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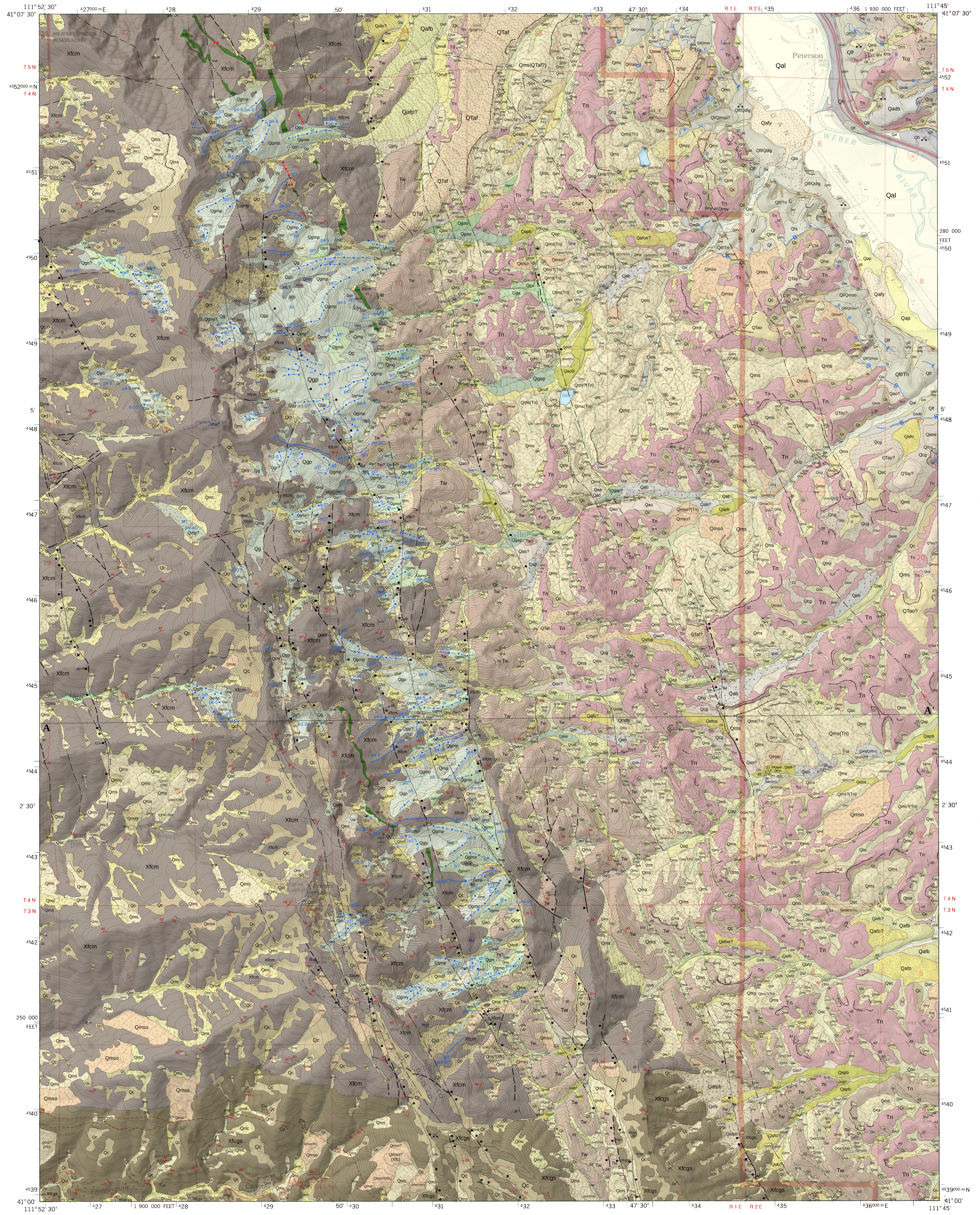

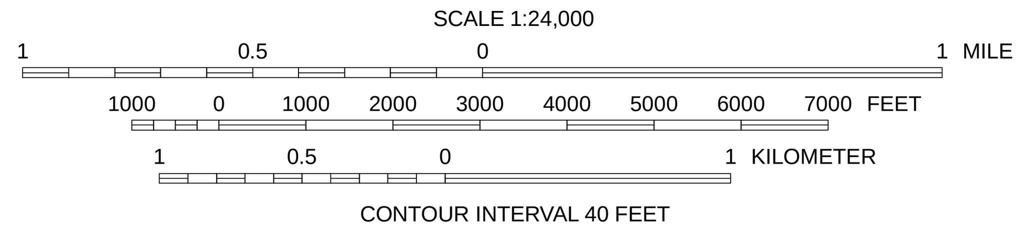

INTERIM GEOLOGIC MAP OF THE PETERSON QUADRANGLE, DAVIS AND MORGAN COUNTIES, UTAH

by
Jon K. King and Greg N. McDonald

2022

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Base from USGS US Topo Peterson 7.5′ Quadrangle (2017)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1927

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1	2	3
4		5
6	7	8

1. Ogden
2. Snow Basin
3. Durst Mountain
4. Kaysville
5. Morgan
6. Farmington
7. Bountiful Peak
8. Porterville

ADJOINING 7.5′ QUADRANGLE NAMES

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MAP UNITS

Symbol	Description
Qal	Stream alluvium and floodplain deposits
Qa_2?	Younger alluvium, level 2
Qay	Younger alluvium
Qay?	Younger alluvium, queried
Qapb	Lake Bonneville-age alluvium
Qapb?	Lake Bonneville-age alluvium, queried
Qap	Lake Bonneville-age alluvium, regressional
Qap?	Lake Bonneville-age alluvium, regressional, queried
Qab	Lake Bonneville-age alluvium, transgressional
Qab?	Lake Bonneville-age alluvium, transgressional, queried
Qao	Older alluvium
Qao?	Older alluvium, queried
Qaoe	Older eroded alluvium
Qaoe?	Older eroded alluvium, queried
Qat	Stream-terrace alluvium
Qaf	Alluvial-fan deposits, undivided, queried
Qafy	Younger alluvial-fan deposits
Qafy?	Younger alluvial-fan deposits, queried
Qafp	Lake Bonneville-age alluvial-fan deposits, regressional
Qafp?	Lake Bonneville-age alluvial-fan deposits, regressional, queried
Qafb	Lake Bonneville-age alluvial-fan deposits, transgressional
Qafb?	Lake Bonneville-age alluvial-fan deposits, transgressional, queried
Qafpb	Lake Bonneville-age alluvial-fan deposits
Qafpb?	Lake Bonneville-age alluvial-fan deposits, queried
Qafo	Older alluvial-fan deposits
Qafo?	Older alluvial-fan deposits, queried
Qafoe	Older eroded alluvial-fan deposits
Qafoe?	Older eroded alluvial-fan deposits, queried
Qly	Young lacustrine deposits
Ql	Lake Bonneville deposits, undivided
Qlf	Lake Bonneville fine-grained deposits
Qls	Lake Bonneville sand
Qg	Glacial till and outwash, undivided age
Qg?	Glacial till and outwash, undivided age, queried
Qgm	Glacial till, undivided age
Qga	Glacial outwash, undivided age
Qga?	Glacial outwash, undivided age, queried
Qgy	Younger glacial till and outwash
Qgy?	Younger glacial till and outwash, queried
Qgmy	Younger glacial till
Qgmy?	Younger glacial till, queried
Qgp	Pinedale glacal till and outwash
Qgp?	Pinedale glacal till and outwash, queried
Qgmp	Pinedale glacial till
Qgmp?	Pinedale glacial till, queried
Qgap	Pinedale glacial outwash
Qgap?	Pinedale glacial outwash, queried
Qgo	Older glacial till and outwash
Qgo?	Older glacial till and outwash, queried
Qgmo	Older glacial till
Qgmo?	Older glacial till, queried
Qgao	Older glacial outwash
Qgao?	Older glacial outwash, queried
Qgr	Rock glacier deposits
Qgr?	Rock glacier deposits, queried
Qmdf	Debris- and mud-flow deposits
Qmdf?	Debris- and mud-flow deposits, queried
Qmdfp	Lake Bonneville age debris- and mud-flow deposits
Qmdfo	Older debris- and mud-flow deposits
Qmdfo?	Older debris- and mud-flow deposits, queried
Qms	Landslide deposits
Qms?	Landslide deposits, queried
Qmsh	Landslide deposits, historical
Qmsy	Landslide deposits, younger
Qmso	Landslide deposits, older
Qmso?	Landslide deposits, older, queried
Qms (QTaf?)	Block landslide deposits
Qms (QTao)	Block landslide deposits
Qms (Ts)	Block landslide deposits
Qms (Tn)	Block landslide deposits
Qms (Tn?)	Block landslide deposits
Qms (rx)	Block landslide deposits
Qms? (QTaf)	Possible block landslide deposits
Qms? (rx)	Possible block landslide deposits
Qms? (Ts)	Possible block landslide deposits
Qms? (Tn)	Possible block landslide deposits
Qms? (Tn?)	Possible block landslide deposits
Qms? (Tw)	Possible block landslide deposits
Qms? (Xfc)	Possible block landslide deposits
Qmso (Tn)	Block landslide deposits, older
Qmso (Xfc)	Block landslide deposits, older
Qmso? (Tn)	Possible block landslide deposits, older, queried
Qmso? (Xfc)	Possible block landslide deposits, older, queried
Qmc	Landslide and colluvial deposits, undivided
Qmc?	Landslide and colluvial deposits, undivided, queried
Qmt	Talus
Qmt?	Talus, queried
Qct	Colluvium and talus, undivided
Qct?	Colluvium and talus, undivided, queried
Qc	Colluvium
Qc?	Colluvium
Qcg	Gravelly colluvial deposits
Qcg?	Gravelly colluvial deposits, queried
Qac	Alluvium and colluvium
Qla	Lake Bonneville lacustrine deposits and post- and pre-Lake Bonneville alluvial deposits, undivided
Qng	Gravel deposits
Qmg	Mass-movement and glacial deposits, undivided
Qmg?	Mass-movement and glacial deposits, undivided, queried
Qadb	Lake Bonneville alluvial-fan and deltaic deposits, undivided
Qh	Human disturbance
QTa	High-level alluvium
QTay?	High-level alluvium, younger
QTao	High-level alluvium, older
QTao?	High-level alluvium, older, queried
QTaf	High-level alluvial-fan deposits
QTaf?	High-level alluvial-fan deposits, queried
Qc/Qmso	Colluvium over landslide deposits, older
Ql/Qmso	Lake Bonneville deposits, undivided over landslide deposits, older
Ql/Qmso?	Lake Bonneville deposits, undivided over landslide deposits, older, queried
Qlf/Qmso	Lake Bonneville fine-grained deposits over landslide deposits, older
Qlf/Qmso?	Lake Bonneville fine-grained deposits over landslide deposits, older, queried
Qapb/Qmso	Lake Bonneville-age alluvium over landslide deposits, older
Qab/Qmso	Lake Bonneville-age alluvium, transgressional over landslide deposits, older
Qms/Qa	Landslide deposits over alluvium, undivided
Qmc/Qadb	Landslide and colluvial deposits, undivided over Lake Bonneville alluvial-fan and deltaic deposits, undivided
Ql/Tn	Lake Bonneville deposits, undivided over Norwood Formation
Qlf/Tn	Lake Bonneville fine-grained deposits over Norwood Formation
Qlf/Tn?	Lake Bonneville fine-grained deposits over Norwood Formation, queried
Qls/Tn	Lake Bonneville sand over Norwood Formation
Qaoe?/Tn	Older eroded alluvium over Norwood Formation
Qafoe?/Tn	Older eroded alluvial-fan deposits over Norwood Formation
QTa/Tn	High-level alluvium over Norwood Formation
QTaf/Tn	High-level alluvial-fan deposits over Norwood Formation
QTaf/Tn?	High-level alluvial-fan deposits over Norwood Formation, queried
Qafy/Qap	Younger alluvial-fan deposits over Lake Bonneville-age alluvium, regressional
Qlf/Qdlg	Lake Bonneville fine-grained deposits over Lake Bonneville deltaic and lacustrine deposits, undivided
Tcg	Unnamed Tertiary conglomeratic rocks
Tn	Norwood Formation
Tn?	Norwood Formation, queried
Tw	Wasatch Formation
Tw?	Wasatch Formation, queried
KXc	Chloritic gneiss, cataclasite, mylonite, and phyllonite
KXc?	Chloritic gneiss, cataclasite, mylonite, and phyllonite, queried
Xfc?	Farmington Canyon Complex, undivided
Xfcm	Farmington Canyon Complex, Migmatitic gneiss
Xfcgs	Farmington Canyon Complex, Gneiss and schist
Xfcgs?	Farmington Canyon Complex, Gneiss and schist, queried
Xfcp	Farmington Canyon Complex, Pegmatite
Xfcp?	Farmington Canyon Complex, Pegmatite, queried
	Water

GEOLOGIC SYMBOLS

Contact, dashed where approximately located, dotted where concealed

Contact, human disturbance that postdates 1986 aerial photographs used in geologic mapping

Marker bed (green=Tertiary, brown=Precambrian, black=Quaternary), extended through Quaternary (Q) units for ease in tracing

Chloritic zone, dashed where approximately located, dotted where concealed

70 Fault, dashed where approximately located, dotted where concealed, sense of movement unknown; red arrow and number indicate fault dip after Bryant (1988)

57 65 Normal fault, bar and ball on downthrown side, dashed where approximately located, dotted where concealed; black arrow and number indicate photogrammetrically measured dip on fault; red arrow and number indicate fault dip after Bryant (1988); arrow on cross section shows offset

57 Lineament, fault or resistant beds, but offset uncertain; arrow and number indicate photogrammetrically measured dip

Lake Bonneville shoreline

B B B B Bonneville (about 5180 feet [1579 m])

t t t t transgressive (prominent at about 5060 feet [1542 m])

Mass-movement scarp, dashed where approximately located

Topographic scarp

Glacial crests, age letters and numbers in blue, lower number is younger; m=Holocene (m1, m2); aretes are p3 and older; p = Pinedale (p3, p4, p5); bl=Bull Lake; pre-bl = Older Bull Lake or pre-Bull Lake; queried where correlation uncertain

Asymmetrical moraine crest, tics on steep (ice) side

Nearly symmetrical moraine crest

Ice-carved bedrock ridge (arete)

A——A' Line of cross section

Strike and dip of bedding (attitudes in red from Bryant, 1988); queried where dip angle uncertain

50 45 Upright

30 45 Upright approximate on left, photogrammetric on right

75 Strike and dip of cleavage, vertical on left (modified from Bryant, 1988)

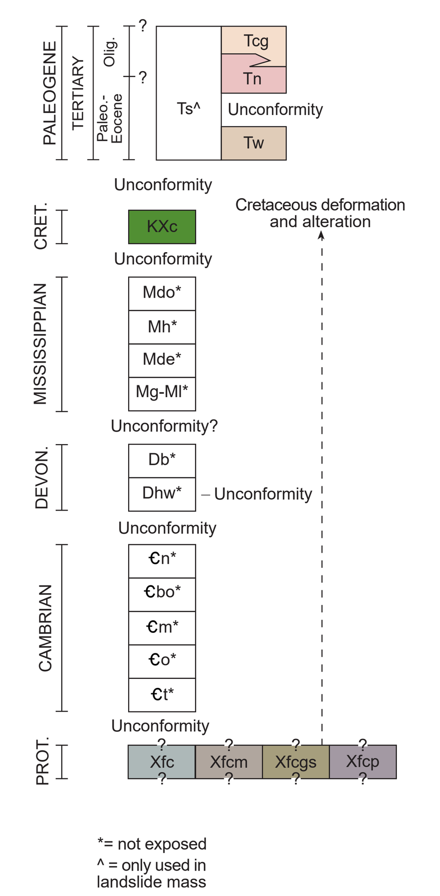
90 70 90 80 45 Strike and dip of foliations and other planar features in metamorphic rocks (attitudes in red from Bryant, 1988); vertical and inclined foliations on left, vertical planar features in center, inclined planar features on right, attitudes determined photogrammetrically on far right

Cu Adit on left; gravel pit on right

Qlf/Qldg Thin Quaternary unit over another unit (for example Qlf/Qldg near Peterson)

Qms (block) Landslide with nearly intact rotated blocks of unit in parentheses, for example Qms(Tw); queried (Qms?, Qmso?) where blocks may be in place and may not be landslides

CORRELATION OF MAP UNITS



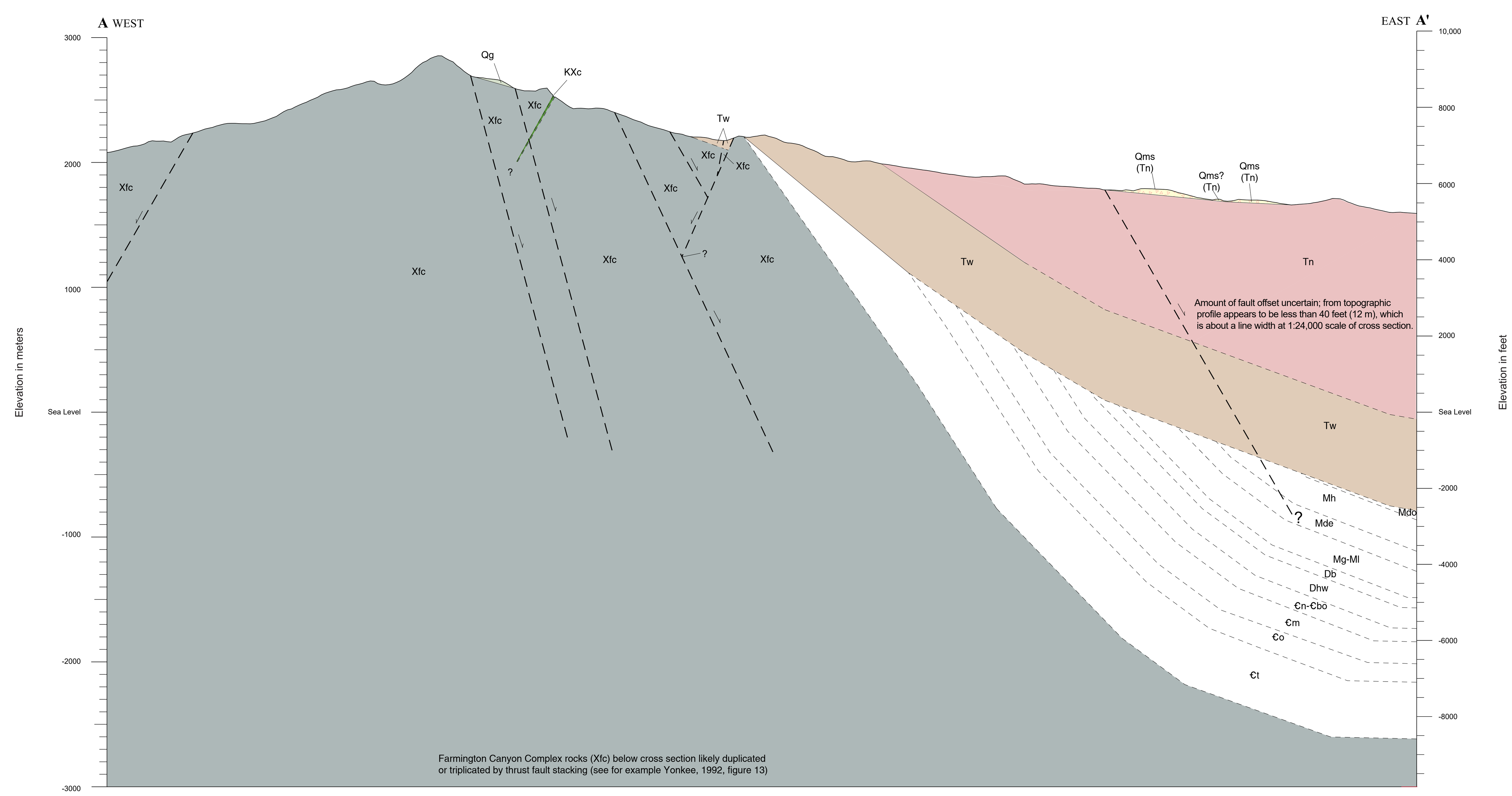
LITHOLOGIC COLUMN

AGE			UNIT SYMBOL	GEOLOGIC UNIT	THICKNESS FEET	THICKNESS METERS	OTHER INFORMATION
Q.			Q various	Surficial deposits	0–160	0–50	Thicker in subsurface
			QT various	High-level alluvium	0–160	0–50	
NEOGENE	TERTIARY	Plio	Thv	Fanglomerate of Huntsville	40–1000	12–300	Thv and Tcy not present in this quadrangle, but exposed just to east
		M.?	Tcy	Younger unnamed cong. rocks	200–400	60–120	
PALEOGENE		Oligo	Tcg	Unnamed conglomeratic rocks	~700	~210	Tcg-Tn interbedded in adjacent quadrangle
			Tn (Ts)	Norwood Tuff	0–5000	0–1525	Altered tuff; 38.4 Ma K-Ar (corrected); Thicker in subsurface
		Pal-Eo	Tw (Ts)	Wasatch Formation	1600–2700	490–830	Thicker to east; MAJOR UNCONFORMITY
K.			KXc	Chloritic gneiss and tectonites	indeterminant		Farmington Canyon Complex protolith; MAJOR UNCONFORMITY
MISSISSIPPIAN			Mdo	Doughnut Formation	500	150	
			Mh	Humbug Formation	700–800	215–240	Mississippian through Cambrian not exposed in this quadrangle
			Mde	Deseret Limestone	500	150	Base phosphatic
			Mg-Ml	Gardison (Lodgepole) Limestone	650–800	200–240	Fossiliferous
DEV.			Db	Beirdneau Sandstone	200–300	60–90	UNCONFORMITY?
			Dhw	Hyrum Dolomite	250–450	75–140	UNCONFORMITY
				Water Canyon Formation	200	60	MAJOR UNCONFORMITY, Silurian and Ordovician missing
CAMBRIAN			Ꞓn	Nounan Dolomite	350–750*	107–230*	Thins to east
			Ꞓbo	Bloomington Formation	0–130?	0–40?	*Eldoradia* sp. trilobites; Thins to east
			Ꞓm	Maxfield Limestone	300–900	90–270	Boundstone; ? *Elrathia* sp. trilobites
			Ꞓo	Ophir Formation	300–650*	90–200*	? *Elrathia* sp. trilobites; *Ehmaniella* sp. trilobites
			Ꞓt	Tintic Quartzite	1000–1500	300–450	Thins to east; MAJOR UNCONFORMITY
EARLY PROTER.			Xfc	Farmington Canyon Complex	indeterminant		1700± Ma; Xfcm=migmatitic gneiss; Xfcgs=gneiss and schist; Xfcp=pegmatite

Diagram is schematic - no fixed thickness scale

*Apparent thickness, deformed rocks

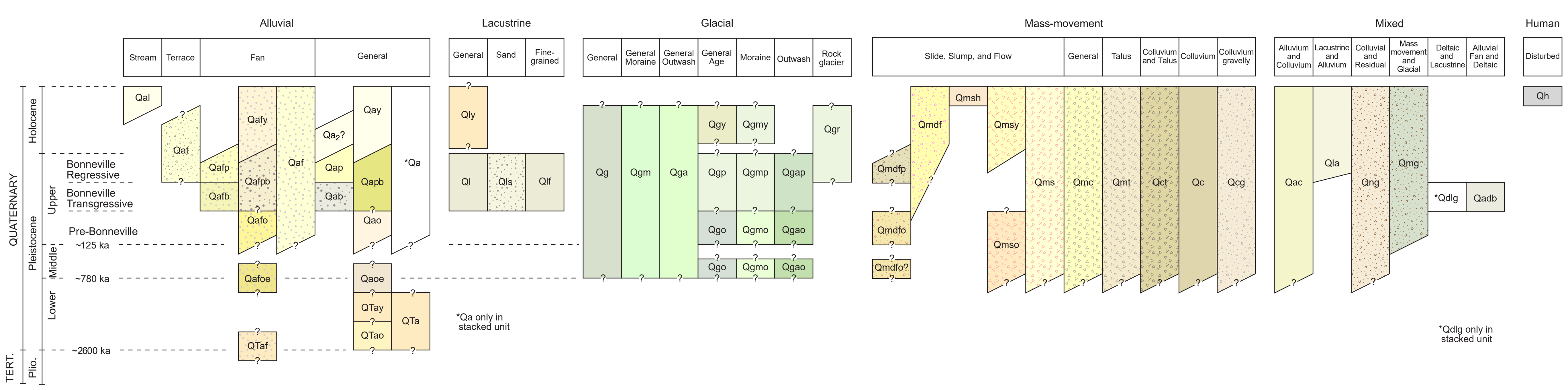
GEOLOGIC CROSS SECTION

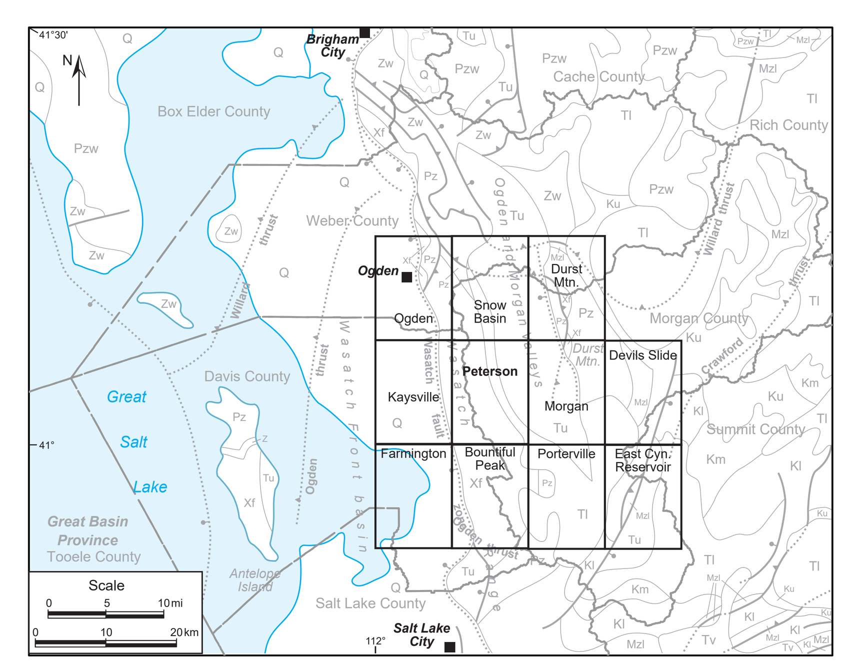


No vertical exaggeration
Thin Quaternary omitted for clarity

Depth to pre-Tertiary rocks is poorly constrained and lack of Paleozoic outcrops on west side of Morgan Valley means geology is conjectural.

QUATERNARY CORRELATION CHART





Q Quaternary deposits
Tu Tertiary, upper
Tl Tertiary, lower
Tv Tertiary volcanics
Ku Cretaceous, upper
Km Cretaceous, middle
Kl Cretaceous, lower
Mzl Mesozoic, lower
Pz Paleozoic
Pzw Paleozoic, Willard thrust sheet
Zw Late Proterozoic, Willard thrust sheet
Xf Farmington Canyon Complex
Contact
Fault, dotted where concealed
Thrust fault, dotted where concealed
Normal fault, dotted where concealed

Generalized geologic map (modified from Yonkee and others, 1997) showing quadrangles adjacent to the Peterson quadrangle and other quadrangles referred to in text.

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Disclaimer

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UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 734DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2021

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INTRODUCTION

The Peterson quadrangle is located southeast of Ogden, Utah (plate 2). The major geographic features in and near the map area are Morgan Valley, the northern Wasatch Range to the west, Durst Mountain to the east, the Weber River in Morgan Valley, and lower Weber Canyon cut into the Wasatch Range by the river.

The most complete map of the Peterson quadrangle prior to this study was by Bryant (1984, 1988) and he focused on the Precambrian Farmington Canyon Complex, as did an earlier dissertation by Bell (1951). King is largely responsible for the bedrock mapping in the quadrangle and after limited field checks chose to modify the Precambrian contacts from Bryant (1984, 1988). Because these rocks were not closely examined in the field, few attitudes are shown in Precambrian rocks on the map. Where strikes can be seen on aerial photographs and orthophotographs, corresponding planar attitudes shown by Bryant (1984, 1988) are included on our map. However, the type of attitudes depicted on our map are not always those shown by Bryant (1984, 1988). Because his attitudes differ from those shown by Yonkee and Lowe (2004) where their mapping overlaps in the Ogden 7.5' quadrangle, his lineations and most of his planar features (mostly foliations) are not included on our map, and we are uncertain that those included are all correct. King and McDonald worked on the surficial deposits in Morgan Valley, and King is responsible for the surficial geology in the Wasatch Range. Despite his focus on the Precambrian, Bryant (1984, 1988) was the first to map the glacial deposits in the Wasatch Range north of Salt Lake City and south of Mount Ogden. Bryant's (1984, 1988) glacial mapping made our more detailed mapping easier; but, much work is still needed to define the glacial deposits and history. Ages (years) of surficial deposits in the text and tables are from various methods, as reported in the references. Ages have not been converted to calendar years for several reasons, in part because the results from some methods cannot be converted. Also, calendar year conversions of carbon-14 ages can only go back 24,000 to 50,000 years (depending on the method of conversion), several conversion methods and updates exist, and all conversions introduce non-analytical errors that decrease the age accuracy (see for example Stuiver, 1993; Stuiver and Reimer, 1993; Stuiver and others, 1998; Hughen and others, 2000; Reimer, 2004; Fairbanks and others, 2005; Reimer and others, 2006; Bronk Ramsey, 2009; Reimer and others, 2013).

GENERAL GEOLOGY

The Precambrian (early Proterozoic) Farmington Canyon crystalline rock complex and unconformably overlying Cenozoic (Eocene and Paleocene) Wasatch Formation are exposed in the Wasatch Range in the west part of the map area. Paleozoic rocks are exposed to the north and south in the Wasatch Range and to the east on Durst Mountain. Mississippian and older strata are likely present in the subsurface below the Wasatch Formation in Morgan Valley (see cross section). However, the subsurface structure and units present beneath the valley are uncertain; for possible variations see Bryant (1990, cross section C-C'), Royse (1993, cross section H-H'), and Yonkee and others (1997, cross section B-B'). The latest Eocene and Oligocene(?) Norwood Formation unconformably overlies the Wasatch Formation in the Peterson quadrangle, but the contact is poorly exposed.

STRUCTURAL GEOLOGY

Deformation in the area is complex. The timing from oldest to youngest is summarized here, although much of the evidence is from outside the Peterson quadrangle. The Precambrian Farmington Canyon Complex was metamorphosed and deformed in the latest Paleoproterozoic or Mesoproterozoic, roughly coeval with igneous intrusion (see Yonkee and Lowe, 2004 for more information). These rocks and Paleozoic strata were faulted and folded during the Cretaceous to Eocene part of the Cordilleran orogeny and were likely rotated down-to-the-east during late Cretaceous to Eocene uplift of the Wasatch anticlinorium (Wasatch culmination of Yonkee and others, 1997). This uplift was in part caused by the Ogden thrust system that was periodically active during movement on thrust faults in the Idaho-Utah-Wyoming region (Yonkee and Weil, 2011) east of the Peterson quadrangle.

The Ogden roof thrust may be present in the subsurface in the map area. This roof thrust is exposed to the north in the Wasatch Range (Yonkee and Lowe, 2004; King and others, 2008) and to the east on Durst Mountain (Coogan and King, 2006; Coogan and others, 2015); its trace between these exposures is likely to the north of the Peterson quadrangle in the Snow Basin quadrangle. The Ogden roof thrust appears to be exposed south of the Peterson quadrangle in the Hardscrabble Creek area of the Porterville quadrangle (after Bryant, 1984, 1988, 1990; Yonkee and others, 1997). The trace between this exposure and the exposures on Durst Mountain may be present in the Morgan and/or Peterson quadrangles in the deep subsurface of Morgan Valley. Yonkee and others (2003) showed this trace in the subsurface in Morgan Valley, but it is not shown on the cross section in this report because it is conjectural. The cross section in this report is modified from J.C. Coogan's (Western State College, now Western Colorado University, July 2, 2005, unpublished digital file) regional cross section through the Ogden 30 x 60-minute quadrangle into Wyoming and beyond the concealed leading edge of the Hogsback thrust. The Ogden roof thrust is east-directed and, due to rotation related to the Wasatch anticlinorium, now dips about 30-degrees east on Durst Mountain (see Coogan and others, 2015).

The roughly north-south-trending normal faults in the Wasatch Formation and Farmington Canyon complex in the Peterson quadrangle are likely due to later, post-thrust Cenozoic extension. In particular, some offset is likely due to latest Eocene and Oligocene relaxation of the Cordilleran fold-and-thrust belt (collapse of Constenius, 1996); this is indicated by about 6000 feet (1850 m) of Eocene and Oligocene(?) Norwood Formation fill in Morgan Valley (Coogan and others, 2015). The Wasatch Formation and overlying Norwood Formation were likely folded into the north-plunging Morgan Valley syncline in the Oligocene and/or early Miocene; the axis is in the Morgan and Porterville quadrangles. Later, Miocene and younger Basin and Range faulting (see for example McCalpin, 1993) occurred in the map area, indicated by roughly north-south-trending normal faults in the Norwood Formation and Quaternary deposits.

Fault scarps in Quaternary to Tertiary(?) deposits appear to be present on the west side of Morgan Valley in and near the heads of high-level alluvial fans (QTaf) in the Peterson and Snow Basin quadrangles. A fault is shown by King and others (2008) near the mountain front at the head of the fan north of Strawberry Creek in the Snow Basin quadrangle. In the Peterson quadrangle, a less distinct scarp is mapped near the mountain front at the head of the fan north of the Right Hand Fork of Peterson Creek (plate 1); this setting is like the scarp in the Snow Basin quadrangle. Other fault scarps cut high-level alluvial fans (QTaf?) between the South Fork of Line Creek and the North Fork of Deep Creek, west of the mountain front.

Quaternary fault scarps are also present east of the mountain front in the Peterson quadrangle. These scarps are along trend with lineaments that may mark the change from carbonate-cemented sandstone beds to less resistant claystone in the Norwood Formation. About a mile (1.6 km) to the east of the Peterson Creek fan-head scarp, surfaces on remnants of QTaf appear to be offset down to the west, such that an antithetic fault is mapped between the two remnants. South of the Right Hand Fork of Peterson Creek, a "hanging" drainage appears to be offset 150 feet (45 m) down to the east; but offset across the scarp to the north in Norwood Formation bedrock is only 70 feet (20 m) (plate 1). A scarp is present in glacial outwash deposits (upper Pleistocene, Pinedale age?) south of and adjacent to the "hanging drainage." Quaternary deposits also appear offset north and south of Smith Creek. North of Smith Creek the surfaces on remnants of what may be high-level alluvial fans (QTaf?) appear to be offset 120 feet (37 m) down to the east. At and south of Smith Creek, the youngest unit a fault cuts is alluvium related to the Bonneville shoreline of Lake Bonneville (Qab) (upper Pleistocene); offset appears to be about 10 to 20 feet (3–6 m). The extension of this fault to the south is largely coincident with the flank of a landslide, complicating any interpretation. Lineaments, rather than faults, are mapped in the Norwood Formation along trend with and east of these faults, because they are parallel to the strike of the Norwood Formation and may be changes in erosional resistance in the Norwood Formation rather than faults. They are extended through Quaternary deposits to emphasize their length and because some are visible in Quaternary deposits.

East of the Peterson quadrangle, middle to lower Pleistocene (Quaternary) deposits are cut by extensional faults along the east side of Morgan Valley. Scarps along the mountain front are part of the 10-mile-long (16-km) fault system that bounds the west side of the Durst-Elk Mountain block, extending from or slightly south of Morgan to north of Cottonwood Creek in the Durst Mountain quadrangle. One scarp is visible in older eroded alluvial-fan (Qafoe) deposits at the mouth of Pine Canyon in the Morgan quadrangle and another scarp may be present in adjacent Qafoe deposits north of the drainage. To the north in the Durst Mountain quadrangle, possible fault scarps are present in Quaternary mass-movement deposits along the east margin of Morgan Valley, and on middle or lower Pleistocene alluvial deposits (Qaoe) north of Cottonwood Creek (see Coogan and King, 2006).

TERTIARY GEOLOGY

The relationships between the Norwood Formation, Keetley Volcanics, Fowkes Formation, and other pre-Miocene volcaniclastic rocks in northern Utah have been discussed periodically (Wingate, 1961; Eardley, 1969; Nelson, 1971, 1979; Bryant and others, 1989) since the name Norwood Tuff was proposed by Eardley (1944). Prior to work on the Ogden 30' x 60' quadrangle, the Norwood Formation was considered to be younger than the Fowkes Formation. However, neither formation is well dated due to alteration of datable minerals and the considerable thicknesses of partially exposed volcaniclastic fill in multiple basins. Further, Veatch (1907), who named the Fowkes, and Eardley (1944) mistakenly placed the Fowkes Formation within the Eocene and Paleocene Wasatch Formation strata (their Almy and Knight Formations), raising questions about whether Fowkes is an appropriate name. Also complicating the naming problems, strata of the type Norwood Tuff were originally named and placed in the Salt Lake Formation/Group by Hayden (1869), and Fowkes-age strata in Cache Valley (see Smith, 1997; Oaks and others, 1999) were mapped as part of the Salt Lake Formation (see for example Williams, 1962). Farther away from the type area, the Norwood contains little tuff because the glass has been altered (devitrified), mostly to clay and zeolite minerals, with some carbonate and silica material, hence the use of Norwood Formation rather than Tuff.

Available isotopic ages now indicate a bimodal age distribution (~39–40 and 48–49 Ma) for Fowkes strata exposed along the Utah-Wyoming border (see Coogan and others, 2015 for more information), with one outlier. This outlier is the sample 96-53, a tuffaceous sandstone from the Fowkes Formation in the Castle Rock quadrangle (2100 feet [640 m] from south line [fsl] and 1800 feet [550m] from east line [fel] section 34 T. 4 N., R. 7 E.), which was isotopically dated by K-Ar analyses on hornblende at 32.3 + 1.2 Ma (Coogan and King, 2016). This sample is from the base of the Fowkes Formation, stratigraphically below samples from the Castle Rock quadrangle that have $^{40}Ar/^{39}Ar$ ages of about 39–40 Ma, and the age is about 6 million years younger than any Norwood or Fowkes Formation age (see Coogan and King, 2016) and appears unreliable.

The young $^{40}Ar/^{39}Ar$ ages for the Fowkes (40.41 Ma and 38.78 Ma on biotite and hornblende, respectively) are from strata a few hundred feet above the upper Wasatch Formation (lower Fowkes) contact in the Yellow Creek graben in the Ogden 30' x 60' quadrangle, Utah (see Coogan and others, 2015). The older Fowkes ages (48–49 Ma) are from farther north and are from different grabens, in particular the Almy graben along the Bear River north of Evanston, Wyoming, that was reported by Nelson (1979), and near the type area of the Fowkes, reported by Oriel and Tracey (1970) and Smith and others (2008, p. 67). K-Ar ages were recalculated using Dalrymple (1979). These older ages and paleontological evidence indicate these older Fowkes strata are essentially the time equivalent of the Bridger Formation to the east in the Green River Basin, Wyoming (Nelson, 1973, 1974; see also Lillegraven, 1993, figures 4O and 4P). As yet, old Fowkes cannot be distinguished in the field from young Fowkes; so abandoning the Fowkes name, and using Bridger for the older Bridger-age strata while using Norwood Formation for the younger strata, is premature. In Morgan Valley and the East Canyon graben (East Canyon Reservoir quadrangle), Norwood Formation isotopic ages (38–39 Ma) (recalculated from Evernden and others, 1964, and Mann, 1974) are near the younger end of the Fowkes age distribution, but Norwood strata isotopically dated in Morgan Valley are at least 2500 feet (800 m) above the base of the Norwood and much older strata may be present. So Fowkes strata cannot be distinguished from Norwood-age strata when they are in the same basin.

Another younger outlier from the bimodal Fowkes-Norwood age ranges is from the Norwood Formation in the East Canyon graben, much closer to the Peterson quadrangle. This sample from the upper part of the Norwood was isotopically dated by K-Ar analyses on biotite at 29.6 + 1.1 Ma, but this age is suspect due to low K_2O content (Bryant and others, 1989). Further, northwest bedding dips mean this outcrop should be older than the strata isotopically dated at ~39 Ma by Mann (1974).

Paleontological evidence on the Norwood is presented in Adamson (1955), Evernden and others (1964), and Nelson (1971, 1977); see also Gazin (1959, p. 137). Paleontological data on the Fowkes Formation near Evanston, Wyoming (where isotopically dated; Nelson, 1979), is presented in Nelson (1971); see also Oriel and Tracey (1970, p. 16 on the white beds west of the Bear River) and Nelson (1973, 1974, 1979).

Isotopic ages of the Keetley Volcanics and their intrusive equivalents are generally younger than or as old as the younger Fowkes and Norwood ages (~33 to 39 Ma) (see Vogel and others, 1997; see also Nelson, 1976), but the ages of some intrusions near Park City are reportedly within the Fowkes age range (38–39 to 48–49 Ma), but some are between the bi-modal age sets (40–47 Ma) (John and others, 1997). Because intrusions cool more slowly than volcanic rocks, the datable minerals in source intrusions pass through their setting temperatures later than they do in their eruptive equivalents and therefore the intrusions can have isotopic ages that are several million years younger than their eruptive equivalents (see Lipman and Bachmann, 2015). Based on these ages and the "lag" in intrusion ages, the Park City area may be the source of the younger volcanic material in the Fowkes Formation more than 25 miles (40 km) to the northeast as well as the Norwood Formation 20 to 50 miles (30–80 km) to the north-northwest. The most likely volcanic source(s) for the older (48–49 Ma) Fowkes-Bridger strata is the Challis volcanic field, Idaho and/or Absaroka volcanic field, Wyoming (see Chandler, 2006; Smith and others, 2008, in particular figure 5), although with the intrusive lag some volcanic material could be from the Park City area.

Similar volcanic to tuffaceous strata of about the same age (38–39 Ma and 44–49 Ma versus 48–49 Ma) as the Fowkes-Bridger and Norwood are exposed to the southwest near Salt Lake City and to the north in southern Cache Valley, Utah about 70 miles (110 km) north of the Park City vents. See Van Horn (1981) and Van Horn and Crittenden (1987), Smith (1997), Oaks and others (1999), and Coogan and others (2015) for more information.

Based on similar ages (discussed above) and geology, the type Norwood Formation appears to be the more distal sedimentary equivalent of the volcano comprised by the Keetley Volcanics to the south near Park City, Utah. This correlation is likely because the Norwood Formation to the southeast in the East Canyon graben is transitional between the Morgan Valley and Park

City locations and lithologies, a relationship previously noted by Eardley (1944) and Bryant and others (1989). The Norwood Formation in East Canyon looks like proximal volcano apron deposits because it contains more tuff and variably rounded, sedimentary volcanic-rock clasts and fragments in conglomerates and sandstones than the Morgan Valley rocks, and the clasts are large enough that they are easily recognizable as volcanic lithologies present in the Keetley Volcanics. Although the ages are similar (see above), the geologic setting and stratigraphy of similar volcaniclastic rocks near Salt Lake City (Tn and Tkb of Bryant, 1990) have not been worked out.

The thickness of fill (Norwood and younger) in Morgan Valley is uncertain, in part because Paleozoic rocks are not exposed on the west side of Morgan Valley and their dip cannot be observed. Overall, the valley-fill thickness seems to increase to the north with the plunge of the Morgan Valley syncline and possibly the throw on the Morgan fault zone. From Lum's (1957) gravity profile, about 8000 feet (2500 m) of low-density fill is in the valley (equal to about 100 m of low-density fill for each milligal on a Bouguer gravity map by Quitzau, 1961), although the profile location is not known because Lum's thesis plates are missing from the University of Utah library. This 8000 feet (2500 m) is the amount of Norwood Formation fill that J.C. Coogan (Western State College, now Western Colorado University, July 2, 2005, unpublished digital file) showed on his cross section just north of Morgan; he also showed about 900 feet (275 m) of Wasatch Formation in the subsurface. Based on outcrop width and 40 degree dip of strata (not adjusted for topography), King chose to show on cross-section A-A' about 1600 to 2500 feet (500–760 m) of Wasatch Formation; about 6000 feet (1800 m) of overlying Norwood; and about 3500 feet (1100 m) of post-Norwood, at least partially conglomeratic (higher density), Tertiary strata in the basin fill (see Coogan and others, 2015). Alternatively, the valley fill is thinner, only about 6400 feet (1950 m) thick, if a factor of 80 meters of lower density valley fill per milligal is used (see data in Phelps and others, 1999 that crudely results in 90 meters per milligal).

QUATERNARY AND LATEST TERTIARY GEOLOGY

Remnants of Pliocene and/or Pleistocene alluvial deposits are present on both sides of Morgan Valley. Upper surfaces of high-level alluvial deposits (QTaf with QTao, and possibly QTa and QTay) in the Morgan, Durst Mountain, Peterson, and Snow Basin quadrangles appear to be the Weber Valley surface of Eardley (1944). However, high-level alluvial fans (QTaf) extend to the mountain front at elevations of about 6800 to 7200 feet (2070–2195 m) (see Coogan and King, 2006; King and others, 2008), rather than to the mountain ridgelines as suggested by Eardley (1944). In the Peterson quadrangle, these fans appear to extend beyond the mountain front and above 7200 feet (2195 m), to almost 8000 feet (2440 m) near the upper reaches of the South Fork of Line Creek. The bench on the Tintic Quartzite at about 8200 feet (2500 m), located below the bowls (cirques) in the Snow Basin quadrangle, may be another example of this surface (see King and others, 2008, map plate); alternatively the bench may be part of the Herd Mountain surface that is at elevations of 7600 to 8600 feet (2300–2620 m) in the Bybee Knoll quadrangle with remnants in the Huntsville, Browns Hole, and Sharp Mountain quadrangles (Coogan and King, 2016). Thin remnants of high-level alluvial deposits (boulder lags, typically quartzite, with unmappable extents) are present on some ridges in the Snow Basin quadrangle, for example between the new and old Snow Basin ski area access roads (southeast T. 6 N., R. 1 E.) and in NW1/4 section 14, T. 5 N., R. 1 E. (Salt Lake Base Line and Meridian [SLBM]). Along and west of the mountain ridgeline in the Peterson quadrangle, the Weber Valley surface of Eardley (1944) and Bell (1951, his thick tan soil) may encompass the erosional surface on which the Wasatch Formation was deposited, rather than being the Pliocene-Pleistocene alluvial Weber Valley surface. Bell (1951) showed Wasatch Formation (his red boulder conglomerate Knight Formation) adjacent to tan soil on the west slope of the range in what we mapped as landslides (see Tw debris in Qms deposits on northwest margin of our map). This is the only confirmed Wasatch material on the range in the Peterson quadrangle, because Wasatch Formation mapped by Bryant (1984, 1988) along fault zones appears to be hematitic fault material (our unit KXc).

Pre-Lake Bonneville Pleistocene alluvial and landslide deposits are present in the Peterson and adjacent quadrangles, and little studied upper and middle Pleistocene glacial deposits cover bedrock in the middle of the Peterson quadrangle on both sides of the crest of the Wasatch Range. Cirques are best developed on the east side of the crest. Upper Pleistocene lacustrine, deltaic, and alluvial deposits related to Lake Bonneville are present in Morgan Valley, although the lake did not occupy the valley after it dropped to the Provo shoreline (~4820 feet [1470 m]). Quaternary deposits that post-date Lake Bonneville are mostly Holocene and uppermost Pleistocene alluvium in the Weber River floodplain and landslides in the Norwood Formation. Note that no landslides are mapped that are younger than the September 1986 aerial photographs used to create the map, though they may be present. Other significant post-Lake Bonneville deposits are alluvial fans (containing debris-flow deposits) on which development is occurring. As documented in water wells in the Weber River floodplain (Utah Division of Water Rights, well drilling database), Quaternary fill in the floodplain is up to about 200 to 250 feet (60–75 m) thick.

In the Peterson quadrangle, ages of alluvium, including terraces and fans, are in part based on heights above present drainages in Morgan Valley, including in the Snow Basin, Durst Mountain, and Morgan quadrangles; see table 1 and note revisions from

Coogan and King (2006) and King and others (2008). This height approach was taken, rather than relating them to elevations (including Lake Bonneville shorelines) or a single drainage (like the Weber River), because erosion over time has incised drainages, increasing the heights of alluvium above drainages; also alluvial surfaces have slopes, and tributaries to the Weber River increase in elevation up their drainages. So the first surface next to a drainage could be ten to hundreds of feet above the Weber River or above a particular elevation. Further, the slopes of alluvial surfaces west of the Weber River off the Wasatch Range and those off Durst Mountain east of the Weber River are not the same. Also, many surfaces predate Lake Bonneville and drainages were likely backfilled during the rise of Lake Bonneville. The eroded valley fill that has moved down the Weber River must be voluminous as the oldest surfaces are now at least 1000 feet (300 m) above the Weber River.

The alluvium ages may extend through the former Quaternary-Tertiary boundary (1.8 Ma, the end of Olduvai normal paleomagnetism subchron [table 2]), but may not be as old as the 2.6 Ma Quaternary-Neogene boundary adopted by the International Union of Geological Sciences (roughly the end of the normal paleomagnetism marking the top of the Gauss chron) (see Gibbard and Cohen, 2008). However, carving nearly a million years out of the episodically shrinking Pliocene (latest Tertiary) means rocks we have listed as Pliocene in the Morgan quadrangle (Coogan and others, 2015), like the fanglomerate of Huntsville (Thv) and younger conglomeratic unit Tcy, may be at least partly Quaternary even though they are consolidated (rock). We have chosen to keep rocks (consolidated and/or lithified) as Tertiary and unconsolidated deposits as Quaternary and Quaternary/Tertiary to emphasize their erosional, geotechnical, and hydrological differences, and because ages are only inferred. Because volcanic ashes noted in table 2 (Mazama, Lava Creek B, Bishop, Mesa Falls, Huckleberry Ridge) would better constrain the ages of these deposits, these Quaternary deposits should be closely examined for volcanic ash beds.

Table 1. *Heights of alluvial deposits above adjacent active drainages in the Peterson quadrangle. Some heights (units with *) are not mapped in the Peterson quadrangle but are around Morgan and Round Valleys in the adjacent Morgan, Durst Mountain, and Snow Basin quadrangles (updated from Coogan and others, 2015). Younger ages (<20 ka) from Lake Bonneville history in carbon-14 years (see Oviatt and others, 1992). See Chadwick and others (1997), Phillips and others (1997) and Licciardi and Pierce (2018) for "Bull Lake" and Qaoe ages (cosmogenic ages). Other age estimates from Sullivan and others (1988) and Sullivan and Nelson (1992).*

Unit(s)	Feet (m) above drainage	Age (ka=1000) years	Comments
Qal, Qay, Qafy	at to slightly above	<~13 ka	Post Lake Bonneville
Qa_2	~15 feet (5 m)	<~13 ka	Younger age limit uncertain, post Lake Bonneville
Qat_2*	~10 to 20 feet (3–6 m)		
Qaf_2*	~20 to 40 feet (6–12 m)		
Qap	~20 to 40 feet (6–12 m)		
Qatp*	20 to 30 feet (6–9 m)	~13-15 ka	Provo shoreline occupation, Lake Bonneville
Qafp	~ 30 to 45 feet (9–14 m)		
Qab	45 to 90 feet (14–27m)		Sites >50 feet (15 m) may be part of unit Qfdb
Qafb	~45 to 70 feet (14–20 m)	~15-20 ka	Bonneville shoreline occupation, Lake Bonneville
Qfdb	~50 to 100 feet (15–30 m)		fans that go into lake and become deltas
Qao	~70 to 120 feet (20–37 m)	~95-153 ka	"Bull Lake" glaciation-related deposits
Qato*	~100 feet (30 m)		
Qafo	~70 to 120 feet (20–37 m)	~98-155 ka	Amino acid ages, also >70–100 ka soil carbonate age
			> 400 ka amino acid age is possible if two alluvial surfaces
Qaoe	120 to 230 feet (35–70 m)	>247ka	>780 ka paleomag age, but paleomag may be on QTay;
Qafoe	~120 to 200 feet (35–60 m)		suspect marine oxygen isotope stage 16
QTay	~215 to 450 feet (66–137 m)	>780 ka	Note height overlap with Qaoe
QTao	~320 to 800 feet (100–240 m)	>780 ka	
QTaf	~230 to 300 feet (70–90 m)	>780 ka	May be upstream equivalent of QTay
	~320 to 1000 feet (100–300 m)	>780 ka	May be entirely Pliocene

Table 2. *Comparison of Marine Oxygen Isotope Stages (OIS) to middle Rocky Mountain glaciation, Great Basin lake cycles, and North American continental glaciation, with ages in kilo-annum (ka). Ages are approximate because determined by different methods. Marine OIS ages are from Bassinot and others (1994) and when marked with * from Lisiecki and Raymo (2005) updated in http://lorraine-lisiecki.com/LR04_MISboundaries.txt, accessed February 4, 2021. Middle Rocky Mountain glacial ages are mostly from data in Phillips and others (1997) and Licciardi and Pierce (2018). Great Basin lake cycle ages are from numerous sources, in particular McCalpin (1986) = a, Kaufman and others (2001) = b, and Balch and others (2005) = c.*

Marine OIS **(bold)**, age in ka	Middle Rocky Mountain glaciation with age in ka	Great Basin lake cycle with age in ka	North American continental glaciation with age in ka	Notes, age in ka
1, <11				Mazama ash, 6.74 Hallett and others, 1997
2, 11-24, 14-29*	"Pinedale" 12-23	Bonneville 12-30; Lake Lahontan	**major**, late Wisconsin end 10	major continental=middle Rocky Mtn glaciers
4, 57-71 both	likely obliterated by "Pinedale"	Cutler Dam 59b; 82a	early Wisconsin start 75	
6, 127-186, 130-191*	"Bull Lake" 101?, 111-131, 118-153, 163?	Little Valley >112-126; 138a; 153-187c; Lake Manly in Death Valley	**major**, late Illinoian end 125	major continental=middle Rocky Mtn glaciers
8, 242-301, 243-300*	"Sacagawea Ridge"? >245	Pokes Point?, >271c	early Illinoian start 265	moraine age from Phillips and others, 1997
10, 334-364, 337-374*			pre-Illinoian A, formerly Kansan 300?-435	type Kansan is Nebraskan in age, so now use pre-Illinoian
12, 427-474, 424-478*	"Sacagawea Ridge" >245 on moraine; best guess for "Sacagawea Ridge" since major continental glaciers	Pokes Point by Oviatt and others, 1999	**major**, pre-Illinoian B, formerly Kansan 300?-435	moraine age from Phillips and others, 1997; major continental=middle Rocky Mtn glaciers
14, 528-568, 533-563*		pre Pokes Point 600? (>500<610)	"Nebraskan" end 500, pre-Illinoian C	
16, 621-659, 621-676*	"Sacagawea Ridge"?, Lava Creek B ash (640) in fluvial deposits correlated across lake by Chadwick and others, 1997	"Lava Creek" lake, pre Pokes Point 600?	**major**, pre-Illinoian D, Nebraskan	ash age Lanphere and others, 2002; major continental=middle Rocky Mtn glaciers; could be "Cedar Ridge"
18, 712-760, 712-761*	older "Cedar Ridge"? Washakie Point?	"Lake Dominguez" top, Bishop ash (760)	pre-Illinoian E?	ash age Izett and Obradovich, 1991
20, 787-<820, 790-814*	type "Washakie Point" not reverse polarized, so "Washakie Point" likely not Marine OIS 20			775+10 bottom of Brunhes normal paleomagnetism chron from Bassinot and others, 1994
22, 865->879, 866-900*; 24 917-936*			pre-Illinoian F	
38, 1244-1264*; 40, 1286-1304*			pre-Illinoian G	Mesa Falls ash, 1285 Lanphere and others, 2002
64, 1782-1802.5*			pre-Illinoian I?, "Nebraskan" start 1800	1770 top of Olduvai normal paleomagnetism subchron
78?, 2043-2088*		"Lake Dominguez" bottom, Huckleberry Ridge ash (2060)		ash age Lanphere and others, 2002

GLACIAL GEOLOGY

Several distinct end and lateral moraines and glacier-carved ridges (aretes) are visible on the east slope of the Wasatch Range in the Peterson quadrangle and are shown on plate 1. The youngest deposits (Qgy, Qgmy; m1 and m2 moraines) are in the cirques, and based on cirque setting and ages of cirque deposits to the south in the Little Cottonwood Canyon area of the Wasatch Range (Madsen and Currey, 1979), they are likely Holocene (<~12 ka [corrected]). Downslope from cirques in the Peterson quadrangle are Pinedale age (~12 to 30 ka) (Gosse and others, 1995; Phillips and others, 1997; see also Licciardi and Pierce, 2008, 2018) glacial deposits (Qgp, Qgmp, Qgap). Farthest upslope are recessional moraines (p3) of glacial stillstands and/or minor advances (deglacial pauses) of late Pinedale-age (~12–15 ka) glaciers that are likely about the same age as the regression of Lake Bonneville from the Provo shoreline; p3 aretes are mapped but may be older (p4 or p5). Downslope (and higher above p3 lateral moraines) are older end and lateral moraines that, like p3 moraines, typically have asymmetrical crests with the gentler side away from the now receded glacier. Unlike the Little Cottonwood Canyon area near Salt Lake City, a pair of overlapping end and lateral moraines (p4 and p5) in the Peterson quadrangle appear to be Pinedale glacial age (formed during transgression of Lake Bonneville to the Bonneville shoreline and during occupation of this shoreline); this Pinedale age is based on vegetation and soil development on, and morphology of moraines. Crests of some p4 and p5 moraines can be traced upslope into aretes of the same age. Still farther downslope from and higher laterally above p4 and p5 lateral moraines are older glacial deposits (Qgo, Qgmo, Qgao), with one or two well-vegetated end and lateral moraines that have more symmetrical crests (bl and pre-bl?). These older moraines are thought to be Bull Lake glacial age (95 to 153 ka) (see Chadwick and others, 1997; Phillips and others, 1997; Licciardi and Pierce, 2008, 2018), but like the older alluvial deposits (Qao, Qato, Qafo) may encompass Bull Lake-age deposits and older deposits (labeled pre-bl? on our map) related to the Pokes Point lake cycle associated with Marine Oxygen Isotope Stage 12 (see Oviatt and others, 1999) (table 2). Correlations of outwash with alluvial deposits have not been documented, but see table 1. The extent of these older outwash deposits is typically small and their existence in some drainages is inferred from aretes above p4-5 glacier-carved ridges.

The numbering and ages of glacial features on the west slope of the Wasatch Range near the heads of Middle and South Forks of Kays Creek and the head of Webb Canyon (Holmes Creek) may not be the same as on the east side. Mass-movement degraded, pre-Pinedale glacial deposits (Qmg?) may be present at the head of Adams Canyon (North Fork of Holmes Creek).

King and others (2008) previously proposed possible age equivalency between moraines in the Snow Basin and Ogden 7.5-minute quadrangles and moraines in Little Cottonwood Canyon near Salt Lake City (see Madsen and Currey, 1979), but examinations of aerial photographs of the Little Cottonwood Canyon area for this report show the moraines are likely not equivalent. In particular the m1 and m2 moraines of the Peterson, Snow Basin, and Ogden 7.5-minute quadrangles are less vegetated and more rocky (less soil development) than the upper and lower Devils Castle moraines in the Albion Basin near Salt Lake City. The Hogum Fork moraines in Little Cottonwood Canyon typically have double crests (Madsen and Currey, 1979); and, although they have similar vegetation development and rocky appearance, the p3 moraines of the Peterson quadrangle (m3 of the Snow Basin quadrangle) lack double crests. Also of importance is that two Pinedale-age end moraines are at least locally present in the Peterson quadrangle (p4 and p5), while only a single Pinedale-age moraine (Bells Canyon) was noted near Salt Lake City (Madsen and Currey, 1979; Laabs and others, 2011; Laabs and Munroe, 2016; Quirk and others, 2018), and the pre-Wisconsin, Bull Lake-age Dry Creek moraine directly underlies the Bells Canyon deposits (Madsen and Currey, 1979). King is still uncertain if the moraines labeled m5? in the Snow Basin quadrangle are Pinedale (p5 of this report) or Bull Lake (bl of this report) age, so only one Pinedale age end moraine (m4) may be present in the Snow Basin quadrangle. Most of the moraines labeled BL? in the Snow Basin quadrangle are likely Bull Lake age, although the glacial deposits in the Maples recreation area (formerly campground) are probably pre-Bull Lake age. Two Bull Lake-age moraines or a Bull Lake and pre-Bull Lake moraine (bl and pre-bl) may be present in the Peterson quadrangle above Jacobs, Peterson, Smith, Dalton, and Line Creeks on the east flank of the Wasatch Range and above the South Fork of Kays Creek on the west side of the range, and possibly up the Middle Fork of Kays Creek on the west side of the range. Pre-Bull Lake glacial deposits may be related to pre-Illinoian continental glaciation (>300 ka) and the Pokes Point lake cycle (>271 ka, see Balch and others, 2005; or most likely ~450 ka, Marine Oxygen Isotope Stage 12, see Oviatt and others, 1999) (see also table 2).

DESCRIPTION OF MAP AND CROSS SECTION UNITS

SURFICIAL DEPOSITS

QUATERNARY

Alluvial Deposits

Qal **Stream alluvium and floodplain deposits** (Holocene) – Sand, silt, clay, and gravel in channels, floodplains, and terraces less than 10 feet (3 m) above Weber River and Peterson and Dalton Creeks; includes muddy, organic overbank and oxbow lake deposits, particularly along the Weber River; composition in creeks depends on source area; composition along Weber River diverse due to extensive drainage basin; 0 to 20 feet (0–6 m) thick; greater thicknesses (60 or 70 feet [~20 m]) reported in Morgan Valley (see Utah Division of Water Rights well drilling database) likely include Lake Bonneville and possibly older Pleistocene deposits.

Qa **Alluvium, undivided** (Holocene and Pleistocene) – Sand, silt, clay, and gravel in stream and alluvial-fan deposits; composition depends on source area; variably sorted; variably consolidated; deposits lack fan shape of Qaf and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage; where possible subdivided, with relative ages indicated by number and letter suffixes (with 1, when present, being the youngest and being at to slightly (<10 feet [3 m]) above drainages in adjacent quadrangles (see table 1); in the Peterson quadrangle Qa with no suffix only used where alluvium underlies landslides (Qms/Qa) along north margin of map area; generally 0 to 20 feet (0–6 m) thick.

Qa_2?, Qay, Qay?

Younger alluvium (mostly Holocene) – Composition, bedding, and characteristics like undivided alluvium with Qay at to slightly above present drainages, unconsolidated, and not incised by active drainages; likely mostly Holocene in age and post-dates late Pleistocene Provo shoreline of Lake Bonneville; Qay queried where age uncertain; generally 0 to 20 feet (0–6 m) thick. The lone Qa_2 is queried (Qa_2?) and located south of Peterson Creek, and is queried because age is uncertain, due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age.

Qapb, Qapb?, Qap, Qap?, Qab, Qab?

Lake Bonneville-age alluvium (upper Pleistocene) – Composition, bedding, and characteristics like undivided alluvium but height above present drainages appears to be related to shorelines of Lake Bonneville; also unconsolidated to weakly consolidated and incised by active drainages; alluvial deposits labeled Qap and Qab are likely related to the Provo (and slightly lower) and Bonneville (at 5180 feet [1580 m] elevation in area) shorelines of Lake Bonneville, respectively; in the Peterson quadrangle, ages of alluvium, including terraces and fans, are in part based on heights above present drainages (table 1); here Qap is about ~20 to 45 feet (6–14 m) above and Qab is 45 to 90 feet (14–27 m) above; Qapb is used where Qap and Qab can not be separated; unit symbols queried where age uncertain due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age; generally 0 to 20 feet (0–6 m) thick, but Qap is up to about 50 feet (15 m) thick with Qapb and Qab locally up to 40 and 90 feet (12 and 27 m) thick, respectively.

A prominent surface ("bench") is present on Qap and Qatp at about 4900 feet (1494 m) along the Weber River in Morgan Valley (Snow Basin, Peterson, Durst Mountain, and Morgan quadrangles), about 25 to 40 feet (8–14 m) above the Weber River, with the Provo shoreline at elevations of 4800 to 4840 feet (1463–1475 m) near the head of Weber Canyon in the Snow Basin quadrangle. Speculatively, the alluvium was derived from erosion of Lake Bonneville deposits (Ql, Qlf, Qls, Qdlg, Qadb) above the bench and alluvium related to the Bonneville shoreline (Qab, Qafb, Qadb) that backfilled valleys during the transgression of the lake.

Qao, Qao?

Older alluvium (mostly upper Pleistocene) – Sand, silt, clay, and gravel in stream and alluvial-fan deposits above and likely older than the Bonneville shoreline; mapped on surfaces above Lake Bonneville-age alluvium (Qap, Qab, Qapb, Qafp, Qafb, Qafpb); composition depends on source area; deposits lack fan shape of Qaf and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage; unit symbol queried where age uncertain due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age; generally 0 to 20 feet (0–6 m) thick, but locally up to 110 feet (34 m) thick.

In the Peterson quadrangle, ages of alluvium, including terraces and fans, are in part based on heights above present drainages (table 1); here Qao is about 70 to 120 feet (20–37 m) above adjacent drainages; see table 1 and note revision from Coogan and King (2006), and King and others (2008).

Qao is likely older than Lake Bonneville and the same age as Qafo, so Qao is likely Bull Lake glaciation age, 95,000 to 153,000 ka (see Chadwick and others, 1997; Phillips and others, 1997; Licciardi and Pierce, 2008, 2018). From work in the Devils Slide quadrangle (Coogan and King, 2016) and age estimates in Sullivan and Nelson (1992) and Sullivan and others (1988), older alluvium (Qao, Qafo, Qato) may encompass an upper (pre-Bull Lake) and lower (Bull Lake) alluvial surface that is not easily recognized in Morgan Valley, but is visible to the east.

Qaoe, Qaoe?

Older eroded alluvium (middle and lower Pleistocene) – Mostly sand, silt, and gravel in eroded remnants of alluvium (stream and alluvial-fan deposits); composition depends on source area; deposits lack fan shape of Qaf and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage; located above the Bonneville shoreline (at 5180 feet [1580 m] elevation in area) and apparently above and older than pre-Lake Bonneville older alluvium (Qao and Qafo); mapped on benches about 120 to 230 feet (35–70 m) above Weber River on west side of Morgan Valley in Peterson quadrangle, at an elevation of about 5300 to 5350 feet (1615–1630 m); this is slightly higher than on east side of Morgan Valley (120–200 feet [35–60 m] above) in the Snow Basin, Durst Mountain, and Morgan quadrangles; unit symbol queried where age uncertain due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age; about 10 to 60 feet (3–20 m) thick.

West of the Weber River in the Morgan quadrangle, age estimated by Sullivan and others (1988) as older than 730 ka based on reversed paleomagnetism (>780 ka in Bassinot and others [1994]), but the sample site is one of the highest alluvial remnants of Qaoe (>200 feet [60 m] above the Weber River) and may be unit QTay. If this high remnant is QTay, it is >780 ka, and Qaoe and Qafoe may be related to Pokes Point lake cycle (Marine Oxygen Isotope Stage 12 by Oviatt and others, 1999) (pre-Illinoian B continental glaciation, >300 ka) and/or be pre-Pokes Point (Marine Oxygen Isotope Stage 16, "Nebraskan" continental glaciation, >500 ka) (see table 2). The age(s) of units Qaoe and Qafoe might be refined if a Lava Creek B and/or Bishop ash were found in them (see table 2).

Qat **Stream-terrace alluvium** (Holocene and Pleistocene) – Sand, silt, clay, and gravel in terraces above floodplains; moderately sorted; variably consolidated; upper surfaces slope gently downstream; Qat with no suffix used at single site along Dalton Creek, because it is the lowest terrace (so should be Qat_2), but only Qap is nearby; this Qat is 20 feet (6 m) above adjacent drainage, and used Qaty in Snow Basin quadrangle for terraces this low; in adjacent quadrangles (see table 1) number and letter suffixes indicate relative ages, with 2 being the youngest terraces; 0 to at least 20 feet (0–6 m) thick.

Qaf **Alluvial-fan deposits, undivided** (Holocene and Pleistocene) – Mostly sand, silt, and gravel that is poorly bedded and poorly sorted; variably consolidated; includes debris-flow deposits, particularly in drainages and at drainage mouths (fan heads); generally less than 60 feet (18 m) thick. Mapped in Peterson quadrangle where fan age uncertain.

Qafy, Qafy?

Younger alluvial-fan deposits (Holocene and uppermost Pleistocene) – Mostly sand, silt, and gravel that is poorly bedded and poorly sorted; unconsolidated; Qafy below the Bonneville shoreline typically contains well-rounded recycled Lake Bonneville gravel; includes debris-flow deposits, particularly in drainages and at drainage mouths (fan heads); unit symbol queried where age uncertain; generally less than 40 feet (12 m) thick.

Qafy fans are active and impinge on and deflect present-day drainages like the Weber River; Qafy fans may be as old as the uppermost Pleistocene regressive shorelines below the Provo shoreline, but are mostly younger than Lake Bonneville (mostly Holocene).

Qafp, Qafp?, Qafb, Qafb?, Qafpb, Qafpb?

Lake Bonneville-age alluvial-fan deposits (upper Pleistocene) – Composition, bedding, and characteristics like undivided alluvial fans, but height above present drainages appears to be related to shorelines of Lake Bonneville (see table 1); also these fans are inactive, unconsolidated to weakly consolidated, and locally dissected; fans labeled Qafp and Qafb are likely related to the Provo (and slightly lower) and Bonneville shorelines of late Pleistocene Lake Bonneville, respectively; where they cannot be separated in the southeast part of the Peterson quadrangle they are shown as Qafpb; unit symbols queried where age uncertain due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age; 10 to less than 60 feet (3 to <18 m) thick.

Like Qa suffixes, fan ages in the Peterson quadrangle are partly based on heights above present drainages (see table 1 and note revisions from Coogan and King, 2006, and King and others, 2008); in this quadrangle heights at drainage-eroded edges of fans are about 30 to 45 feet (9–14 m) above adjacent drainages for Qafp, and 45 to 70 feet (14–20 m) above adjacent drainages for Qafb.

Qafo, Qafo?

Older alluvial-fan deposits (mostly upper Pleistocene) – Incised and at least locally dissected fans; contain sand, silt, and gravel that is poorly bedded and poorly sorted; includes debris-flow deposits, particularly in drainages and at drainage mouths (fan heads); unit Qafo is typically above and apparently "cut" by (older than) the Bonneville shoreline, indicated by a bench at the shoreline; upstream unit Qafo is topographically higher than fans that are likely related to the Bonneville shoreline (Qafb); generally less than 60 feet (18 m) thick. Map unit symbol queried where age is uncertain due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age.

Like Qa suffixes, fan ages in the Peterson quadrangle are partly based on heights above present drainages (see table 1 and note revisions from Coogan and King, 2006, and King and others, 2008); in this quadrangle heights at drainage-eroded edges of older fans are about 75 to 120 feet (23–37 m) above adjacent drainages for Qafo.

The amino-acid age estimates presented in Sullivan and Nelson (1992) imply Qafo to the east in the Morgan quadrangle considerably predates Lake Bonneville and is middle Pleistocene in age (>400 ka). However, the Bonneville shoreline is obscure on this fan when it should be sharp, and soil-carbonate age estimates (>70–100 ka) and other amino-acid age estimates (~98–155 ka) in Sullivan and others (1988) imply these older fans are related to Bull Lake glaciation (95,000 to 153,000 ka; see Chadwick and others, 1997; Phillips and others, 1997; Licciardi and Pierce, 2008, 2018). From work in the Devils Slide quadrangle (Coogan and King, 2016) after release of the Snow Basin map of King and others (2008), Qafo (Qao, Qato) may encompass two ages of older alluvial deposits (Qao, Qafo) with the lower younger set being Bull Lake age and the older upper set possibly being related to the Pokes Point lake cycle (at about 450 ka according to Oviatt and others, 1999) (see table 2); also see unit Qgao.

Qafoe, Qafoe?

Older eroded alluvial-fan deposits (middle and lower Pleistocene) – Eroded fan remnants located above and apparently older than other pre-Lake Bonneville alluvial deposits (Qafo and Qao); contains mostly sand, silt, and gravel that is poorly bedded and poorly sorted; less bouldery and lower relative to high-level alluvium (QTa, QTao, QTaf); about 120 to 200 feet (35–60 m) above present streams on both sides of Morgan Valley in Peterson and Morgan quadrangles, and about 300 feet (100 m) and greater than 400 feet (120 m) above Weber River northwest of Peterson and in southeast Snow Basin quadrangle, respectively; 0 to 60 feet, (0–18 m) thick. Map unit symbol queried where age is uncertain due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age. Likely same age as Qaoe (Marine Oxygen Isotope Stage 12 and/or 16; middle Pleistocene), but possibly older than >780 ka paleomagnetic reversal (see table 2) and early Pleistocene in age.

Lacustrine Deposits

Qly **Young lacustrine deposits** (Holocene) – Deposits in ponds in landslides along Line Creek and seasonal lakes in cirques on east flank of the Wasatch Range; likely formed after Pleistocene glaciation, and possibly after Holocene moraines (m1 and m2); may be underlain by glacial deposits (Qgy) in cirques; composition depends on local substrate; likely less than 20 feet (6 m) thick.

Ql **Lake Bonneville deposits, undivided** (upper Pleistocene) – Silt, clay, sand, and cobbly gravel in variable proportions; mapped where grain size is mixed, or surface weathering obscures grain size and deposits are not exposed in scarps and construction cuts; mapped along west side of Weber River in Peterson quadrangle; thickness uncertain.

Qlf **Lake Bonneville fine-grained deposits** (upper Pleistocene) – Mostly silt, clay, and fine sand (typically eroded from shallow Norwood Formation) in Morgan Valley; deposited near- and off-shore in lake; yellow clay about 13 feet (4 m) thick in water well south of Peterson; red laminated claystone at least 12 feet (4 m) thick on Frontier Drive in Snow Basin quadrangle (see Rogers, 1986, borehole 1).

Deeper water fine-grained deposits overlie older shoreline and delta gravels (Qlf/Qdlg) at the mouths of several drainages along Weber River; the gravels were deposited above the Provo shoreline during transgression of Lake Bonneville to the Bonneville shoreline (see unit Qdlg).

Qls **Lake Bonneville sand** (upper Pleistocene) – Mostly sand with some silt and gravel deposited nearshore; mapped south of Peterson on west side of Morgan Valley below the Bonneville shoreline and above the Provo shoreline; typically less than 20 feet (6 m) thick, but thicker in "bench" east of Cottonwood Creek in Snow Basin quadrangle.

Glacial Deposits

Qg, Qg?, Qgm, Qga, Qga?

Glacial till and outwash, undivided age (Holocene and upper and middle? Pleistocene) – Undivided because age is uncertain and unit symbols queried where interpretation as glacial deposits is uncertain. Qg is undivided glacial deposits (till and outwash) with various possible ages; till is non-stratified, poorly sorted clay, silt, sand, and gravel, to boulder size; Qgm is moraines of unknown age that are mapped where distinct shapes of end, recessional, and lateral moraines are visible; outwash (Qga) is stratified and variably sorted, but better sorted and bedded than till due to alluvial reworking; Qga is mapped directly downslope from other glacial deposits where it is thick enough to obscure older deposits and bedrock, and where it can be separated from ground moraine (mapped as Qg) and alluvium (mapped as various Qa__); all glacial deposits locally include mass-movement (Qms, Qmt, Qct) and rock glacier (Qgr) deposits that are too small to show separately at map scale; 0 to 150 feet (0–45 m) thick, ground moraine and outwash thinner. Glacial deposits of any age are prone to slope failures, because they are typically clay rich.

Qgy, Qgy?, Qgmy, Qgmy?

Younger glacial till and outwash (Holocene) – Mapped in cirques as undivided (Qgy) and distinct moraines (Qgmy); see sub-unit differences under undivided glacial units (Qg, Qgm, Qga); moraines are mapped where distinct shapes of end and lateral moraines are visible; include 8000- to 10,000-year-old and possibly middle Holocene (about 5000 years old) deposits with very poorly developed soil and sharp, mostly non-vegetated moraines (m2 and m1 crests, respectively); ages modified from Madsen and Currey (1979); estimate distinct moraines 10 to 40 feet (3–12 m) thick and all deposits (Qgy, Qgy?) possibly up to 80 feet (24 m) thick. Qgy and Qgmy queried where age uncertain or interpretation as glacial deposits is uncertain.

Qgp, Qgp?, Qgmp, Qgmp?, Qgap, Qgap?

Pinedale glacial till and outwash (upper Pleistocene) – Pinedale-age (~12 to 30 ka) (see Gosse and others, 1995; Phillips and others, 1997; see also Licciardi and Pierce, 2008, 2018); for exposure age summary to south in central Wasatch Range see Quirk and others (2020), and note ages do not agree with corrected carbon-14 ages of Madsen and Currey (1979); variably vegetated deposits mapped as undivided (Qgp), distinct moraines (Qgmp), and outwash (Qgap); see sub-unit differences under undivided glacial units (Qg, Qgm, Qga); moraines are mapped where distinct shapes of end, recessional, and lateral moraines are visible; mapped moraines have poorly developed soil and moderate to sharp moraine morphology (p5 and p4 moraine crests); upslope these younger units include partially vegetated recessional deposits from glacial stillstands and/or minor advances (deglacial pauses) (p3 moraine crests); located up drainage or laterally downslope from likely older glacial deposits (Qgo, Qgmo, Qgao); 0 to 150 feet (0–45 m) thick, ground moraine and outwash thinner. Qgp is queried where deposits may be younger. Qgmp is queried along Right Hand Fork of Dalton Creek where moraine may be younger. Qgap is queried along Dalton Creek where it may be alluvium that is not related to glaciation.

Qgo, Qgo?, Qgmo, Qgmo?, Qgao, Qgao?

Older glacial till and outwash (upper and middle? Pleistocene) – Mapped down drainage from and locally laterally above Pinedale deposits as undivided (Qgo), till in distinct vegetated moraines (Qgmo), and outwash (Qgao); see sub-unit differences under undivided glacial units (Qg, Qgm, Qga); mapped moraines have well-developed soil and subdued moraine morphology; located down drainage or laterally upslope from Pinedale glacial deposits (Qgp, Qgmp, Qgap); may have two Bull Lake moraines and deposits, or Bull Lake and pre-Bull Lake deposits (on plate 1 labeled bl and pre-bl?); Bull Lake glaciation age about 95 to 153 ka (see Chadwick and others, 1997; Phillips and others, 1997; Licciardi and Pierce, 2008, 2018); unit symbols queried where age uncertain or identification as glacial deposits is uncertain; estimated 0 to 160 feet (0–50 m) thick from topography and geologic mapping; ground moraine and outwash thinner.

Potential pre-Bull Lake glacial deposits (pre-bl?) are possibly above Jacobs Creek, and likely between Middle and Left Hand Forks of Peterson Creek, Dalton Creek, north of Smith Creek and between forks of Line Creek; may have deposits this old on west side of Wasatch Range up Middle Fork of Kays Creek. The pre-Bull Lake deposits may be related to the Pokes Point lake cycle (see unit Qaoe and table 2 for timing).

Qgr, Qgr?

Rock glacier deposits (Holocene and uppermost Pleistocene) – Angular, mostly cobble- to boulder-sized debris with little matrix in un-vegetated mounds with lobate crests; includes protalus ramparts; probably inactive (no ice matrix); in Peterson quadrangle mapped in several cirques on east flank of Wasatch Range and, as Qgr?, in cirques up Middle Fork of Kays Creek and Holmes Creek on west flank; may be as much as about 10,000 years old (m1-2) and as young as Little Ice Age (A.D. 1500 to 1800) (see for example Luckman, 1986); likely 0 to 30 feet (0–9 m) thick. Map unit symbol queried where unit may be entirely protalus ramparts, in which ice matrix was never present.

Mass-Movement Deposits

Qmdf, Qmdf?

Debris- and mud-flow deposits (Holocene and upper Pleistocene) – Poorly sorted, clay- to boulder-sized material in unstratified deposits characterized by rubbly mounded surfaces, natural lateral levees, channels, and lobes; variably vegetated; in drainages, typically form mounded surfaces rather than being flat like unit Qac, possibly indicating Qmdf is more viscous; many debris-flow deposits cannot be shown separately from alluvial fans at map scale; age(s) uncertain; deposits in drainages likely post-date the Provo shoreline of Lake Bonneville, whereas deposits on slopes are likely as old as Pinedale glaciation, but could pre-date Lake Bonneville; 0 to 40 feet (0–12 m) thick. Map unit symbol queried where may not be debris flow.

Qmdfp, Qmdfo, Qmdfo?

Lake Bonneville age and older debris- and mud-flow deposits (upper and middle? Pleistocene) – These units are like Qmdf, including thickness, but are above present drainages and may be glacial outwash deposits (Qgap, Qgao). Qmdfp only mapped south of Smith Creek and may be related to upper Pleistocene Pinedale recessional glacial deposits or be a failure of younger adjacent Provo shoreline related alluvium (Qap). Qmdfo and Qmdfo? only mapped north of Right Hand Fork of Peterson Creek; Qmdfo? is truncated up drainage (slope) by later landslides and may be related to Bull Lake glacial deposits (like Qmdfo), or be related to middle Pleistocene pre-Bull Lake glaciation, or be alluvial deposits of some other age.

Qms, Qms?, Qmsh, Qmsy, Qmso, Qmso?

Landslide deposits (Holocene and Pleistocene) – Poorly sorted clay- to boulder-sized material; includes slides and slumps and locally flow and flood deposits; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced blocks; composition depends on local sources; morphology becomes more subdued with time and amount of water in material during emplacement; thickness highly variable, because boreholes in Snow Basin quadrangle indicate about 20 to 30 feet (6–9 m) thick in small slides/flows (see Rogers, 1986), and 80 to 100 feet (25–30 m) thick for larger landslides; unit Qms may be in contact with unit Qms where two different/distinct slides abut; Qms and Qmso queried (?) where identification as a landslide uncertain. Numerous landslides are too small to show at map scale and typically landslides less than 6 feet (2 m) thick have not been mapped.

Qms without suffix is mapped where the age is uncertain (though likely Holocene and/or late Pleistocene), where portions of slide complexes have different ages but cannot be shown separately at map scale, or where boundaries between slides of different ages are not distinct. The estimated time of emplacement is indicated by relative-age number and letter suffixes with: h = mostly historical, likely emplaced in the last 80 to 150 years, with unvegetated scarps; y = younger than Bonneville shoreline, and mostly pre-historic, landslides deflect streams or failures are in Lake Bonneville deposits, and scarps are variably vegetated; and o = likely older than (emplaced before) Lake Bonneville transgression. Suffixes y and o indicate probable Holocene and Pleistocene ages, respectively. Qmso typically mapped where deposits are perched above present drainages, rumpled morphology typical of mass movements has been diminished, and/or younger surficial deposits cover or cut Qmso. These older deposits may be as unstable as other landslides, and are easily reactivated with the addition of water, be it rain, snow melt, altered drainage, irrigation, or septic tank drain fields.

Qms(QTaf?), Qms(QTao), Qms(Ts), Qms(Tn), Qms(Tn?), Qms(rx)

Qms?(QTaf), Qms?(rx), Qms?(Ts), Qms?(Tn), Qms?(Tn?), Qms?(Tw), Qms?(Xfc)

Qmso(Tn), Qmso(Xfc)

Qmso?(Tn), Qmso?(Xfc)

Block landslide and possible block landslide deposits (Holocene and upper and middle? Pleistocene) – Mapped where nearly intact block is visible in landslide (mostly block slide) with stratal strikes and dips that are different from nearby in-place bedrock; unit in block shown in parentheses, for example Qms(Tw); composition depends on unit in block; see surficial deposits or rock unit in parentheses for descriptions of blocks; rx indicates multiple or unknown bedrock unit(s); thickness highly variable, up to about 20 to 30 feet (6–9 m) for small slide blocks, and cross sections show larger blocks are about 150 feet (45 m) thick. Relative ages are like those for other landslide deposits (Qms, Qmso).

Unit symbols queried (Qms?, Qmso?) where bedrock block may be in place, as suggested by stratal strikes and dips in the block that are about the same as nearby in-place bedrock.

Qmc, Qmc?

Landslide and colluvial deposits, undivided (Holocene and Pleistocene) – Poorly sorted to unsorted clay- to boulder-sized material; mapped where landslides are difficult to distinguish from colluvium (slopewash and soil creep) and where mapping separate, small, intermingled areas of landslide and colluvial deposits is not possible at map scale; locally includes talus and debris flow and flood deposits; typically mapped where landslides are thin (“shallow”); also mapped where the blocky or rumpled morphology that is characteristic of landslides has been “smoothed” (diminished) by slopewash and soil creep; composition depends on local sources; unit symbol queried where identification is uncertain; 0 to 40 feet (0–12 m) thick. These deposits may be as unstable as other landslide units (Qms, Qmsh, Qmsy, Qmso).

Qmt, Qmt?

Talus (Holocene and Pleistocene) – Unsorted clay- to boulder-sized angular debris (scree) at the base of and on steep slopes; typically on unvegetated slopes in cirques in Wasatch Range; only larger debris fields can be shown at map scale; includes colluvium locally and grades laterally into Qct; unit symbol queried where identification is uncertain; 0 to 30 feet (0–9 m) thick.

Deposits west of Francis Peak are unique in that they are not in cirques and almost look like they have flowed downhill, possibly due to periglacial solifluction.

Qct, Qct?

Colluvium and talus, undivided (Holocene and Pleistocene) – Unsorted, clay- to boulder-sized, angular debris (scree) at base of and on steep, typically partly vegetated slopes of Wasatch Range; unit symbol queried where identification is uncertain; 0 to 30 feet (0–9 m) thick.

Qc, Qc?

Colluvium (Holocene and Pleistocene) – Unsorted clay- to boulder-sized material; includes materials moved by slopewash and soil creep; composition depends on local sources; unit symbol queried where identification is uncertain; generally 6 to 20 feet (2–6 m) thick; not mapped where less than 6 feet (2 m) thick.

Qcg, Qcg?

Gravelly colluvial deposits (Holocene and Pleistocene) – Clay to boulder-sized material moved by slopewash and soil creep downslope from gravel-rich rocks and deposits of various ages, for example units Tcg, QTaf, QTay/QTao, Qafoe/Qaoe, and Qafo/Qao; may contain residual deposits; typically differentiated from colluvium and residual gravel (Qc, Qng) by prominent stripes trending downhill on aerial photographs; stripes are concentrations of gravel up to boulder size; unit symbol queried where identification is uncertain; generally 6 to 20 feet (2–6 m) thick; some deposits previously included in the Huntsville fanglomerate (see Coogan and others, 2015).

Mixed Deposits

Qac **Alluvium and colluvium** (Holocene and Pleistocene) – Unsorted to variably sorted gravel, sand, silt, and clay in variable proportions; includes stream and fan alluvium, colluvium, and, locally, mass-movement deposits too small to show at map scale; typically mapped along smaller drainages that lack flat bottoms; 0 to 20 feet (0–6 m) thick.

Qla **Lake Bonneville lacustrine deposits and post- and pre-Lake Bonneville alluvial deposits, undivided** (Holocene and upper? Pleistocene) – Mostly poorly sorted and poorly bedded sand, silt, and clay, with some gravel; mapped in Peterson quadrangle near Bonneville shoreline (about 5180 feet [1579 m] elevation in area) where lake deposits are reworked by stream action; deposits typically eroded from shallow Norwood Formation; thickness uncertain.

Qng **Gravel deposits** (Holocene and Pleistocene?) – Poorly sorted pebble to boulder gravel in a matrix of silt and sand; mostly gravel-armored deposits on and near alluvial and colluvial deposits like units Qcg, Qab, Qao, and QTaf; locally on gravel-rich bedrock (Tcg); typically have gently dipping upper surface; generally 6 to 20 feet (2–6 m) thick; mapped in northeast corner of Peterson quadrangle and on benches above streams in east part of quadrangle. Gravel of uncertain origin probably includes alluvium, colluvium, and/or residuum.

Qmg, Qmg?

Mass-movement and glacial deposits, undivided (Holocene and Pleistocene) – Unsorted and unstratified clay, silt, sand, and gravel; mapped where glacial deposits lack typical moraine morphology, and appear to have failed or moved down slope; unit symbol queried where may be either mass-movement or glacial deposits; likely less than 30 feet (9 m) thick; may be thicker in cirque at the head of the South Fork of Kays Creek and the queried deposits at the head of North Fork of Holmes Creek (above Adams Canyon), both on the west side of the Wasatch Range.

Qdlg **Lake Bonneville deltaic and lacustrine deposits, undivided** (upper Pleistocene) – Mostly sand, silty sand, and gravelly sand deposited near shore as the lake transgressed to and was at the Bonneville shoreline; only mapped in the Peterson quadrangle under Qlf as a stacked unit (Qlf/Qdlg); in Morgan Valley it is more gravel rich and cobbly than in the Snow Basin quadrangle along Cottonwood Creek; 34 feet (10 m) thick below yellow clay (Qlf) in water well south of Peterson and at least 40 feet (12 m) thick in the Snow Basin quadrangle.

Qadb **Lake Bonneville alluvial-fan and deltaic deposits, undivided** (upper Pleistocene) – Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where shorelines are obscure, so that line cannot be drawn between alluvial fan and delta; typically better sorted delta and lake deposits over poorly sorted alluvial-fan deposits; in the Peterson quadrangle, present on both sides of the Weber River above the Provo shoreline and deposited as the lake transgressed to the Bonneville shoreline; Qadb mapped above Dry Hollow and Peterson and Dalton Creeks and on north edge of quadrangle near big fans; best developed along Deep Creek to the southeast in the Morgan quadrangle and Strawberry Creek to the north in the Snow Basin quadrangle; at least 40 feet (12 m) thick.

Qh **Human disturbance** (Historical) – As mapped obscure original rocks or deposits by cover or removal; only larger disturbances shown; includes engineered fill, particularly along Interstate Highway 84 and the Union Pacific Railroad grades, and some dam fill and large gravel pits; also at Francis Peak radar station. Edges of disturbances that post-date the 1986 aerial photographs used to map the geology in this quadrangle are shown with hatchures and were added from and are visible on 2006, 2009, and/or 2011 orthophotographs of the quadrangle.

QUATERNARY AND TERTIARY

QTa, QTay?, QTao, QTao?

High-level alluvium (lower Pleistocene and/or Pliocene) – Variably sorted gravel, sand, silt, and clay above other stream-terrace and alluvial-fan deposits; located above Qaoe; typically contains more boulders than lower alluvium (including units Qafoe and Qaoe); at least locally gravel-armored and poorly sorted; where possible, divided into younger (y) and older (o) based on relative height of deposits above drainages (see table 1) and elevation difference of more than 150 feet (45 m) on adjacent high-level alluvial deposits; in Morgan Valley, heights above drainages overlap and appear to decrease upslope with QTay about 215 to 450 feet (66–137 m) above drainages and QTao about 320 to 800 feet (100–240 m) above drainages; queried due to overlap and wide range in heights above drainages; due to uncertainty in correlating alluvial remnants, QTay may be 780 ka or older based on Brunhes-Matuyama paleomagnetic reversal (see table 2); estimated 10 to 80 feet (3–24 m) thick. The age(s) of these deposits and unit QTaf might be refined if a Lava Creek B, Bishop, Mesa Falls, and/or Huckleberry Ridge ash were found in them (see table 2). Some of these deposits were previously included in the Huntsville fanglomerate (see Coogan and others, 2015).

QTaf, QTaf?

High-level alluvial-fan deposits (lower Pleistocene and/or Pliocene) – Gravel, sand, silt, and clay above other stream-terrace and alluvial-fan deposits (including QTa and QTao); typically contains more boulders than alluvium younger than QTao and QTa (including units Qafoe and Qaoe); at least locally gravel-armored and poorly sorted; unit symbol queried where age uncertain due to height not fitting into ranges in table 1 and/or typical order of surfaces contradicts height-derived age; slightly eroded fans are present about 320 to 1000 feet (100–300 m) above and south of the Weber River in Morgan Valley and decreasing upslope to about 230 feet (70 m) above adjacent streams; QTaf may encompass two sets (ages) of fans because one fan is ~360 and 520 feet (110–160 m) above adjacent drainages while several eroded fans are lower (~230 to 300 feet [70–90 m] above adjacent drainages and downslope) and may be upstream equivalents of unit QTay; best example of lower and upper surfaces is south of Line Creek; estimate fans are 30 to 200 feet (9–60 m) thick.

On the margin of the slightly eroded fan south of the Weber River, we mapped high-level fan over the Norwood Formation (QTaf/Tn) although the fan cover material may be older than the slightly eroded QTaf fan adjacent to it.

STACKED UNITS

Numerous stacked units are on this map. This is partly a result of the compromise between showing surficial deposits and bedrock on the same map. By stacked, we mean a thin covering of one unit over another, which is shown by the upper map unit (listed first) then a slash and then the underlying unit (for example, Qc/Tw). The upper unit is typically an unconsolidated surficial deposit and the lower unit is rock (Q__-/rx), but exceptions are present. We map the stacked units where it is important to show both units as they have potential geologic hazards and/or economic value (for example landslides or landslide-prone impermeable clayey bedrock units, and sand and gravel). The upper unit is typically about 6 feet (2 m) thick and conceals but does not obscure the lower unit. This thickness was chosen because a building foundation would penetrate a thinner upper unit, particularly colluvium (Qc), making it a small factor in construction. We have not mapped most of the colluvium as it is thinner than 6 feet (2 m) and we can tell what unit is underneath. The exceptions to this approach are where the thin deposits obscure the geologic details of faulting, lithologies, and age relationships. The underlying unit in the stack has been identified based on exposures at the edges of the stacked unit and small exposure windows (gaps) or excavations in the cover that cannot be shown at map scale, and materials in the cover that came from the underlying unit.

Qc/Qmso, Ql/Qmso, Ql/Qmso?, Qlf/Qmso, Qlf/Qmso?, Qapb/Qmso, Qab/Qmso

Surficial deposits over mass-movement deposits – These units were mapped because they inform the map user about underlying potential landslide hazards.

Qms/Qa, Qmc/Qadb

Mass-movement deposits over surficial deposits – These units were mapped because they inform the map user about overlying potential geologic hazards.

Ql/Tn, Qlf/Tn, Qlf/Tn?, Qls/Tn, Qaoe?/Tn, Qafoe?/Tn, QTa/Tn, QTaf/Tn, QTaf/Tn?

Surficial deposits over bedrock – The units were mapped because they inform the map user about potential geologic hazards due to the underlying landslide-prone and impermeable clayey bedrock of the Norwood Formation.

Qafy/Qap, Qlf/Qdlg

Surficial deposits over surficial deposits – These units were mapped because they inform the map user about stratigraphic age-relation details seen in the field that went into the Quaternary correlation chart.

EXPOSED BEDROCK UNITS

TERTIARY

Ts **Tertiary strata, undivided** (Oligocene-upper Paleocene?) – Used where the Norwood and Wasatch Formations are likely in landslide blocks Qms(Ts) or are in what may be landslide blocks – Qms?(Ts).

Tcg **Unnamed Tertiary conglomeratic rocks** (Oligocene?) – Only mapped in the northeast corner of the Peterson quadrangle east of the Weber River. Characterized by rounded, pebble- to boulder-sized, quartzite-clast conglomerate with less than 10 to more than 50 percent gray, tan, or reddish-gray to reddish-tan claystone/mudstone matrix; interbedded with tan, gray and reddish-brown, pebble-bearing mudstone to sandstone and some claystone (altered tuff); most beds poorly indurated and poorly exposed; some non-conglomeratic beds in Tcg look like the gray upper Norwood Formation (Tn) and are locally tuffaceous; some Tcg pebble beds have carbonate and chert (like Norwood beds) and lesser quartzite clasts; to northeast in Durst Mountain quadrangle, Tcg conglomerates include rare altered tuff clasts from Norwood Formation (Tn) (see Coogan and King, 2006; Coogan and others, 2015); locally erodes to gravel-covered slopes; locally includes landslides that are too small to show at map scale; despite clay matrix, seems less prone to mass movements than Norwood strata; only base of unit exposed in the Peterson quadrangle, the map unit is about 700 feet (210 m) thick where upper and lower contacts are exposed in the adjacent Morgan quadrangle (see Coogan and others, 2015).

The Tcg-Tn contact is problematic because altered tuff (Tn) and conglomerate (Tcg) are interbedded and the contact lacks an angular unconformity. In the Durst Mountain quadrangle, the Norwood and at least the lower part of this map unit (Tcg) are interbedded (Coogan and King, 2006), so Oligocene(?) age.

Tn, Tn?

Norwood Formation (lower Oligocene and upper Eocene) – Typically light-gray to light-brown, altered tuff (claystone), tuffaceous siltstone, sandstone, and conglomerate; locally colored light shades of red and green; variable calcareous cement and zeolitization that is less common to south, such that extensive unaltered tuff is present in southern Peterson quadrangle; zeolite and other marker beds mapped as an aid to recognizing geologic structure (green dashed lines); involved in numerous landslides of various sizes and locally includes landslides that are too small to show at map scale; landslides are due to high clay content and Norwood is an aquitard; based on outcrop pattern, dip, and topography, the Norwood is at least 7000 feet (2135 m) thick to the northwest in the Snow Basin quadrangle (King and others, 2008) and thins to the south so about 5000 feet (1525 m) thick where exposed west of the Weber River north of Morgan; about 2800 foot (850 m) thickness exposed east of East Canyon Creek (and Morgan Valley syncline axis) in type area (Eardley, 1944) in Porterville quadrangle (see also Bryant and others, 1989, p. K6); note that the type-area thicknesses reported in Coogan and King (2006) and King and others (2008) are incorrect.

Unit symbol queried where identification is uncertain, typically because of poor exposures and/or red coloration inherited from eroding underlying Wasatch Formation (Tw); see Coogan and others (2015) for such complications on the east side of Morgan Valley.

The Norwood is different in the southern Peterson and Morgan quadrangles, nearer the type area (see Eardley, 1944), as it contains extensive unaltered tuff (hence his name Norwood Tuff), has cut-and-fill structures (fluvial), and includes volcanic-clast conglomerate beds. In the Morgan quadrangle, it also contains local limestone and silica-cemented rocks (Coogan and others, 2015). The Norwood map unit is herein referred to as Norwood Formation, rather than Norwood Tuff, because the type area includes only part of the formation (see thickness discussion), the Norwood contains many lithologies, and this emphasizes that it is not glassy away from the type area (see Coogan and others, 2015; Coogan and King, 2016).

Corrected Norwood 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 southeast in 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). The sample from near the type area, and a *Protoreodon* fossil (Adamson, 1955, p. 39), are from near the top of the section exposed east of East Canyon Creek. The relationships to other volcanic deposits of similar age are in the Tertiary Geology section of this report.

Tw, Tw?

Wasatch Formation (Eocene and upper Paleocene) – Typically red-weathering conglomerate, as well as lesser sandstone, siltstone, and mudstone; clasts typically rounded and from Precambrian and Paleozoic rocks; lighter shades of red, yellow/tan, and light gray more common in upper Wasatch near contact with Norwood Formation; basal conglomerate less likely to be red since dominated by locally derived material, with clasts of Precambrian crystalline rocks; thickness varies due to relief on basal and overlying erosional surfaces; thickness uncertain; locally includes landslides that are too small to show at map scale; involved in landslides because it is at least locally clay rich and poorly consolidated. Permeability in the Wasatch Formation is complicated due to clay content, limestone beds, and variable cementation that is so strong in some areas that quartzite clasts are broken through rather than around during fracturing. The variability is indicated by perched springs in the unit. Unit symbol queried where identification as Tw is uncertain.

The Wasatch seems to be about 1600 feet (490 m) thick where exposed on the north margin of the map area but the contact with Precambrian rocks is likely faulted and the 40 degree stratal dip is uncertain; a 30 to 45 degree dip range gives a 1250 to 1767foot (380–540 m) thickness range for a 2500-foot (770 m) outcrop width (not adjusted for topography because dip range is the largest factor). The Wasatch is thicker in the central part of map area, about 2700 feet (830 m) thick from a 4200-foot (1300 m) outcrop width and 40 degree dip (not adjusted for topography); then it thins in the south part of map area to about 2000 feet (620 m) from a 3200-foot (1000 m) outcrop width and a 40 degree dip (not adjusted for topography). King estimates the Wasatch is 2350 feet (725 m) thick, from a 3650-foot (1125 m) outcrop width and a 40 degree dip along the line of cross section (not adjusted for topography). The Norwood Formation unconformably overlies these Wasatch strata so this apparent variation may only be a difference in the amount of Wasatch covered by Norwood. The Wasatch Formation may be even thicker to the east in the subsurface, because the total thickness on the east side of Morgan Valley is estimated as 5000 to 6000 feet (1500–1800 m) (Coogan and others, 2015).

Eocene and upper Paleocene age based on palynology of Wasatch strata to the northeast (Coogan and King, 2016, appendix table 1, sample 97-7, P4-5 palynomorphs and sample 97-13, Eocene palynomorphs) and southeast (Jacobson and Nichols, 1982, figure 7, P5 and P5-6 samples P3044-2A, 3B, and P3387-2 updated with mapping by Bryant, 1990; Jacobson and Nichols, 1982, figure 11, P5-P6 samples P2833-1 and P2833-2, updated with mapping from Coogan and King, 2016). Also to the southeast, Wasatch strata contain P5-6 palynomorphs (upper Paleocene), and the palynomorph *Platycarya platycaryoides* (Nichols and Bryant plate 2 in Bryant, 1990, sample D6052), which is Eocene (see Nichols, 2003). We used Jacobson and Nichols (1982) for Paleocene (P) biozones based on palynology and their Paleocene-Eocene boundary, which is likely the C24 paleomagnetic reversal (see Hicks and others, 2003). Other Eocene-Paleocene boundaries would put P6 palynomorphs in the Eocene and P stands for Paleocene.

Wasatch debris, in a landslide west of the range crest (labeled Tw debris in section 5, T. 5 N., R. 1 E.), is the only Wasatch material in the Peterson quadrangle that is on the Wasatch Range. The debris appears to be associated with an Eocene-Paleocene deeply weathered erosion surface (paleosol) (tan soil of Bell, 1951; see Wilf, 2000).

CRETACEOUS

KXc, KXc?

Chloritic gneiss, cataclasite, mylonite, and phyllonite (Cretaceous and Proterozoic) – Dark- to gray-green, variably fractured and altered rock with local micaceous cleavage; contains variable amounts of fine-grained, recrystallized chlorite, muscovite, and epidote; present in shear and fracture zones, and in diffuse altered zones associated with quartz bodies that crosscut basement rocks (Yonkee, 1992; Yonkee and others, 1997); in the Peterson quadrangle, typically non-resistant and locally hematite stained; some linear zones of this unit mapped as faults by Bryant (1984, 1988); unit symbol queried where poorly exposed, so identification uncertain. Unit produced by mostly Cretaceous deformation and greenschist-facies alteration that overprints various Farmington Canyon Complex protoliths (Yonkee and Lowe, 2004). However, Bryant (1988) indicated that some quartz veins and pods may be related to Precambrian alteration.

SUBSURFACE PALEOZOIC UNITS

The units present in the subsurface below the Wasatch Formation in Morgan Valley are not known, because the width and height of the Wasatch anticlinorium is uncertain, the amount of erosion of the Ogden thrust sheet and sub-thrust strata are uncertain, and the subsurface structure has been interpreted differently (compare Bryant, 1990, cross-section C-C'; Royse, 1993, cross-section H-H'; Yonkee and others, 1997, cross-section B-B'; Yonkee and others, 2003). Also the Paleozoic Tooele arch and Stansbury uplift have affected the area, so the units exposed to the north in the Ogden Canyon area (Yonkee and Lowe, 2004; King and others, 2008) are not the same as those to the east on Durst Mountain (Coogan and King, 2006; Coogan and others, 2015), or those exposed to the south in the Wasatch Range near Salt Lake City (see Bryant, 1984, 1988, 1990; Van Horn and Crittenden, 1987). Because the Paleozoic erosion increased to the south and the Durst Mountain exposures are directly east of the Peterson quadrangle, we have emphasized descriptions of the Durst Mountain exposures. We have attempted to present undeformed unit thicknesses although thicknesses in the area are highly variable due to tectonic thinning and duplication (see for example Yonkee and others, 1997; Yonkee and Lowe, 2004). Following Coogan (Western State College [now Western Colorado University], July 2, 2005, unpublished digital cross section), we have shown eroded Mississippian and older Paleozoic strata below the Wasatch Formation, and have not shown the Ogden thrust(s), although Yonkee and others (1997, 2003) did.

MISSISSIPPIAN

Mdo **Doughnut Formation** (Upper Mississippian) – Upper part is limestone and siltstone that is about 300 feet (90 m) thick on Durst Mountain; lower part is siltstone, black shale, and limestone that is typically less resistant than adjacent map units and is about 200 feet (60 m) thick on Durst Mountain (Coogan and others, 2015) where not attenuated.

Mh **Humbug Formation** (Upper Mississippian) – Gray to tan limestone in upper part and quartzose sandstone with limestone and dolomite interbeds in lower part; about 700 to 800 feet (215–245 m) thick north of Ogden Canyon (after Sorensen and Crittenden, 1974); about 700 feet (215 m) thick on Durst Mountain (Coogan and King, 2006). Thickness uncertain because contact with underlying Deseret Limestone is not placed at a consistent horizon in the Ogden Canyon area of the Wasatch Range and on Durst Mountain, as both units contain sandstone and carbonate strata in varying proportions.

Mde **Deseret Limestone** (Mississippian) – Limestone, dolomite and sandstone, with dark, non-resistant, phosphatic shale at base (Delle Phosphatic Shale Member); about 500 feet (150 m) thick on Durst Mountain (Mullens and Laraway, 1973; Coogan and King, 2006); upper contact shown on the map of the Snow Basin quadrangle (King and others, 2008) is incorrect (see Coogan and King, 2016).

Mg-Ml

Gardison (Lodgepole) Limestone (Lower Mississippian) – Gray limestone and lesser dolomitic limestone, locally cherty; variably fossiliferous; estimate thickness as 650 to 800 feet (200–240 m); called Gardison Limestone in Wasatch Range by Sorensen and Crittenden (1972), Bryant (1984, 1988, 1990), Yonkee and Lowe (2004), and King and others (2008), and Lodgepole to east on Durst Mountain (Coogan and King, 2006).

DEVONIAN

Devonian and Cambrian strata that are exposed to the east on Durst Mountain and to the south in the Wasatch Range near Salt Lake City are a transitional shelf sequence between deeper-water marine strata exposed north of the map area on the Willard thrust sheet and shallower-water strata exposed to the east on the Crawford thrust sheet (see for example Coogan, 1992). Therefore, the use of Devonian Beirdneau, Hyrum, and Water Canyon names, along with Cambrian St. Charles, Nounan, and Bloomington names from the outer shelf sequence (Willard thrust sheet) may not be appropriate for the Durst Mountain strata, Ogden Canyon (Ogden thrust sheet) strata, and/or the strata near Salt Lake City. We chose to retain these Devonian and Cambrian formation names because: (1) they have been used previously (Williams, 1971; Sorensen and Crittenden, 1979; Crittenden and Sorensen, 1985; Yonkee and Lowe, 2004), (2) previous work on the Devonian and upper Cambrian strata in the area is confusing (see previous references as well as Eardley, 1944; Brooks and Andrichuk, 1953; Brooks, 1954; Schick, 1955; Brooks, 1959; Mullens and Laraway, 1973; Coogan and King, 2006), and (3), except for the Water Canyon, the strata, although thinner, are like the strata on the Willard thrust sheet. To the south near Salt Lake City, Bryant (1984, 1988, 1990) mapped different Devonian lithologies (Pinyon Peak and Stansbury Formations) related to the Stansbury uplift, that include erosion (unconformities) and clastic sediment deposition. Devonian age subdivisions are not noted due to unit name uncertainty.

Pinyon Peak Limestone (Devonian) – Pale tan to gray, thin-bedded nodular limestone containing gray shale interbeds; overlies Stansbury Formation near Salt Lake City; reportedly 165 to 200 feet (50–60 m) thick, but shown as 300 feet (90 m) thick in cross section (see Bryant, 1990); mostly younger than Beirdneau Sandstone so would be in the unconformity shown on Peterson quadrangle lithologic column.

Stansbury Formation (Devonian) – Light-gray to yellowish-gray, calcareous sandstone and siltstone, and silty limestone; some reddish shale; basal pale-gray to white laminated dolomite, dark-gray dolomite, and quartzite bed; unconformably overlies Maxfield(?) Formation near Salt Lake City with Devonian, Silurian, Ordovician, and Cambrian rocks missing; reportedly ~500 feet (150 m) thick, but shown as 300 feet (90 m) thick in cross section (see Bryant, 1990); roughly the same age as the Beirdneau Sandstone and contains similar rock types.

Db **Beirdneau Sandstone** (Devonian) – Gray to buff to orange-yellow to reddish-colored dolomitic to calcareous sandstone and siltstone, some silty to sandy dolomite and limestone, and lesser intraformational (flat-pebble) conglomerate; about 200 to 300 feet (60–90 m) thick on Durst Mountain (Coogan and King, 2006) and likely 250 to 300 feet (75–90 m) thick in Wasatch Range to west in Ogden Canyon area (see Sorensen and Crittenden, 1972, 1974). The Beirdneau-Hyrum contact likely not consistently mapped in adjacent quadrangles.

Dhw **Hyrum and Water Canyon Formations, undivided** (Devonian) – Missing near Salt Lake City.

Hyrum Dolomite (Devonian) – Dark- to medium-brownish-gray and gray dolomite and minor silty limestone; in center has less-resistant beds that grade laterally into reddish- colored, dirty carbonate like the Beirdneau Formation (Db); this gradation created problems in mapping Db-Dh contacts and estimating thicknesses; estimate 250 to 450 feet (75–140 m) thick on Durst Mountain (Coogan and King, 2006) and reportedly about 200 to 350 feet (60–105 m) thick to west near Ogden Canyon (after Sorensen and Crittenden, 1972, 1974; Yonkee and Lowe, 2004); unconformably overlies Water Canyon Formation.

Water Canyon Formation (Devonian) – Interbedded dolomitic to calcareous sandstone and sandy dolomite, and lesser limestone and calcareous siltstone, with distinctive light-colored carbonate at top; about 200 feet (60 m) thick on Durst Mountain (Coogan and King, 2006) and reportedly 30 to 100 feet (9–30 m) thick in Wasatch Range to west in Ogden Canyon area below Willard thrust sheet (Yonkee and Lowe, 2004).

SILURIAN AND ORDOVICIAN

Silurian and Ordovician strata are missing on Durst Mountain (Coogan and others, 2006) and to the south in the Wasatch Range near Salt Lake City (Bryant, 1990), along with all or most(?) of the St. Charles Formation equivalent strata (uppermost Cambrian), due to thinning over Stansbury uplift (see Rigby, 1959) and/or Tooele arch (see Hintze, 1959). Note that about 15 miles (25 km) to the north of the Peterson quadrangle in Ogden Canyon, 1000 feet (300 m) of Ordovician and upper Cambrian strata are present (Fish Haven, Garden City, and St. Charles Formations), as is part of the Bloomington Formation between the Nounan and Maxfield Formations. The Nounan, Maxfield, and Tintic Formations are also thicker in Ogden Canyon, although the Ophir Formation, between the Maxfield and Tintic Formations, is about the same thickness (see Yonkee and Lowe, 2004).

CAMBRIAN

Units below may not be directly comparable to Bryant's (1990); but overall, units are thinner on Durst Mountain than in the Wasatch Range.

Cn **Nounan Formation** (Upper and Middle Cambrian) – Medium-dark-gray, thick-bedded dolomite and limestone; estimated 350 to 400 feet (105–120 m) thick on Durst Mountain (see Coogan and King, 2006) and about 500 to 750 feet (150–230 m) thick in Ogden Canyon area in Wasatch Range (Yonkee and Lowe, 2004). Nounan not mapped to south near Salt Lake City by Bryant (1984, 1988, 1990), but likely present in his atypically thick Maxfield Limestone unit (Cm). Van Horn and Crittenden (1987) locally divided Bryant's Maxfield into an upper dolomite (likely the Nounan) and lower limestone (Maxfield).

Aerial-photographic reconnaissance of Sessions Mountain in Bryant's (1984, 1988, 1990) map areas shows a reddish-brown swale in roughly the middle of his Maxfield, which marks the lithologic change in Van Horn and Crittenden's (1987) Maxfield. This swale is characteristic of shales in the Bloomington Formation. To the north in Ogden Canyon, a similar or the same shale underlies the Nounan and is apparently 40 to 200 feet (10–60 m) thick (after Sorensen and Crittenden, 1972; Yonkee and Lowe, 2004).

Cbo **Bloomington Formation** (Cambrian) – Gray to olive-gray, silty argillite interlayered with thin- to medium-bedded, silty limestone, nodular limestone, and wavy-bedded (ribbon) limestone; thins over Tooele arch and not present on Durst Mountain and was not mapped to the south in the Wasatch Range (see Bryant, 1984, 1988, 1990; Van Horn and Crittenden, 1987). However, a shale appears to be present to the south on Sessions Mountain in the Wasatch Range (see Cn above) and appears to be about 130 feet (40 m) thick.

In Ogden Canyon the shale is lithologically similar to the Calls Fort (upper) and Hodges (lower) Shale Members of Bloomington Formation (King and others, 2008). *Eldoradia* sp. trilobite fossil in Ogden Canyon (Rigo, 1968, USGS No. 5949-CO) supports the correlation with the Calls Fort Member, but this would require the Maxfield Limestone to be partly equivalent to the Bloomington Formation.

Cm **Maxfield Limestone** (Middle Cambrian) – Limestone and calcareous siltstone; some dolomite at least locally; estimated thickness 300 feet (90 m) on Durst Mountain (Coogan and King, 2006; Coogan and others, 2015) and about 600 to 900 feet (180–270 m) thick in Ogden Canyon in Wasatch Range (Rigo, 1968; after Yonkee and Lowe, 2004). Because he reported a thickness of 1180 feet (360 m) and showed ~1400 feet (425 m) on his cross section, the Maxfield of Bryant (1984, 1988, 1990) and Van Horn and Crittenden (1987) likely includes all of the overlying Bloomington and Nounan Formations (see Cbo and Cn above) and may include upper and middle members of the underlying Ophir Formation.

Co **Ophir Formation** (Middle Cambrian) – Includes upper argillite member, middle limestone member and lower argillite member; argillites are brownish-gray to olive-gray, variably calcareous and micaceous argillite and slate with intercalated medium-gray limestone beds; middle limestone is thin- to medium-bedded, light- to medium-gray, with local silty partings to layers; total thickness at least 440 to 725 feet (135–220 m) on Durst Mountain (Coogan and King, 2006; Coogan and others, 2015) and about 300 to 650 feet (90–200 m) thick near Ogden Canyon (Yonkee and Lowe, 2004). Ophir of Bryant (1990) may or may not include upper and middle members because he reported a thickness of about 200 feet (60 m) but showed a cross-section thickness of 400 feet (120 m).

Ct **Tintic Quartzite** (Middle and Lower Cambrian) – Tan, very well-cemented quartzite; thin beds of argillite more abundant at top; conglomeratic in lower half with Precambrian quartzite pebbles and cobbles; basal 50 to 100 feet (15–30 m) is arkosic conglomerate of Farmington Canyon Complex material; about 1000 feet (300 m) thick on Durst Mountain (Coogan and King, 2006) and thickens to about 1100 to 1500 feet (335–450 m) to west in Wasatch Range (Sorensen and Crittenden, 1972; Yonkee and Lowe, 2004; King and others, 2008).

PROTEROZOIC, EXPOSED

Xfc, Xfc?

Farmington Canyon Complex, undivided (lower Proterozoic) – In approximate order of abundance, migmatitic gneiss, quartz-rich gneiss, and biotite-rich schist, with lesser layers to pods of white quartzite, pegmatite, amphibolite, mafic rocks, and meta-ultramafic rocks; pods and layers are typically gradational into surrounding rock, with diffuse unmappable contacts and/or too small to show at map scale. Bryant (1988) described these rocks as less migmatitic to the south and mapped a schist and gneiss unit (his Afs, our Xfcgs) south of a gradational contact with more migmatitic rocks (his Afm, our Xfcm) in the Peterson quadrangle.

All Farmington Canyon units display local retrograde alteration, largely chloritic, partly related to Cretaceous hydrothermal fluids. More information on the complex in the adjacent Ogden 7.5' quadrangle is available in Yonkee and Lowe (2004); see also Bryant (1988) for information on the complex in the Peterson, Snow Basin, Kaysville, and Bountiful Peak quadrangles as well as the Ogden 7.5' quadrangle. Barnett and others (1993) reported the various isotopic ages of the complex and concluded it is latest Paleoproterozoic (about 1700 Ma) in age. See also Nelson and others (2002) for $^{40}Ar/^{39}Ar$ age spectra (plateau) on amphiboles from the Santaquin, Utah area of the complex. Locally includes landslides that are too small to show at map scale. The Farmington Canyon Complex rocks are at least locally prone to slope failures because they have been deeply weathered to clay, likely during the Eocene and/or Paleocene (see for example Wilf, 2000), and possibly altered to clay on the west side of the Wasatch Range along the Wasatch Fault Zone during Basin and Range normal faulting. The map unit symbol is queried where Xfc may be completely covered by surficial deposits or unit may be the Wasatch Formation (Tw). Xfc label used in landslide blocks. Where possible rock types in the complex are divided into the following units:

Xfcm **Migmatitic gneiss** (lower Proterozoic) – Medium- to light-pink-gray, strongly foliated and layered (migmatitic) quartzo-feldspathic rock with widespread garnet and biotite; cut by variably deformed pegmatite dikes; unit also contains unmapped amphibolite bodies, granitic gneiss pods, and some thin layers of sillimanite-bearing, biotite-rich schist; contact with granitic gneiss and schist (Xfcgs) is gradational (after Yonkee and Lowe, 2004).

Xfcgs, Xfcgs?

Gneiss and schist (lower Proterozoic) – Biotite-feldspar-quartz gneiss and biotite schist, with less abundant layers of white quartzite; also contains pegmatite and amphibolite bodies; unit locally contains sillimanite-rich layers but does not contain widespread sillimanite or garnet like the biotite-rich schist, mapped and described by Yonkee and Lowe (2004), because the "degree" of metamorphism increases to the north. Garnet is present as a few percent in about half the schist and gneiss but is absent in the quartzite (Bryant, 1988).

This unit is basically Bryant's (1988) schist and gneiss unit Afs. Our very approximately located contact is south of Bryant's (1988, p. 15) contact and is based on the change in weathering from less resistant to the north to more resistant with brighter colored, strongly foliated(?) ribs of quartzite(?) to the south. The marker beds on the map are from changes in resistance. Some of these ribs are described as chloritized quartz phyllonites by Gloyn and others (1995); but, they are not mapped as such by Bryant (1988, part of his Afq unit and many of his faults) or in this report. Phyllonites are part of unit KXc in this report. The gneiss and schist unit is queried (Xfcgs?) on the south border of the map where it is poorly exposed and identification is uncertain.

Xfcp, Xfcp?

Pegmatite (lower Proterozoic) – Typically coarse-grained quartz, plagioclase, microcline, and biotite in varying proportions; unit symbol queried where identification uncertain, that is the outcrop was not field checked; likely contains muscovite where mapped by Bryant (1984) in the Peterson quadrangle. Bell (1951) also showed several pegmatites (and aplites) on his map and the two on the range crest in the Peterson quadrangle are visible and are therefore on our map.

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