale; estimated thickness less than 120 feet (36 m).

Locally, large (up to 15 feet [5 m] diameter), subrounded boulders of Farmington Canyon Complex are conspicuous in outcrop and in aerial photography, particularly along the lakeward edges of shorelines. These boulders were likely derived from rockfall and slope failure upslope prior to and during the Lake Bonneville transgression, and were subsequently rounded by wave action.

Lake Bonneville deposits, undivided – Mapped below the Provo shoreline but uncertain if these deposits are related to the transgressive, regressive, or both phases of Lake Bonneville.

Qlf **Lacustrine silt and clay** (upper Pleistocene) – Interbedded deposits of moderately to well-sorted silt and clay; locally may contain areas with sand; typically thin bedded; downslope of and likely laterally equivalent to parts of regressive alluvial (Qafp) and deltaic deposits (Qldp); mapped in southwest corner of quadrangle; estimated thickness 20 feet (6 m).

Qls **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; thin to thick bedded; commonly ripple laminated with some planar bedding and minor channel features; may grade laterally and vertically into Qlg; mapping and unit designation after Nelson and Personious' (1993) "Lacustrine sand, undivided" (lbps); estimated thickness less than 60 feet (20 m).

Qlg, Qlg?

Lacustrine gravel and sand (upper Pleistocene) – Moderately to well-sorted, clast- to matrix-supported, pebble to cobble gravel in a matrix of sand and pebbly sand; locally interbedded with thin beds and lenses containing sand, silt, and clay; clasts commonly subrounded to rounded; may grade laterally and vertically into Qls; mapping and unit designation after Nelson and Personious' (1993) "Lacustrine sand and gravel, undivided" (lbpg); queried where uncertain of unit designation; estimated thickness less than 60 feet (20 m).

Glacial Deposits

Upper to middle(?) Pleistocene glacial features and deposits are present in the upper reaches of most north-, northeast-, and east-facing drainages in the quadrangle that have catchment terrain over approximately 8600 feet (2620 m) in elevation. Erosional glacial features carved into bedrock units include cirque headwalls and arêtes. Glacial deposits are dominantly till of ground, end, recessional, and lateral moraines but may include a minor component of alluvial outwash. End, recessional, and lateral moraines form distinct curvilinear ridges that are either symmetrical or non-symmetrical. Non-symmetrical moraines have a steeper side that faces toward the former glacier. All glacial deposits are prone to slope failure due to their high clay content and locally include mass-movement deposits (Qms and Qmc) that are too small to show separately at map scale.

Three distinct glacial cycles are represented in the quadrangle, each roughly correlative in timing to the wetter and/or colder Marine Oxygen Isotope Stages (MIS) 2, 6, and possibly 8 or 12. The youngest is the Pinedale glaciation, which is roughly correlative in age to MIS 2 (14 to 29 ka; Lisiecki and Raymo, 2005). In the Wasatch Range, maximum ice extent during the Pinedale glaciation occurred about 19-22 ka (Laabs and Munroe, 2016; Quirk and others, 2018) with deglaciation and minor moraine-building pauses lasting through about 13 ka (Laabs and others, 2011; Laabs and Munroe, 2016; Quirk and others, 2018). These ages coincide well with ages of the Pinedale glaciation in the Wind River and Teton Ranges (about 13 to 30 ka; Gosse and others, 1995; Phillips and others, 1997; Pierce and others, 2018 and references therein). The Bull Lake glaciation is roughly correlative in age to MIS 6 (130 to 191 ka; 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 during 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 and others (2018) reported a ^{10}Be exposure age of 132.2 ± 5.9 ka from a striated bedrock surface in Big Cottonwood Canyon (about 20 mi [6 km] to the south of the quadrangle) and interpreted this as a minimum age for the onset of Bull Lake glacial retreat. Sharp and others (2003) and Pierce and others (2018, and references there in) suggest a Bull Lake glacial maxima of about 140 to 160 ka for the Wind River and Teton Ranges. Evidence of a glacial event older than the Bull Lake is present in the quadrangle (map unit Qgo). The older glacial event may be similar in age to MIS 8 (243 to 300 ka; Lisiecki and Raymo, 2005), which is roughly correlative to the start of the Illinoian continental glaciation, or MIS 12 (424 to 478 ka; Lisiecki and Raymo, 2005), which is roughly correlative to the Pokes Point lake cycle of the Bonneville basin (Oviatt and others, 1999).

Qg, Qg?

Glacial deposits, undivided (upper to middle? Pleistocene) – Mostly glacial till with some component of alluvial outwash; till is non-stratified, poorly sorted clay- to boulder-size sediment; alluvial component is better sorted and bedded than till and is similar to map unit Qal but is derived mainly from glacial till; mapped as undivided glacial because deposits lack distinct geomorphic shapes of end, recessional, and lateral moraines; mapped as undivided age because of lack of significant cross-cutting or geomorphic relationship to Pinedale (Qgmp) or Bull Lake (Qgmb) moraines and older glacial deposits (Qgo) (see discussion of ages of glaciation above); queried where uncertain if deposits are of glacial origin; estimated thickness up to 120 feet (35 m).

Qgmp, Qgmp?

Glacial moraines, Pinedale age (upper Pleistocene) – Till of ground, end, recessional, and lateral moraines; till is non-stratified, poorly sorted clay- to boulder-size sediment; mapped moraines have poorly to moderately developed soil and moderate to sharp moraine morphology; inset lateral and recessional moraines mapped within Qgmp suggest episodes of minor glacial advance or pauses during the Pinedale deglaciation, as described by Quirk and others (2018); multiple Pinedale-age moraines present in upper Holbrook Canyon, Right Hand Fork of Shingle Mill Creek, Right Hand Fork of Authors Creek, and the Right Fork of Farmington Creek; queried where interpretation as end, recessional, or lateral moraine is uncertain; see discussion of ages of Pinedale glaciation above; estimated thickness up to 120 feet (36 m).

Just east of Bountiful Peak and at Farmington Lakes are multiple recessional moraines that are mapped here as Qgmp and are interpreted to be recessional moraines of the Pinedale glaciation. These moraines have a distinctly sharper morphology than the larger Qgmp moraines down drainage and laterally upslope and therefore could be related to a younger (Holocene) glacial cycle. However, the soil and vegetation development on these moraines is more similar to other Pinedale moraines downslope and it is likely that these cirques lacked the appropriate elevation and northly aspect to form glaciers during the Holocene.

Qgp **Glacial deposits, undivided, Pinedale age** (upper Pleistocene) – Mostly glacial till with some component of alluvial outwash; till is non-stratified, poorly sorted clay- to boulder-size sediment; alluvial component is better sorted and bedded than till and is similar to map unit Qal but is derived mainly from glacial till; mapped as undivided glacial because deposits lack distinct geomorphic shapes of end, recessional, and lateral moraines; see discussion of ages of Pinedale glaciation above; estimated thickness less than 60 feet (20 m).

Qgmb, Qgmb?

Glacial deposits and moraines, Bull Lake age (middle? Pleistocene) – Till of ground, end, recessional, and lateral moraines; till is non-stratified, poorly sorted clay- to boulder-size sediment; commonly heavily vegetated with well-developed soil; moraine morphology more subdued and disected than Pinedale moraines (Qgmp); lateral moraines commonly directly downslope of mapped bedrock aretes and ridges between higher parts of cirques; mapped down drainage or laterally upslope from Pinedale moraines (Qgmp) and mapped laterally downslope from older glacial deposits (Qgo); mapped in Farmington Flats and upper part of Holbrook Canyon; queried where age designation is uncertain; see discussion of ages of Bull Lake glaciation above; estimated thickness up to 120 feet (36 m).

Qgb, Qgb?

Glacial deposits, undivided, Bull Lake age (middle? Pleistocene) – Mostly glacial till with some component of alluvial deposits; till is non-stratified, poorly sorted clay- to boulder-size sediment; alluvial component is better sorted and bedded than till and is similar to similar to map unit Qal but is derived mainly from glacial till; mapped as undivided glacial because deposits lack distinct geomorphic shapes of end, recessional, and lateral moraines; see discussion of ages of Bull Lake glaciation above; queried where age designation is uncertain; estimated thickness less than 60 feet (20 m).

Qgo **Glacial deposits, older** (middle? Pleistocene) – Compositionally similar to other glacial deposits but laterally above Bull Lake deposits on knobs at north end of Farmington Flats between Farmington Canyon and Right Fork of Farmington Creek; morphology more subdued and rounded than those of Qgmb; the location and high elevation of these deposits suggest either very large glaciers in Farmington Flats during deposition or large amounts of incision of the Right Fork of Farmington Creek between Qgo and Qgmb; see discussion of glacial chronology above for age estimates; estimated thickness up to 120 feet (36 m).

Mass-Movement Deposits

Qmsh, Qms, Qms?(Tw)

Landslide deposits (historical to upper? Pleistocene) – Poorly sorted clay- to boulder-size material with some large (100s of cubic feet) bedrock blocks; includes slides, slumps, and debris-flow and flood deposits; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced blocks; composition depends on local sources but in this quadrangle is primarily Farmington Canyon Complex metamorphic rocks and the Wasatch Formation; Farmington Canyon Complex rocks are prone to sliding because most of their mica and amphibole crystals have been altered to clay by deep weathering; morphology typically becomes more subdued with age but can also be a function of water content during emplacement; estimated thickness up to 120 feet (40 m).

Only two landslides are mapped as Qmsh (h for historical movement). One is in section 16, T. 2 N., R. 1 E. (Salt Lake Base Line and Meridian) along the Ward Canyon/Skyline Drive road. This landslide initiated in 2006 as a smaller mass that slid again in 2011 as a larger landslide (Rich Giraud, UGS, verbal communication, August 2018). The map shows the extent of the 2011 landslide and its prominent main scarp that is within the road switchback. The other landslide mapped as Qmsh is in lower Rudd Creek on the south side of the drainage (section 17, T. 2 N., R. 1 E). The landslide moved in 1983 (Brabb and others, 1989) and again in 2011 (Rich Giraud, UGS verbal communication, March 2019); the scar is still clearly visible on recent aerial imagery. Several other landslides in the quadrangle mapped as Qms have similar fresh morphology and may have moved during the late Holocene, and potentially during historical times, but there is no documentation of historical movement. However, Brabb and others (1989) documented over 120 small debris flows and debris avalanches that occurred in 1983 within the quadrangle. There were also debris flows and floods in 1986 and 1987 within the quadrangle as shown and described by Lowe (1990). All small slope failures, except the landslide in Rudd Creek mentioned above, are too small to show at map scale. Lowe (1989a, 1989b, 1989c, 1990) mapped and described slope-failure hazards for Davis County and labeled several slope failures in Bountiful Peak quadrangle as “active” based on the classification of McCalpin (1984). Most “active” slope failures of Lowe (1989c) are debris slides and debris flows that are incorporated into units Qms, Qmc, or Qac on this map.

Landslides mapped as Qms (likely Holocene to upper Pleistocene) commonly have distinct morphological features such as main scarps, flanks, and toes that are conspicuous on slope-shade images of 2-meter lidar data for the western three-fourths of the quadrangle (UAGRC, 2011). Landslides mapped as Qms may be in contact with other

Qms slides where distinct/different slides abut or are inset into larger landslide complexes. In most places these deposits deflect modern streams. In other places, like along the western range front, these deposits are both younger and older than the Bonneville shoreline occupation, indicating a gradational and overlapping age range with older landslide deposits (Qmso).

Qms?(Tw) is similar in age and origin to Qms but is derived mainly from the Wasatch Formation (Tw) and is queried because the interpretation as landslide is uncertain; units may be in place. This unit is present only in section 30, T. 3 N., R. 2 E.

Landslides of all ages may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003). Vegetation and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as lidar may reveal evidence of creep or shallow landslides. Understanding the location, age, and stability of landslides and slopes requires detailed geotechnical investigations.

Qmso, Qmso?

Landslide deposits, older (upper? to middle? Plesitocene) – Compositionally similar to landslide deposits (Qms); pre-date the Bonneville shoreline occupation; have more subdued morphological elements than Qms; commonly larger than individual Qms landslides and Qms landslide complexes; queried where interpretation as a landslide is uncertain, particularly along ridges of the western mountain front where the slide may consist of large bedrock blocks that were interpreted as "in place" by Bryant (1988, 1990) and hence may have bedrock attitude measurements in them; estimated thickness up to 160 feet (50 m).

Between Ford Canyon (Ricks Creek) and Steed Creek (section 32, T. 3 N., R. 1 E.) is a prominent Qmso complex downslope from a distinct evacuated area of the mountain front. The toe of this landslide complex is covered by Lake Bonneville deposits (see stacked units) and is mostly in the Farmington 7.5′ quadrangle (Lowe and others, 2018) in sections 30 and 31, T. 3 N., R. 1 E. The Bonneville and Provo shorelines do not change elevation as they cross the landslide mass but are deflected from their normal northwesterly trend in an arcuate pattern suggesting the shorelines developed on the toe of the landslide mass and that the landslide pre-dates Lake Bonneville. Mapping by Nelson and Personious (1993) showed the Wasatch fault zone splays into many strands as it passes through landslide masses, as is the case in the toe of this particular landslide mass (see mapping in Farmington 7.5′ quadrangle, Lowe and others, 2018).

QTms?(Xfcgs), QTms?(Xfcp)

Landslide blocks(?) of Farmington Canyon Complex rocks (middle? Pleistocene to Pliocene?) – Large, intact blocks of Farmington Canyon Complex rocks that have subtle and commonly absent main scarps, flanks, toes, and slide planes; identified primarily from probable main scarps at the top of large areas or "blocks" of land that are generally lower than the surrounding topography; the slide plane is likely at or near the bottom of the modern drainages and likely continues west an unknown distance into the valley; field and structural evidence of these massive landslides has not yet been extensively examined; mapped near the mouth of Farmington Canyon (sections 16 and 17, T. 3 N., R 1 E.) and between Ward Canyon (Stone Creek) and Centerville Canyon (sections 14, 15, and 16, T. 2 N., R 1 E.); queried because interpretation as landslide or other mass movement is uncertain; estimated dimensions (length by width by thickness) are approximately 2 by 2.5 by 0.4 miles (3.2 by 4 by 0.8 km).

Qmt **Talus deposits** (Holocene) – Unsorted, angular to rounded cobbles to boulders with minor sand and silt; unconsolidated; clast supported; deposited on and at base of steep, unvegetated slopes at the head of Right Fork of Shingle Mill Creek; derived from and primarily consists of clasts of Wasatch Formation, conglomerate and sandstone unit (Twc); estimated thickness up to 30 feet (10 m).

Colluvial Deposits

Qc **Colluvial deposits** (Holocene to middle Pleistocene?) – Pebble, cobble, and boulder gravel, commonly clast supported, in a matrix of sand, silt, and clay; clasts commonly angular to subangular, but includes some subrounded to rounded recycled lacustrine gravel below the Bonneville shoreline; unlithified; very poorly sorted, poorly stratified, locally derived; consists of residium, slopewash, and soil creep deposits; may include landslides, rockfalls, and debris flows that are too small to map separately; mapped as small cones and debris aprons near the bottom of very small drainages and on hillsides; similar to Qac but mapped where drainage is poorly developed or very small; similar to Qct but typically mapped on less steep slopes and where soil and vegetation are more developed; most bedrock is covered by at least a thin veneer of colluvium, but only the larger, thicker (> 3 feet [1 m]) deposits are mapped; estimated thickness up to 30 feet (10 m).

Mixed-environment Deposits

Qct **Colluvial and talus deposits, undivided** (Holocene to upper Pleistocene?) – Unsorted, unstratified, angular to subangular pebbles, cobbles, and boulders with variable component of sand, silt, and clay; unlithified; locally derived; deposited on moderate to steep, partially vegetated slopes by slopewash, rockfall, and minor soil creep; commonly deposited on Bonneville shoreline bench and conceals the shoreline; also mapped in steeper parts of glacial cirques near Bountiful Peak, in upper parts of Holbrook Creek (derived from Tintic Quartzite [Ꞓt]), and in Deep Creek near Mahogany Ridge; estimated thickness up to 30 feet (10 m).

Qac **Alluvial and colluvial deposits, undivided** (Holocene to middle Pleistocene?) – Poorly to moderately sorted, angular to rounded, poorly to well stratified, clay- to boulder-size sediment; aggraded deposits in bottoms of drainages and on adjacent slopes; deposited by slopewash, soil creep, floods, and minor perennial fluvial processes; includes debris-flows, talus, stream deposits, alluvial-terrace deposits, earth-flow deposits, small fans, and minor landslides that are too small to map separately; incised 0 to 12 feet (0–4 m) by modern drainages; estimated thickness up to 60 feet (20 m).

Qmc **Mass-movement and colluvial deposits, undivided** (Holocene to upper Pleistocene?) – Poorly sorted to unsorted clay- to boulder-size material; mixed landslide, slump, slopewash, and soil creep that are gradational into one another; typically have a hummocky appearance on the slope-shade images derived from lidar but lack clear landslide scarps and flanks; thickness 0 to 30 feet (0–10 m).

Qla **Lacustrine and alluvial deposits, undivided** (Holocene to upper Pleistocene) – Sand, silt, and clay with minor pebble and cobble gravel in areas of mixed alluvial and lacustrine deposits that cannot be shown separately at map scale because deposits are gradational into each other or thin patches of one unit overlie the other (most commonly alluvial deposits overlying lacustrine deposits); mapped below Provo shoreline in the flatter parts of the valley near section 20, T. 2 N., R. 1 E.; estimated thickness up to 40 feet (12 m).

Qlm **Lacustrine and marsh deposits, undivided** (Holocene) – Organic-rich silt and clay with minor sand and pebbles; likely some boulders derived from rockfall and Qc upslope; deposited in lakes, ponds, marshes, and other wetlands in and around Farmington Lakes; commonly wet, but partially seasonally dry; estimated thickness less than 30 feet (10 m).

Stacked Units

The term “stacked” means a thin covering of one unit over the other, which is shown by the upper map unit (listed first) then a slash and then the underlying unit second. In this map, these stacked units are mapped where alluvial-fan and Lake Bonneville deposits have been deposited on older landslide deposits (Qmso) but are only mapped where the morphological characteristics of the landslide are apparent beneath the thin sedimentary cover. See map units above for thickness and description of each component of the stacked units.

Qafp/Qmso

Alluvial-fan deposits of regressive phase of Bonneville lake cycle over older landslide deposits (upper Pleistocene/upper to middle? Pleistocene)

Qlsp/Qmso

Lacustrine sand and silt of regressive phase of Bonneville lake cycle over older landslide deposits (upper Pleistocene/upper to middle? Pleistocene)

Qlgb/Qmso

Lacustrine gravel and sand of transgressive phase of Bonneville lake cycle over older landslide deposits (upper Pleistocene/upper to middle? Pleistocene)

Qlsb/Qmso?

Lacustrine sand and silt of transgressive phase of Bonneville lake cycle over older landslide deposits (upper Pleistocene/upper to middle? Pleistocene) – Queried because it is uncertain if Qmso is beneath Qlsb.

Qls/Qmso

Lacustrine sand and silt of Lake Bonneville over older landslide deposits (upper Pleistocene/upper to middle? Pleistocene)

Major unconformity

TERTIARY

Neogene

Tg **Tertiary gravel** (Miocene?) – Unconsolidated, poorly to moderately sorted cobbles to boulders with minor component of pinkish sand, silt, and clay; cobbles and boulders are subangular to rounded, range in size from small cobbles to boulders up to 9 feet (3 m) (along their long axis); dominantly quartzite clasts with minor amounts of Farmington Canyon Complex metamorphic rocks, black chert, and moderately indurated sandstone; forms conspicuous, large, relatively flat, stepped surfaces on crest of Wasatch Range in sections 18 and 19, T. 2 N., R. 2 E. that dip gently north-northeast; aside from stepped surfaces there is no evidence of any planar fabric; escarpments between the stepped surfaces are 30 to 45 feet (10–15 m) high and separate minor variations in heterogeneity of clast lithology, possibly suggesting each step is a different depositional pulse; unconformably overlies Farmington Canyon Complex rocks, Tintic Quartzite, and Wasatch Formation, and is covered by end moraines of Pinedale age in upper Holbrook Canyon; mapped by Bryant (1990) as "Wasatch Formation, conglomerate dominant" (his Twc) in both faulted and depositional juxtaposition with older rocks; includes small landslides and colluvial deposits too small to show at map scale; estimated approximately 160 feet (50 m) thick, but possibly up to 400 feet (120 m).

Clast lithology and size create a conundrum about the age and origin of these deposits. Some quartzite clasts are white, light cream, or tan with minor reddish streaks, some of which have thin conglomerate beds of rounded white chert pebbles. These quartzite clasts look similar to the locally exposed Tintic Quartzite. Other quartzite clasts are multi-color white, pink, red, brown, purple, and greenish black and have too much color variation to be derived from the locally exposed Tintic Quartzite; they are more likely from the Geertsen Canyon Quartzite, Mutual Formation, Caddy Canyon Quartzite, and other Neoproterozoic quartzites of the Willard thrust sheet (Adolph Yonkee, Weber State University, and Jon K. King, UGS, verbal communications, August 2017). Some of these foreign clasts are among the largest in the deposits (up to 9 feet [3 m] long) suggesting a proximal source or reworking of a proximally sourced deposit. The nearest exposure of the Willard thrust sheet is currently ~20 miles (32 km) to the north. The most reasonable timing to erode and transport large clasts from the Willard thrust sheet is pre-Eocene when the Wasatch anticlinorium was at its peak structural height and now-eroded rocks of the Willard thrust sheet were likely much closer to the location of the Tg deposit (see Yonkee and Weil, 2011, and Coogan and King, 2016, for further discussion of Wasatch anticlinorium and rocks of the Willard thrust sheet). These spatiotemporal relationships are likely why Bryant (1984, 1988, 1990) interpreted and mapped these deposits as conglomerate of the Wasatch Formation. However, map relationships around a small knob at 435020 E., 4528365 N. (UTM NAD 83) (section 18, T. 2 N., R. 2 E.) suggest Tg unconformably overlies dipping and lithified Wasatch Formation conglomerate and sandstone (Twc), indicating Tg is younger than Twc. In addition, rare clasts of moderately indurated, immature, brown sandstone, here interpreted as sourced from the Wasatch Formation, are present within Tg suggesting Tg is younger than the Wasatch Formation.

Major unconformity

Paleogene

Tn **Norwood Formation** (lower Oligocene? to Eocene) – Only one minor exposure is present in the northeast corner of the quadrangle. The exposure is on private land that the author could not access, hence this description is modified from Coogan and others' (2015) unit description from the adjacent Morgan 7.5′ quadrangle map, Bryant's (1990) Salt Lake City 30′ x 60′ quadrangle map, Coogan and King's (2016) Ogden 30′ x 60′ quadrangle map, and observations in the adjacent Porterville and Peterson quadrangles: typically light-gray to light-brown, altered tuff, claystone, siltstone, sandstone, conglomerate, and minor limestone; may have beds of unaltered tuff and volcanic-clast conglomerate similar to adjacent Porterville quadrangle; variable calcareous cement and zeolitization that is less common to south, such that more unaltered tuff is present in the Porterville quadrangle; typically weathers into low-relief hills; unconformable lower contact with Tw; corrected K-Ar isotopic ages are 38.4 Ma (sanidine) from a sample taken along Utah Highway 66 near the Norwood type area (Evernden and others, 1964) to the east in the northern part of the Porterville quadrangle, and 39.3 Ma (biotite) from farther south in a different depositional basin, the East Canyon graben, East Canyon Reservoir quadrangle (Mann, 1974); Bryant (1990) reported a thickness of approximately 3300 feet (1000 m) in the southern end of Morgan Valley near Porterville, which is likely representative of the thickness only in the east limb of the Morgan Valley syncline (Coogan and others, 2015); approximate exposed thickness in the quadrangle is 250 feet (75 m).

Tw, Tw?

Wasatch Formation (Eocene to upper Paleocene) – Light-red, moderate reddish-orange to pale-brown, moderately to well-indurated sandstone, conglomerate, and minor siltstone; sandstone beds are thin to very thick bedded with planar laminations to structureless, poorly to well-sorted, fine- to coarse-grained; they are composed of rounded quartz and black chert grains, angular grains of gray limestone, and variably colored lithic fragments; conglomerate beds are up to 1 foot-thick (30 cm) beds of pebbles to cobbles of subangular to rounded quartzite, limestone, sandstone, and minor metamorphic rocks; forms subdued slopes and ridges that are commonly heavily vegetated; unconformable lower contact with all map units except Twc, which is gradational; locally includes landslides, slumps, and colluvium that are too small to show separately at map scale; queried where not visited in the field and interpretation as Tw from stereo photographs is uncertain.

Palynomorph data from Wasatch strata to the northeast in the Ogden 30′ x 60′ quadrangle (Coogan and King, 2016), and to the east in the Salt Lake City 30′ x 60′ quadrangle (Nichols and Bryant, 1990), yielded late Paleocene to Eocene ages. McKean and others (2016) reported a detrital zircon age of 48.47 ± 0.76 Ma (middle Eocene) from the upper part of a package of conglomeratic rocks exposed on the Salt Lake salient that are tentatively correlated to the Wasatch Formation (Anderson and McKean, 2018).

Thickness of the upper main part of the Wasatch Formation in the quadrangle is difficult to determine because it was deposited across hilly topography that developed prior to deposition, and because the base is commonly faulted in the map area. Thickness of the upper main part of the Wasatch Formation is estimated to vary from 500 to 2300 feet (150–700 m) in the quadrangle. Bryant (1988) reported 1320 feet (400 m) north of the map area, and 3960 feet (1200 m) to the south (including Twc). King and McDonald (in preparation) reported 1600 to 2700 feet (490–830 m) in the adjacent Peterson quadrangle.

Twc, Twc?

Wasatch Formation, conglomerate and sandstone unit (Eocene? to upper Paleocene) – Moderate reddish-orange, pale-brown, light-gray to grayish red-purple conglomerate, sandstone, calcareous sandstone, and minor siltstone; conglomerate beds are up to 9 feet (3 m) thick, clast- to matrix-supported, with subangular to rounded pebbles to cobbles and some large (6 feet [2 m]) boulders; conglomerate clasts are dominantly quartzite, well-indurated gray sandstone, limestone, minor chert, and locally metamorphic and intrusive rocks of the Farmington Canyon Complex; conglomerate matrix is reddish brown, moderately sorted, medium sand with some silt and clay; conglomerate beds commonly have scoured bases, channel shaped geometries, and fine upward into pebble conglomerate and sandstone; sandstone beds are up to 3 feet (1 m) thick, are mostly structureless with some planar bedding, and contain moderately sorted, fine- to coarse-grained, rounded to angular sand; sandstone beds are typically laterally discontinuous, moderately to well-indurated, and form rubbly slopes with some ledges in steeper terrain; upper contact with Tw is gradational and its location in T. 2 N., R. 2 E. is modified from Bryant (1990); lower contact is unconformable; age range is uncertain but is likely equivalent to the lower parts of Tw (see discussion of ages above); map pattern in T. 2 N., R. 2 E. suggest a maximum thickness of about 1500 feet (450 m).

Identification of boulder deposits at the south end of Farmington Flats (section 25, T. 3 N., R. 1 E.) is less certain and is hence mapped as Twc? There the unit is unconsolidated, unlithified cobble to boulder deposits that look very similar to Tg with dominantly brown, white, or reddish-purple quartzite clasts. These deposits also contain rare reddish, well-indurated, well-sorted sandstone with medium-size, rounded grains interpreted as clasts of Jurassic Nugget Sandstone, which is problematic as the nearest outcrops of this unit are currently 10 miles (16 km) to the south in Fort Douglas quadrangle. However, compared to Tg these deposits have more abundant subrounded, large boulders of hornblende gneiss and pegmatite that are likely locally derived from the Farmington Canyon Complex. I interpret these deposits as a basal cobble-boulder deposit of the Wasatch Formation rather than a younger deposit like Tg primarily due to the presence of the large boulders of Farmington Canyon Complex clasts. However, this interpretation is tenuous. Thickness of Twc? is up to about 40 feet (12 m).

Major unconformity

MISSISSIPPIAN AND DEVONIAN – Mississippian Gardison and Deseret Limestones and Devonian Stansbury and Fitchville Formations are not exposed in the quadrangle but are likely present beneath the Wasatch Formation (Tw, Twc) in the southeast part of the quadrangle. These units are exposed immediately to the south in the Fort Douglas 7.5′ quadrangle (Van Horn and Crittenden, 1987; Anderson and others, in preparation). Ordovician and Silurian strata are missing at a major regional unconformity below Devonian rocks (Hintze, 1959; Rigby, 1959).

Major unconformity

CAMBRIAN

Ꞓsc **St. Charles Formation** (Upper Cambrian) – Gray- to light-gray dolomite and sandy dolomite that weathers light gray to white; medium- to thick-bedded with some wavy laminations and mottled shale partings; lower contact is gradational; gradational interval in included in this unit and consists of a thick-bedded, vuggy, gray dolomite overlain by a light gray to white horizon of sandy dolomite that may be equivalent to parts of the Worm Creek Quartzite (not mapped in this area); forms steep blocky slopes and cliffs; not mapped by Byrant (1988) as a separate unit and was likely included in his Maxfield Formation (his Ꞓm); likely included in the upper part of Van Horn and Crittenden's (1987) "dolomitic unit" of the Maxfield Limestone (their Ꞓmd); Lochman-Balk's (1976) figure 2 shows a dolomitic unit at the top of a Parleys Canyon stratigraphic column as Upper Cambrian, which may be equivalent to the newly mapped Nounan and St. Charles Formations of this report; Taylor and others (1981) reported an earliest Ordovician and Late Cambrian age in the Bear River Range based on trilobite and conodont fossils, but here the upper part may be eroded due to the Ordovician Tooele Arch and/or the Devonian Stansbury uplift (see Hintze, 1959; Rigby, 1959); upper portion and contact with the Devonian Stansbury Formation are not exposed in the quadrangle but are exposed about ¾ of a mile to the south in the neighboring Fort Douglas 7.5′ quadrangle (Van Horn and Crittenden, 1987; Anderson and others, in preparation) where map patterns suggest a total thickness of 440 to 520 feet (130–160 m).

Ꞓn **Nounan Formation** (Upper Cambrian) – Very light gray to yellowish-gray limestone and dolomite with some silty shale partings, "twiggy structures," and "flat-pebble conglomerates" (as described in Lochman-Balk [1976]); thin to medium wavy bedding that becomes thick bedded up section; forms subdued blocky outcrops; lower contact is gradational and interfingers with shale and limey shale of upper Bloomington Formation; not mapped by Byrant (1988) as a separate unit and was likely included in his Maxfield Formation (his Ꞓm); likely included in the lower part of Van Horn and Crittenden's (1987) "dolomitic unit" of the Maxfield Limestone (their Ꞓmd); Oviatt (1986) reported the upper Nounan is Dresbachian (Upper Cambrian) based on *Dunderbergia*(?) and *Crepicephalus* zone trilobite fauna; map pattern suggests a thickness of about 550 to 590 feet (160–180 m).

Ꞓbo **Bloomington Formation** (Middle Cambrian) – Light-gray to light-brown, moderate yellowish-brown, light olive-brown to light-olive calcareous shale, shaley limestone and limestone; limestone is mottled with shale partings, is thin bedded, commonly micritic, with some oolites, "twiggy" structures, and "flat pebble conglomerates" (as described in Lochman-Balk [1976]); tri-part stratigraphy of an upper shale-rich interval, medial limestone-rich interval, and a lower shale-rich interval; differs from the tri-part stratigraphy of the older Ophir Formation in that the shale intervals have more limestone component, and the limestone intervals have more shale; mostly forms slopes with the medial limestone-rich interval forming ledgey slopes and the shale-rich intervals forming swales on ridges; lower contact with the Maxfield Formation is gradational; in the Wellsville Mountains (allochthonous strata in the Willard thrust sheet), the Bloomington Formation is Middle Cambrian (*Bolaspidella* zone; Oviatt, 1986; Jensen and King, 1996); in Ogden Canyon (autochthonous strata in the footwall of the Willard thrust), Rigo (1968) reported *Eldoradia* sp. trilobite fossils from the Bloomington Formation, suggesting the Bloomington Formation of the Wellsville Mountains may be equivalent to parts of what is mapped as Maxfield Limestone in Ogden Canyon and this quadrangle; Yonkee and Lowe (2004) reported a thickness of 100 to 200 feet (30–60 m) in the Ogden 7.5′ quadrangle to the north; in this quadrangle, map pattern suggests a thickness of about 200 feet (60 m), but is likely structurally thickened to as much as 350 feet (110 m) by unmapped small faults and folds.

The tri-part stratigraphy described here and the stratigraphic location of the unit match that of the Bloomington described and mapped in Ogden Canyon (King and others, 2008), however, this unit has previously not been mapped in this part of the Wasatch Range (see Bryant, 1988, 1990) (see discussion below in Ꞓmu description). The Bloomington Formation in the map area is likely the upper part of what Van Horn and Crittenden (1987) mapped as a “lower limestone unit” of the Maxfield Limestone (their Ꞓml).

Maxfield Limestone

Bryant (1988, 1990) mapped all Cambrian limestones and shales above the Ophir Formation (Ꞓn, Ꞓb, Ꞓmu, Ꞓmm, Ꞓml of this report) as Maxfield Limestone (his Ꞓm); Van Horn and Crittenden (1987) mapped a “lower limestone and shale” unit of the Maxfield Limestone (their Ꞓml) that is likely equivalent to this report’s Bloomington Formation (Ꞓb) and all units of the Maxfield Formation (Ꞓmu, Ꞓmm, Ꞓml). In this report the Maxfield Limestone is separated into three informal units after Yonkee and Lowe (2004).

Ꞓmu **Maxfield Limestone, upper limestone unit** (Middle Cambrian) – Dark-gray to gray mottled limestone and dolomite with moderate orange-pink, light-red, grayish yellow-green shale partings and interbeds; well bedded, thick bedded to wavy laminated; abundant “twiggy” structures (as described in Lochman-Balk [1976]) that are more apparent on weathered surfaces; limestone and dolomite are mostly micritic with some oolitic beds and rare “flat pebble conglomerate” (as described in Lochman-Balk [1976] and Yonkee and Lowe [2004]); shale content increases up section; forms a resistant ridge between Ꞓmm and Ꞓb; lower contact is gradational but abrupt over about 6 feet (2 m); Robison (1976, figure 2) showed a Middle Cambrian age for limestone strata overlying the Ophir Formation in the Wasatch Range, however this may be based on correlation rather than paleontological samples; Yonkee and Lowe (2004) reported a thickness of 330 to 500 feet (100–150 m) in the Ogden 7.5′ quadrangle; in this quadrangle map pattern suggests a thickness of about 250 to 280 feet (75–85 m).

Ꞓmm **Maxfield Limestone, middle mixed unit** (Middle Cambrian) – Mostly gray to black argillaceous shale and limey shale and shaley limestone that weather light-gray to pale yellowish-orange; well bedded; thick bedded and structureless to ripple laminated; limestone content increases up section; nodular limestone is present near the top of the unit and is extremely mottled with shale; forms a dark recessive swale; lower contact is gradational but abrupt over about 3 feet (1 m); Robison (1976, figure 2) showed a Middle Cambrian age for limestone strata overlying the Ophir Formation in the Wasatch Range, however this may be based on correlation rather than paleontological samples; Yonkee and Lowe (2004) reported a thickness of 130 to 260 feet (40–80 m) in the Ogden 7.5′ quadrangle to the north; in this quadrangle map pattern suggests a thickness of about 200 to 350 feet (60–110 m) but it is likely structurally thickened and thinned.

Ꞓml **Maxfield Limestone, lower limestone unit** (Middle Cambrian) – Medium light-gray, dark-gray, to very pale blue, mostly microcrystalline limestone with oolitic beds and boundstones; well-bedded, very thin to medium-bedded sets that are commonly wavy; limestones are commonly mottled with pale to dark yellowish-orange siltstone and shale partings with no apparent orientation; forms distinctive resistant blue-gray ridge; lower contact is gradational over about 3 feet (1 m) and is placed above the last shale of the Ophir Formation; in strata of Ogden Canyon, Rigo (1968) reported *Bathyuriscus* sp., *Elrathia* sp., *Peronopsis* sp., and *Ptychagonstus* sp. trilobite fossils in the middle limestone of the Ophir, but the fossils are actually in the basal limestone of the Maxfield Formation (Yonkee and Lowe, 2004); *Elrathia* sp. indicates a Middle Cambrian age; Yonkee and Lowe (2004) reported a thickness of 130 to 260 feet (40–80 m) in the Ogden 7.5′ quadrangle; in this quadrangle map pattern suggests a thickness of about 160 to 200 feet (48–60 m).

Ꞓo **Ophir Formation** (Middle Cambrian) – Grayish-green to grayish yellow-green, grayish orange, light- to dark-gray, sometimes with a metallic (phyllitic-micaceous) sheen, thinly laminated to medium-bedded shale and argillite with a medial mottled shaley limestone and minor sandy limestone; where exposed, shale is commonly fissile or has thin, wavy laminations and is micaceous; limestone beds are mottled with pale yellowish-orange shale partings; commonly deformed so thickness is variable; commonly poorly exposed and forms recessive, commonly heavily vegetated swales; lower contact is gradational and is mapped just above the last sandstone of the Tintic Quartzite; Rigo (1968) reported an early Middle Cambrian age for the lower part of the Ophir in Ogden Canyon based on *Ehmaniella* sp., *Alokistocare* sp., and *Zachanthoides* sp. trilobites; Bryant (1988) reported a thickness of 495 to 660 feet (150–200 m); in this quadrangle, map pattern suggests a thickness of 300 to 380 feet (90–115 m).

The Ophir Formation commonly exhibits a tri-part stratigraphy: an upper shale unit, a medial micritic and mottled shaley limestone unit, and a lower argillaceous shale unit. These units are not distinguishable in the Bountiful Peak quadrangle but are discernable and mappable to the south in the adjacent Fort Douglas quadrangle (Anderson and others, in preparation) as well as in the Ogden 7.5′ quadrangle to the north (Yonkee and Lowe, 2004).

Ꞓt **Tintic Quartzite** (Middle and Lower? Cambrian) – Mostly white, yellowish- to pinkish gray, very pale orange, grayish orange-pink, grayish-pink, with moderate red to very dark red, and grayish red-purple, well-indurated orthoquartzitic sandstone and conglomerate with minor argillaceous siltstone and shale; well bedded with thin laminations in shale and siltstone and very thin to thick bedding in sandstone and conglomerate; conglomerate beds vary from matrix to clast supported with quartz sandstone matrix and clasts of well-rounded pebbles and cobbles of white, grayish red-purple and very dark red chert and quartzite; sandstones are fine to very coarse grained, quartz arenite with planar beds and trough and planar-tabular cross-beds; pale-purple to dark-gray argillaceous siltstone and shale beds are common toward the base and top of the unit that are typically thinly bedded, ripple-laminated, and contain minor muscovite; forms light-colored, blocky, resistant ridges and prominent outcrops; basal contact with Farmington Canyon Complex rocks is sharp, unconformable, and locally has up to 20 feet (6 m) of relief; trace fossils in the upper part of the formation in the Ogden Canyon area include *Skolithus* tubes and *Plagiogmus* traces that indicate Middle Cambrian age (Peterson and Clark, 1974); Robison (1976) reported an Early and/or Middle Cambrian age for the Tintic Quartzite in the Wasatch Range, however, as noted in Lochman-Balk (1976), Robison (1976) did not present any fossils to support these ages; Bryant (1988) reported a thickness of 1980 feet (600 m) at the south end of the map area; map pattern suggests a thickness of about 1500 feet (450 m) near the south end of the quadrangle where it is not cut by mappable faults.

Major unconformity

PROTEROZOIC

Farmington Canyon Complex rocks are separated into four informal units after Bryant (1988). The units are listed in order of abundance in the map area. Contacts between all units are gradational, hard to distinguish in the field, and mostly follow the mapping from Bryant (1988). Metamorphic grade generally increases to the north in the map area, as described and mapped by Bryant (1988), Yonkee and Lowe (2004), and Coogan and King (2016). Most rocks show some degree of retrograde chloritic alteration and some have pervasive phyllonitization and are mapped separately as KXc by King and others (2008) and King and McDonald (in preparation), and as “areas of sheared and retrogressively metamorphosed rock” by Bryant (1988). This alteration is likely a result of strain during retrograde metamorphism in the Cretaceous when these rocks were deformed (Bryant, 1988; Yonkee, 1992; Yonkee and others, 1997, 2003; Yonkee and Lowe, 2004; Yonkee and Weil, 2011). In the Bountiful Peak quadrangle, contacts of these retrograde shear zones are diffuse, and I did not recognize them as mappable features. Gloyn and others (1995) reported minor precious metal mineralization in quartz veins, minor faults, and shear zones. Peak metamorphism occurred about 1700 Ma (Barnett and others, 1993; Nelson and others, 2002, 2011). Zircon ages indicate protoliths of the Farmington Canyon Complex rocks are possibly Archean or the zircons are from Archean sources (Wyoming Province) (Hedge and others, 1983; Bryant, 1988; Yonkee and others, 2014). The thickness of the Farmington Canyon Complex and most sub-units is unknown due to lack of structurally deeper exposures anywhere in the Wasatch Range or in drill hole data, and because of the shape and nature of the contacts between the sub-units. The thickness of the pegmatite unit (Xfcp) can be estimated from map patterns because it is primarily composed of layered dikes (see unit description below). All units likely contain landslides that are too small to show at map scale.

Xfcgs **Farmington Canyon Complex, gneiss and schist** (Paleoproterozoic) – Grayish yellow to moderate-brown, dusky- to pale-green, light olive-gray to greenish gray, and dark-gray biotite-feldspar-quartz gneiss, muscovite- and biotite-schist, sillimanite-garnet-biotite schist, pegmatite, and minor quartzite and amphibolite; mylonite, garnet, and sillimanite are more common in the northern part of the quadrangle, consistent with the pattern of metamorphic grade increasing to the north, as described by Bryant (1988); forms both cliffs and slopes; internal contacts are sharp to diffuse and are commonly concordant with foliation and cleavage; mylonitic zones are present but contacts are diffuse and very difficult to map.

Xfcq **Farmington Canyon Complex, quartzite, gneiss, and schist** (Paleoproterozoic) – Light-brown, very pale orange, medium-gray to grayish yellow, fine- to medium-grained quartzite with interlayered gneiss and schist; similar to Xfcgs but with more abundant quartzite and less sillimanite and garnet-bearing schist and gneiss; forms cliffs and slopes; contacts with Xfcgs are gradational; mapped contacts are from Bryant (1988).

Xfcp **Farmington Canyon Complex, pegmatite, gneiss, and schist** (Paleoproterozoic) – Generally white, yellowish gray, pale yellowish orange, and light-pink, coarse-grained mica-feldspar-quartz pegmatite with minor schist, gneiss, and quartzite; feldspars are plagioclase and microcline with individual crystals up to 5 inches (13 cm); veins and books of biotite and muscovite; contacts with surrounding metamorphic rocks are mostly sharp where dikes cut across foliation but can be diffuse where pegmatite layers are concordant with foliation; only larger pegmatite dikes, veins, and pegmatite-rich bodies are mapped; smaller pegmatite veins, dikes, and layers are lumped into other Farmington Canyon Complex units; outcrops tend to be slightly lighter in color and more resistant than surrounding units; commonly forms cliffs and ridges; thickness of veins and dikes up to 60 feet (20 m); thickness of pegmatite-rich bodies of rock estimated up to 800 feet (240 m) in NW1/4, section 34, T. 3 N., R. 1 E.

Xfca **Farmington Canyon Complex, amphibolite** (Paleoproterozoic) – Black, greenish-black, to dark-gray lenses and pods of hornblende-plagioclase amphibolite; metamorphic fabrics are typically poorly developed; only the largest pods mapped and are mostly as shown on Bryant (1988); small lenses and pods occur in other Farmington Canyon Complex units; forms slopes and ledges; contacts with other Farmington Canyon Complex units are indistinct and gradational; as described by Yonkee and Lowe (2004), the amphibolite pods may represent metamorphosed gabbro that was intruded into Xfcgs during later stages of metamorphism, or xenoliths of older amphibolite dikes.

ACKNOWLEDGMENTS

This geologic map was funded by the Utah Geological Survey (UGS) and the U.S. Geological Survey (USGS), National Cooperative Geologic Mapping Program through USGS STATEMAP award number G17AC00266. UGS staff Jon K. King, Adam McKean, Greg McDonald, Rich Giraud, Bob Biek, and Adam Hiscock, and Weber State University Professor Adolph Yonkee provided helpful and engaging discussions both in and out of the field. UGS staff Jon K. King, Don Clark, Grant Willis, Kimm Harty, and Mike Hylland also improved this map and text through their thoughtful reviews.

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

Lake Cycle and Phase	Shoreline (map symbol)	Age		Shoreline Elevation feet (meters)
		radiocarbon years (^{14}C yr B.P.)	calibrated years (cal yr B.P.)[1]	
Lake Bonneville				
Transgressive phase	Stansbury shorelines (S)	22,000–20,000[2]	26,000–24,000	4480–4500 (1365–1372)
	Transgressive shorelines (t)	~20,000–15,200[3]	24,000–18,500[3]	4920–5160 (1490–1564)
	Bonneville (B) flood	~15,200–15,000[4]	~18,500–18,000	5160–5235 (1564–1586)
Overflowing phase	Provo (P)	15,000–12,600[5]	18,000–15,000	4820–4890 (1460–1481)
Regressive phase	Regressive shorelines (r)	12,600–11,500[5]	15,000–13,000	4780–4820 (1448–1460)
Gilbert episode	Gilbert	10,000[6]	11,500	Not present[9]
Great Salt Lake	early Holocene highstand	9700–9400[7]	11,000–10,500	Not present[9]
	late Holocene highstand	4200–2100[8]	5000–2000	Not present[9]
	Historical highstand		late 1860s to early 1870s and 1986–87[10]	Not present[9]

[1] All calibrations made using OxCal ^{14}C calibration and analysis software (version 4.3.2; Bronk Ramsey, 2009; using the IntCal13 calibration curve of Reimer and others, 2013), rounded to the nearest 500 years. B.P. = before present, meaning the number of years before A.D. 1950

[2] Oviatt and others (1990)

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

[4] Oviatt, 2015; Miller, 2016; and references therein; Bonneville shoreline highstand duration may have been shorter than the rounding error of 500 years

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

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

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

[8] Miller and others (2005)

[9] Shoreline ages are provided for reference only, as they are present only below the lowest elevations in the quadrangle: Gilbert-episode at 4245 to 4250 feet (1294–1295 m), Great Salt Lake early Holocene highstand at 4225 to 4230? feet (1288–1289? m), Great Salt Lake late Holocene highstand at 4217 to 4221 (1285–1287 m) and Great Salt Lake historical highstand at 4212 feet (1284 m)

[10] Arnow and Stephens (1990)