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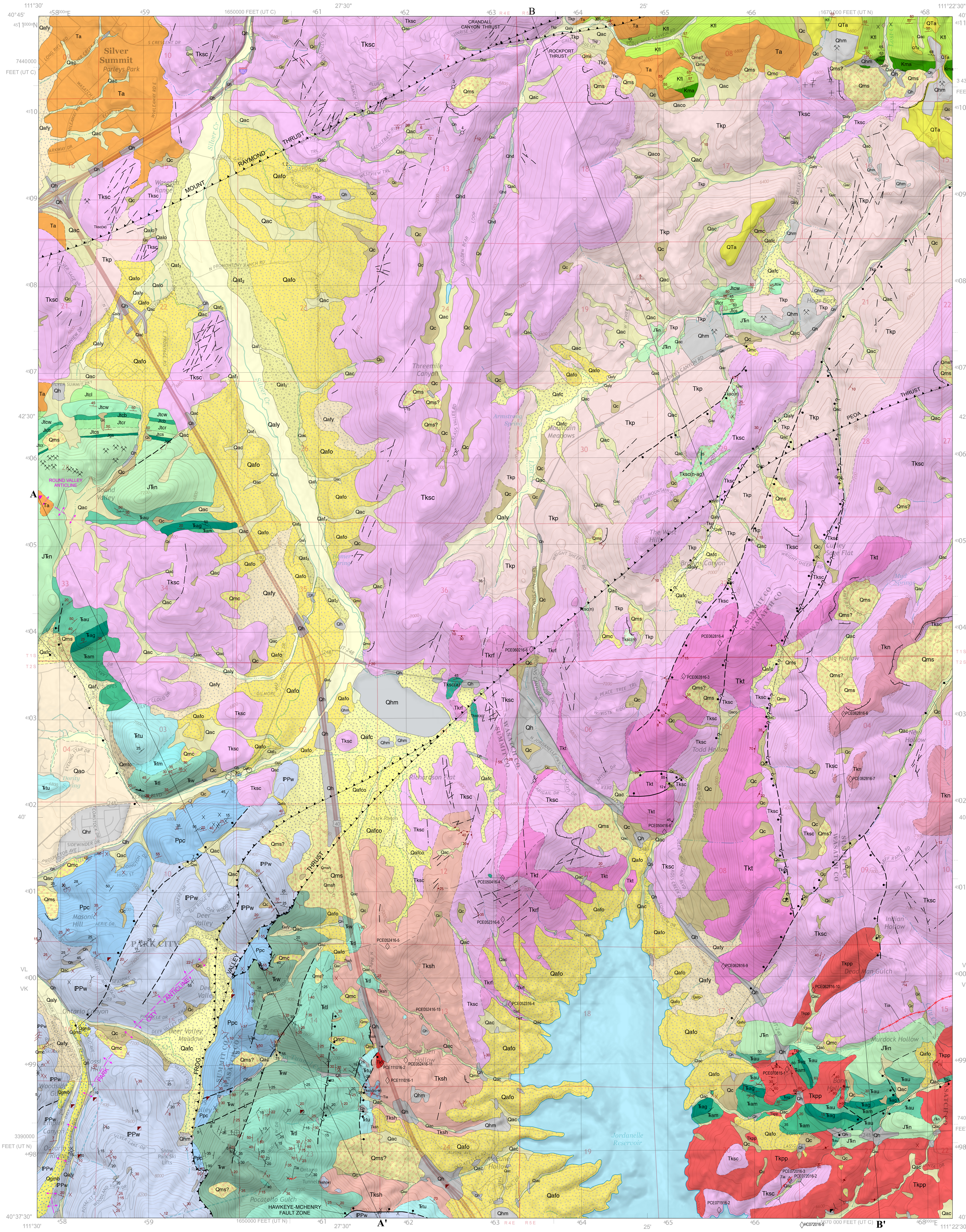

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Geology intended for use at 1:24,000 scale.

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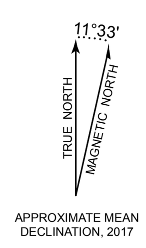


APPROXIMATE MEAN DECLINATION, 2017

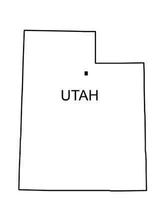
SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET

INTERIM GEOLOGIC MAP OF THE PARK CITY EAST QUADRANGLE, SUMMIT AND WASATCH COUNTIES, UTAH

by

Robert F. Biek

2017



QUADRANGLE LOCATION

Base from USGS Park City East 7.5' Quadrangle (2014)
Projection: UTM Zone 12
Datum: NAD 1983
Spheroid: Clarke 1866

Project Manager: Grant C. Willis
GIS and Cartography: Basia Matyjasik

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This map was created from Geographic Information System (GIS) data.

1	2	3
4		5
6	7	8

1. Big Dutch Hollow
2. Wanship
3. Crandall Canyon
4. Park City West
5. Kamas
6. Brighton
7. Heber City
8. Francis

ADJOINING 7.5' QUADRANGLE NAMES

Utah Geological Survey
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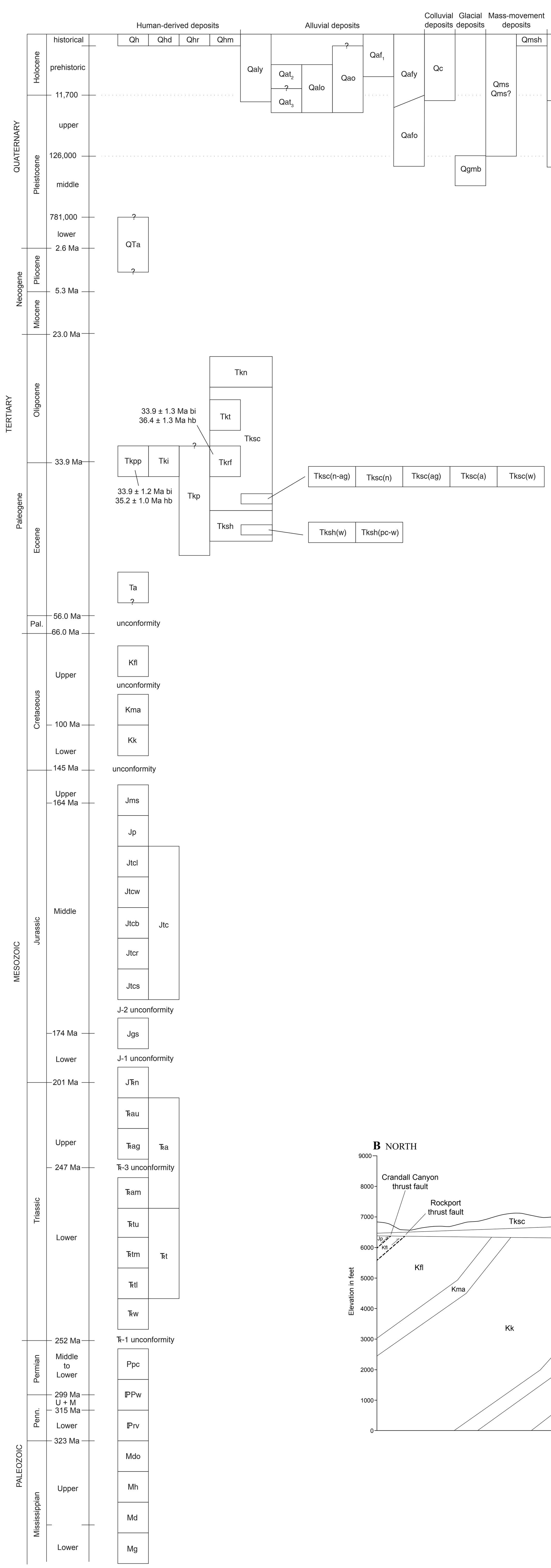
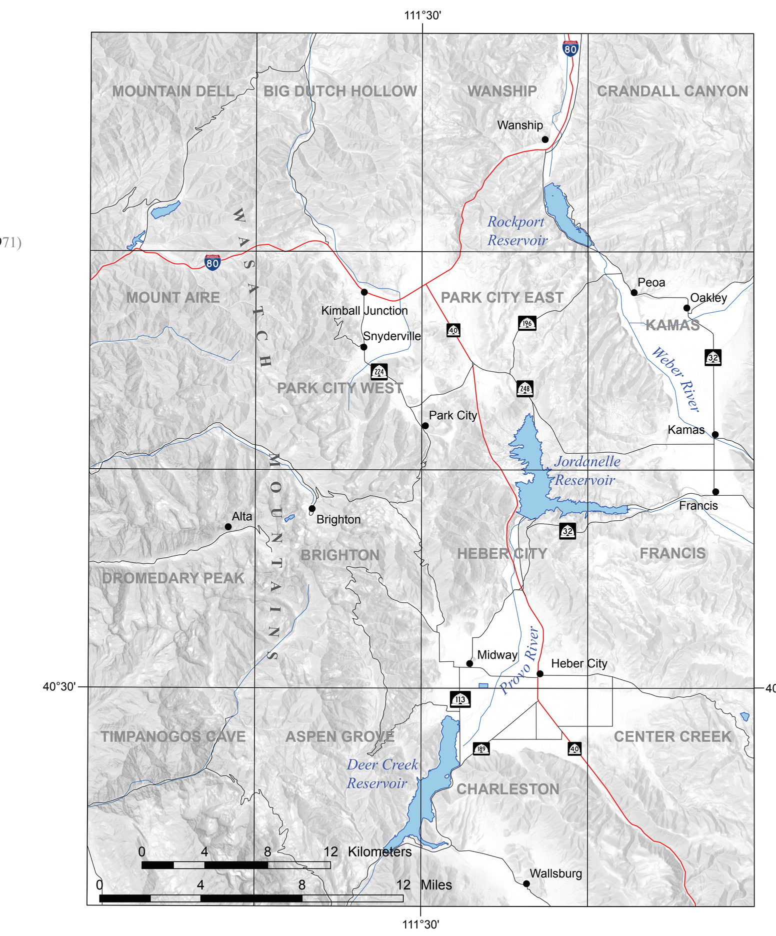
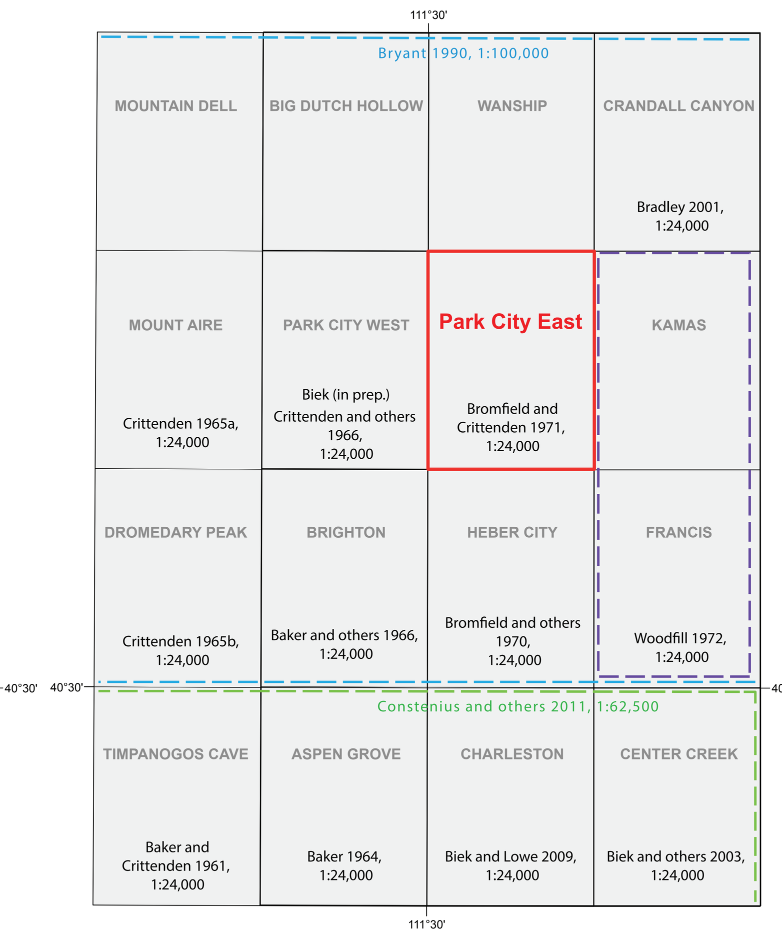
CORRELATION OF MAP UNITS

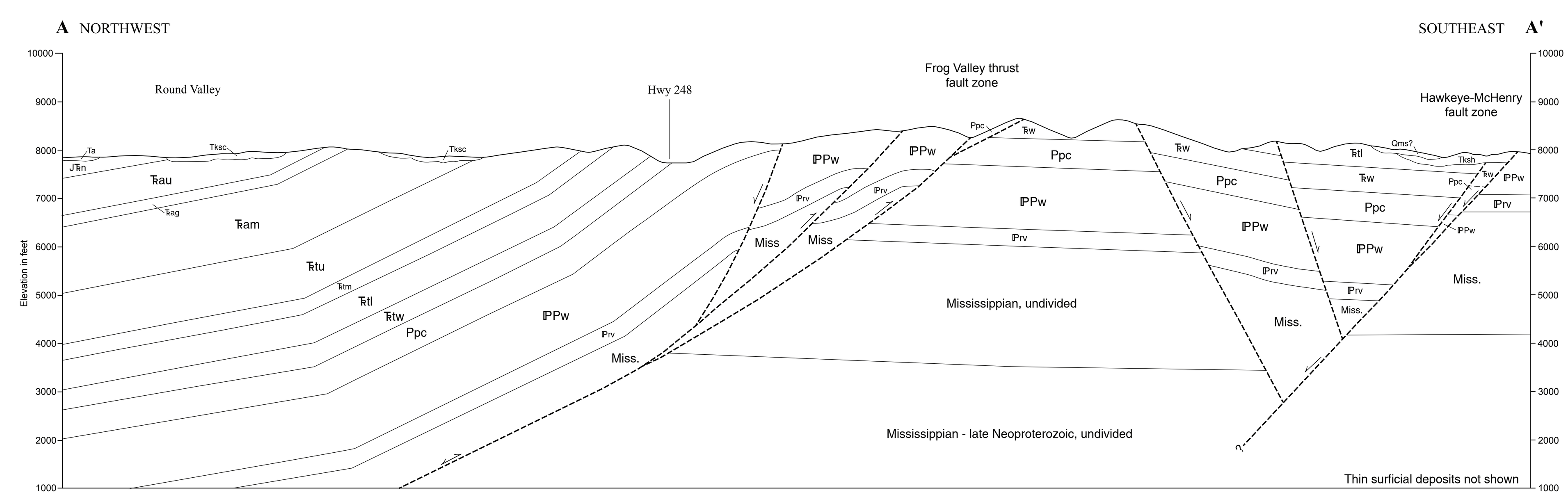


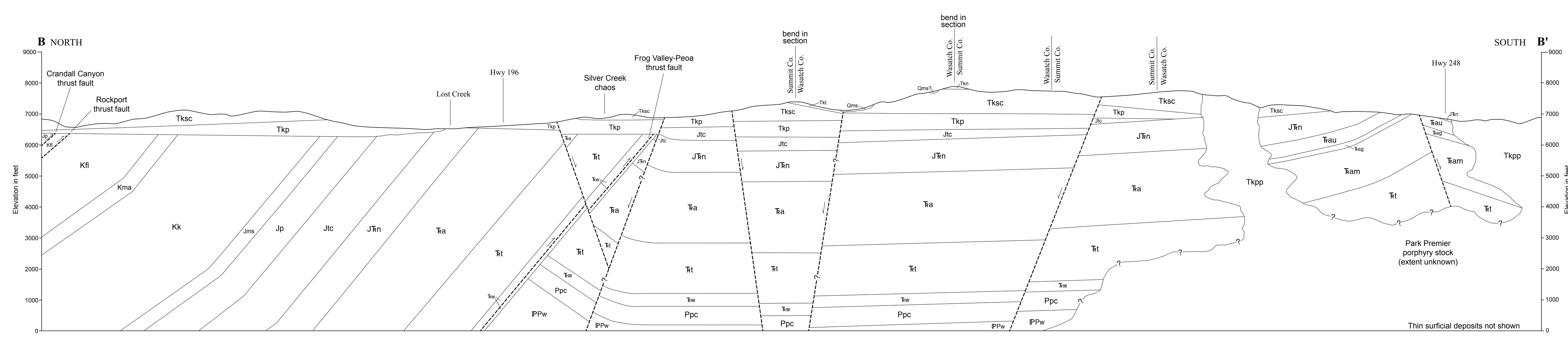
MAP SYMBOLS

- Contact, dashed where approximately located
- Normal fault – dashed where approximately located, dotted where concealed; queried where existence uncertain; bar and ball on down-thrown side
- Fault – uncertain origin and offset, dashed where approximately located, dotted where concealed
- Thrust fault – dashed where approximately located, dotted where concealed; saw teeth on upper plate
- Lineations visible on aerial photographs; most are likely joints, some may exhibit small displacement
- Approximate axial trace of anticline; dashed where approximately located, dotted where concealed
- Igneous dike
- Landslide scarp, hachures on down-dropped side
- 50 Strike and dip of inclined bedding; red symbols indicated attitudes from Bromfield and Crittenden (1971)
- 25 Strike and dip of inclined bedding determined photogrammetrically
- 30 Approximate strike and dip of inclined bedding
- Horizontal bedding
- 15 Strike and dip of foliation, red symbols are from Bromfield and Crittenden (1971)
- Strike of vertical foliation, red symbols are from Bromfield and Crittenden (1971)
- Small exotic blocks of the Silver Creek chaos
- Spring
- Sinkhole (plugged); see Condrat and Loughlin (in press)
- Quarry
- Quarry, inactive
- Sand and gravel pit
- 1 Approximate location of selected water well (see table 3)
- Exploration drill hole, plugged (see table 3)
- PCE 111016-2 Sample location and number
- Prospect, red symbols are from Bromfield and Crittenden (1971)
- Adit, inaccessible, red symbols are from Bromfield and Crittenden (1971)
- A — A' Line of cross section
- Shaft, inaccessible, from Bromfield and Crittenden (1971)









STRATIGRAPHIC COLUMN

Ma	System	Series	Map Unit	Map Symbol	Thickness feet (meters)	Regional Tectonic Setting	Depositional Environment	Dominant Rock Type and Weathering Profile	Notes
.012	QUATERNARY	Holocene, Pleistocene	various surficial deposits see correlation of map units		variable	modern basin and range extension	alluvium and mass-wasting deposits in modern drainages and basins	unconsolidated gravel, sand, silt and clay	Typically maximum thickness reported
2.6	Neogene	Pliocene	older alluvial deposits	QTa	20–30 (6–9)		ancestral Weber River	sand and gravel	
5.3		Miocene							
23.0	TERTIARY Paleogene	Oligocene	Keetley Volcanics, undivided: lava flows of Neel Hollow	Tku: Tkn	300 (90)	early extension and collapse of Sevier orogenic belt; development of Wasatch instrusive belt calc-alkaline volcanism	lava flows and volcanic mudflow breccias sourced from stratovolcanoes that once rose above the eastern stocks of the Wasatch intrusive belt; basal tuffaceous part deposited in floodplains and lakes	lava flows and volcanic mudflow breccia	Tia - andesitic dikes
			lava flows of Todd Hollow	Tkt	1000 (300)				Tkpp - Park Premier porphyry stock 33.9 ± 1.2 Ma bi 35.2 ± 1.2 Ma hb
33.9			volcanic mudflow breccia of Silver Creek	Tksc	1000 (300)				
			lava flows of Richardson Flat	Tkrf	200 (60)				Tki - latite porphyry stock
		Eocene	Silver Creek chaos	Tksc(_)	variable				
			flows and breccia of Sage Hen Hollow	Tksh	1300 (400)				
			exotic blocks	Tksh(_)	800 (245)				
			tuffaceous unit	Tkp	600 (180)			tuffaceous mudstone and sandstone	unconformity
56.0			Tertiary alluvial deposits	Ta	50+ (15+)		river channel and floodplain	conglomerate, sandstone, mudstone	unconformity
66.0		Paleocene							Laramide uplift of Uinta Mtns.
	CRETACEOUS	Upper	Frontier Fm. lower members, undivided	Kfl	2000+ (600+)	foreland basin; thrust faults and basin inversion	coastal plain, shoreline and brackish water	sandstone, siltstone, mudstone	
			Aspen Shale	Kma	400+ (120+)		shallow marine	shale	
100		Lower	Kelvin Fm., undivided	Kk	~3600 (~1100)		fluvial	sandstone, siltstone, cgl.	unconformity not exposed
	JURASSIC	Upper	Pruess Fm.	Jms	460 (140)	back bulge basin; Sevier Orogeny	fluvial, shallow marine	sandstone, mudstone	
		Middle		Jp	1000 (300)		shallow marine	sandstone, siltstone, anhydrite	
			Twin Creek Limestone: Leeds Creek Member	Jtc: Jtcl	1357 (414): 350+ (105+)		shallow marine: transgressive	argillaceous limestone	
			Watton Canyon Member	Jtcw	300–350 (90–105)			limestone	
			Boundary Ridge Mbr.	Jtcb	100 (30)		regressive	mudstone, siltstone, sandstone	
			Rich Mbr.	Jtcr	200 (60)		transgressive	argillaceous limestone	
			Sliderock Mbr.	Jtcs	100 (30)			limestone	J-2 unconformity
174			Gypsum Spring Fm.	Jgs	30 (9)		shallow marine transgression	silty sandstone	J-1 unconformity
		Lower	Nugget Sandstone	JTRn	1000+ (300+)	low-relief continental interior of a back-arc basin	vast eolian dune field of arid west coast subtropical desert	sandstone	large cross-beds
201	TRIASSIC	Upper	Ankareh Fm.: upper member	TRa: TRau	2100–2400 (655–745): 600–700 (180–210)		fluvial, floodplain and lake	mudstone, siltstone, sandstone	
			Gartra Grit Mbr.	TRag	200 (75)		braided river	pebbly sandstone	TR-3 unconformity
247		Lower	Mahogany Member	TRam	1300–1500 (400–460)		fluvial, floodplain and lake	mudstone, siltstone, sandstone	
			Thaynes Fm.: upper limestone member	TRt: TRtu	1600 (490): 1000 (335)	shallow-marine continental shelf	shallow marine	limestone calcareous sandstone shale	
			middle shale mbr.	TRtm	200 (60)		tidal flat	siltstone, sandstone	micaceous
			lower limestone mbr.	TRtl	300 (90)		shallow marine	limestone calcareous sandstone shale	
			Woodside Shale	TRw	400 (120)		tidal-flat and shallow marine	siltstone, sandstone	micaceous
252	PERMIAN	Middle to Lower	Park City and Phosphoria Fms., undivided	Ppc	~600 (~180)		shallow marine phosphatic shale is deeper water, oxygen-starved basin	limestone, cherty limestone, calcareous sandstone, phosphatic shale	TR-1 unconformity; phosphatic shale
299	PENN.	Upper to Middle	Weber Quartzite	IPPw	1300–1500 (400–460)		coastal eolian dune field and shallow–marine shelf	sandstone	indistinct bedding highly fractured
315		Lower	Round Valley Limestone	IPrv	225–400 (70–120)		shallow marine	limestone	not exposed
323	MISS.	Upper to Lower	Doughnut Fm.	Mdo	425 (130)			limestone	
			Humbug Fm.	Mh	800 (245)			sandstone, limestone	
			Deseret Fm.	Md	800 (245)			limestone, shale	
			Gardison Fm.	Mg	500 (150)			limestone	

INTERIM GEOLOGIC MAP OF THE PARK CITY EAST QUADRANGLE, SUMMIT AND WASATCH COUNTIES, UTAH

by Robert F. Biek

Disclaimer

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UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 677
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
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2017

MAP UNIT DESCRIPTIONS

QUATERNARY

Human-derived deposits

Qh **Artificial fill** (Historical) − Engineered fill and general borrow material used mostly for major highways and secondary roads that cross small drainages; includes large area of fill and disturbed land near the intersection of Utah Highway 248 and Browns Canyon Road; fill of variable thickness and composition should be anticipated in all developed or disturbed areas; mapped only where fill is typically 6 feet (2 m) or more thick.

Qhr **Reclaimed land** (Historical) – Approximate extent of reclaimed tailings pond along Silver Creek south of Kearns Boulevard.

Qhd **Disturbed land** (Historical) – General borrow material from adjacent, colluvium-covered slopes used to smooth the cross sectional profile of valley bottoms once occupied by incised, intermittent streams; mapped in Deer Valley Ski Resort area for larger ski runs and in the upper reaches of Threemile Canyon for a golf course; generally less than 10 to 15 feet (3–5 m) thick.

Qhm **Aggregate and building stone pits, mine dumps, and tailings ponds** (Historical) – Land disturbed by sand, gravel, aggregate, and building stone operations; extent of disturbed land based on 2009 NAIP imagery; land within these areas contains a complex, rapidly changing mix of cuts and fills; operations near Browns Canyon extract Nugget Sandstone as building and landscape stone; map unit includes waste rock from mining operations of the Park City mining district, once one of the West's most important Ag-Pb-Zn districts; includes the Richardson Flat tailings site southeast of the U.S. Highway 40–Utah Highway 248 interchange, which, along with nearby Silver Creek, is the focus of current reclamation efforts to address contamination by heavy metals such as arsenic, cadmium, copper, lead, mercury, silver, and zinc; thickness highly variable to several tens of feet.

Alluvial deposits

Qaly **Young stream alluvium** (Holocene to upper Pleistocene) – Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel mapped in major drainages; deposited in active stream channels and floodplains; locally includes small alluvial-fan and colluvial deposits adjacent to channel margins, and minor terraces as much as 10 feet (3 m) above current stream level; locally includes historical debris-flow and debris-flood deposits; 0 to about 30 feet (0–9 m) thick.

$Qat_{2,3}$ **Stream-terrace alluvium** (middle? Holocene to upper Pleistocene) – Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel that forms level to gently sloping surfaces above, and incised by, Silver Creek; deposited in a stream-channel environment, but locally includes colluvium and small alluvial fans derived from adjacent slopes; each terrace represents the elevation of the stream base level prior to incision; subscript denotes relative age and height above modern drainage: Qat_2 ranges from about 5 to 10 feet (2–3 m) and Qat_3 ranges from about 15 to 25 feet (3–8 m) above adjacent Silver Creek; as much as about 30 feet (0–9 m) thick.

Qalo **Old stream alluvium** (Holocene to upper Pleistocene) – Similar to young stream alluvium (Qaly), but forms incised deposits southeast of the Interstate 80–U.S. Highway 40 junction that lie about 15 to 25 feet (5–8 m) above nearby Silver Creek; query indicates reddish-brown, fine-grained silty sand deposits exposed during recent construction over volcanic mudflow breccia; probably less than 15 feet (5 m) thick.

Qao **Valley-fill deposits** (Holocene to upper Pleistocene) – Moderately sorted sand, silt, and pebble to boulder gravel that forms the broad, planar, gently sloping surface of Park Meadows; inferred to have been deposited as glacial outwash in braided-stream channels and is thus principally late Pleistocene in age, but may locally include veneer of Holocene alluvial deposits; surface morphology mostly disturbed by development, making it difficult to discern the relative contributions of the Silver Creek headwater drainages and Thaynes Canyon drainage; these deposits form the upper part of Park Meadows basin-fill deposits that, based on water well data, are less than 80 feet (25 m) thick (Ashland and others, 2001).

Qaf_1 **Young fan alluvium** (Holocene) – Poorly to moderately sorted, weakly to non-stratified, clay- to boulder-size sediment deposited principally by debris flows and debris floods at the mouths of active drainages; forms characteristic alluvial fan morphology whose upper parts exhibit abundant boulders and debris-flow levees that radiate away from fan apex; equivalent to the upper part of young and middle fan alluvium (Qafy), but differentiated because Qaf_1 typically forms small, isolated, undissected fan surfaces; probably less than 40 feet (12 m) thick.

Qafy **Young and middle fan alluvium, undivided** (Holocene to upper Pleistocene) – Similar to young fan alluvium (Qaf_1), but forms both active depositional surfaces (Qaf_1 equivalent) and low-level, typically inactive surfaces incised by small streams; deposited principally as debris flows and debris floods, but colluvium locally constitutes a significant part adjacent to range fronts; upper parts of fans are commonly incised; probably less than 40 feet (12 m) thick.

Qafo **Old fan alluvium** (upper to middle Pleistocene) – Poorly to moderately sorted, weakly to non-stratified, clay- to boulder-size sediment deposited principally as debris flows and debris floods; deeply incised by modern drainages, but still exhibits characteristic fan morphology; upper parts of fans locally receive debris-flow and colluvial sediment from adjacent slopes; characterized by well-developed secondary calcium carbonate in upper part of deposit; exposed thickness as much as several tens of feet.

Colluvial deposits

Qc **Colluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, clay- to boulder-size, locally derived sediment deposited on moderate slopes and in shallow depressions principally by slope wash and soil creep; locally includes talus and mixed alluvial and colluvial deposits too small to map separately, and locally grades downslope into deposits of mixed alluvial and colluvial origin; because most bedrock in the quadrangle is covered by at least a veneer of colluvium, only the larger, thicker deposits, which commonly accumulate in swales and below abrupt changes in slope, are mapped; typically less than about 30 feet (0–9 m) thick.

Glacial deposits

Alpine glacial deposits in the Wasatch Range are of the Pinedale glacial advance and an older glaciation of uncertain but likely Bull Lake age. Pinedale deposits in their type area in the Wind River Range of Wyoming are about 12 to 24 ka (Imbrie and others, 1984) (with glacial maxima about 16 to 23 ka on the basis of cosmogenic ^{26}Al and ^{10}Be dating; Gosse and others, 1995), and they are roughly coeval with the late Wisconsin glaciation, global Last Glacial Maximum (LGM, about 26.5 to 19.0 ka; Clark and others, 2009), and Marine Oxygen Isotope Stage 2 (MIS 2, 26 to 14 ka; Lisiecki and Raymo, 2005). In contrast, deposits of the Bull Lake alpine glacial advance in their type area in the Wind River Range are about 128 to 186 ka (Imbrie and others, 1984) (with glacial maxima about 140 to 160 ka; Gosse and Phillips, 2001; Sharp and others, 2003), and are roughly coeval with the Illinoian glaciation or MIS 6 (167 to 132 ka; Lisiecki and Raymo, 2005).

Glaciation in the map area has not been studied in detail, but it probably followed patterns of Wasatch Front glaciation and was influenced by late Pleistocene Lake Bonneville. Laabs and Munroe (2016) described the problems of relative timing of glacial advances and retreats and the rise and fall of Lake Bonneville. Based on new ^{10}Be cosmogenic exposure ages, they reported that Pinedale terminal moraines at the entrances of Little Cottonwood and Bells Canyons were occupied near the time of the Bonneville highstand 18 ka and subsequently abandoned while the lake continued to overflow, consistent with stratigraphic studies of Godsey and others (2005). Further, based on stratigraphic relationships between lake and glacial deposits, Laabs and Munroe (2016) reported that glaciers extended to the mountain front more than once during the last glaciation and that the youngest moraines were abandoned near the time of, or possibly before, the Bonneville flood at 18 ka. Previous studies, reviewed by Laabs and Munroe (2016), suggested that the main phase of Pinedale deglaciation here began later, at or after 15 ka when Lake Bonneville occupied the Provo level. Although undated, the proximity of the Park City area glaciers to those of the western Wasatch Range suggests that they too reached their maximum extent about 18 ka.

Small cirque-floor moraines in the highest parts of several drainages in the nearby Wasatch Range show that these basins held small, high-elevation glaciers after the Pinedale retreat, likely during a period of global cooling 12,800 to

11,500 years ago called the Younger Dryas (at this same time, a nearly desiccated Lake Bonneville rose to about 60 feet [18 m] above the historical average level of today's Great Salt Lake, forming the Gilbert episode) (Oviatt, 2014, 2015).

Qgmp **Glacial till of Pinedale age** (upper Pleistocene) – Glacial till of Pinedale age is widely present in the adjacent Wasatch Range (Crittenden and others, 1966; Biek, in preparation), but is not present in the comparatively low elevations of the Park City East quadrangle.

Qgmb **Older glacial till of likely Bull Lake age** (middle Pleistocene) – Non-stratified, poorly sorted clay, silt, sand, gravel, cobbles, and boulders; clasts are typically matrix supported, subangular to subrounded, and reflect sources in upstream drainage basins, including monzonite and granodiorite porphyries of the Clayton Peak and Flagstaff stocks; caps Ontario Ridge and is present at the entrance to Empire Canyon in the southwest corner of the map area; lies as much as 350 feet (105 m) above Empire Creek, but it is unclear to what extent this is due to subsequent incision versus deposition as possible lateral moraine against pre-existing topography; poorly exposed, but likely as much as several tens of feet thick.

Mass-movement deposits

Qms, Qms? Qmsh

Landslides (Holocene to upper Pleistocene) – Unsorted, locally derived material deposited by rotational and translational movement; composed of clay- to boulder-size debris as well as large bedrock blocks; characterized by hummocky topography, numerous internal scarps, chaotic bedding attitudes, and common small ponds, marshy depressions, and meadows; query indicates areas of unusual morphology that may be due to landsliding; landslides with definitive historical movement (Qmsh) are present in a U.S. Highway 40 road cut south of Keetley Junction; thickness highly variable, but larger deposits exceed several tens of feet thick; most mapped landslides are newly recognized—only one, for example, is shown on the map of Bromfield and Crittenden (1971) (the focus of their work was bedrock geology, as it was for most maps of that era) and several are shown on the reconnaissance inventory map of Elliott and Harty (2010), including some areas clearly not of mass movement origin—the result of newly available lidar data and aerial imagery, more detailed and accurate map production techniques, and our modern attention given to understanding surficial deposits and their relationship to the built environment; undivided as to inferred age because even landslides that have subdued morphology (suggesting that they are older, weathered, and have not experienced recent, large-scale movement) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003).

Vegetation and widespread colluvium may conceal unmapped landslides, and more detailed imaging techniques such as lidar (which is not yet available for more than half of the map area) may show that many slopes host surficial deposits that reveal evidence of creep or shallow landsliding. Understanding the location, age, and stability of landslides, and of slopes that may host as-yet unrecognized landslides, requires detailed geotechnical investigations.

Mixed-environment deposits

Qac **Alluvium and colluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment (colluvium) deposited in swales, small drainages, and the upper reaches of larger ephemeral streams by slope-wash and creep processes; sediment is locally reworked by ephemeral streams, which is not differentiated here due to map scale; generally less than 30 feet (9 m) thick.

Qaco **Older alluvium and colluvium** (upper to middle Pleistocene) – Similar to alluvium and colluvium (Qac), but forms incised, inactive surfaces as much as several tens of feet above modern drainages; probably about 20 to 30 feet (6–9 m) thick.

Qafc **Fan alluvium and colluvium** (Holocene to upper Pleistocene) – Poorly to moderately sorted, weakly to non-stratified, clay- to boulder-size sediment deposited principally by debris flows and debris floods at the mouths of active drainages and as colluvium shed from adjacent slopes; varies locally from mostly fan alluvium to mostly colluvium but is combined here due to map scale and typically poor geomorphic contrast; probably less than 50 feet (15 m) thick.

Qafco **Older fan alluvium and colluvium** (upper to middle Pleistocene) – Similar to fan alluvium and colluvium (Qafc), but forms incised surfaces several tens of feet above modern drainages; probably about 20 to 30 feet (6–9 m) thick.

Qmc **Landslides and colluvium** (Holocene to upper Pleistocene) – Unsorted, locally derived, clay- to boulder-sized material; mapped where possible landslide deposits are difficult to identify and possibly covered by colluvium; most deposits probably less than 20 feet (6 m) thick.

Qmtc **Talus and colluvium** (Holocene to upper Pleistocene) – Poorly sorted, cobble- to boulder-size angular debris and finer-grained interstitial sediment deposited principally by rock fall and slope wash; mapped only east of Park Meadows at the base of Thaynes Formation; talus and colluvium are common on steep slopes across the map area, but are mapped only where they conceal contacts or form broad aprons below cliffs of resistant bedrock units; probably less than 20 feet (6 m) thick.

unconformity

QUATERNARY AND TERTIARY

QTa **Older alluvial deposits** (lower Pleistocene to Pliocene?) – Unconsolidated, moderately well sorted, clast-supported gravel with a pebbly sand matrix that forms deeply incised, isolated deposits in the northeast corner of the map area; deposits reflect two different source areas: (1) deposits in sections 9, 10, 15, and 16, T. 1 S., R. 5 E., derived from the east in the Uinta Mountains, and (2) deposits in sections 17 and 20, T. 1 S., R. 5 E., derived from the southwest in the nearby Wasatch Range. Deposits of the former contain rounded clasts as much as 1.5 feet (0.3 m) in diameter; most clasts are light-brown to white fine-grained quartzite likely derived from the Weber Quartzite with lesser but still abundant quartzite from the Uinta Mountain Group; also contains rounded andesitic volcanic clasts likely derived from the Keetley Volcanics and minor quarztose sandstone clasts possibly from the Nugget Sandstone, both of which are locally grussy weathering; rare pebbly quartzite conglomerate cobbles and boulders may be derived from the Tintic Quartzite; apparently lacks limestone clasts; locally exhibits well-developed pedogenic carbonate (Stage IV of Birkeland and others, 1991); extensively mined for sand and gravel; these deposits lie 500 feet (150 m) above the nearby Weber River and likely represent ancestral Weber River deposits; typically 20 to 30 feet (6–9 m) thick. Deposits of sections 17 and 20 contain subrounded cobbles and boulders of Keetley affinity and less common clasts of Weber, Nugget, and Gartra Grit strata; these deposits lie 250 to 300 feet (75–90 m) above the nearby Lost Creek and likely represent ancestral Lost Creek stream channel deposits that tapped sources west of Keetley Junction; about 40 feet (12 m) thick.

unconformity

OLIGOCENE and EOCENE

The Keetley Volcanics are late Eocene to earliest Oligocene volcanic mudflow breccias, lava flows, fine-grained tuffaceous strata, volcaniclastic conglomerate, and volumetrically minor ash-flow tuffs of intermediate composition that rest subhorizontally in a structural and topographic saddle between the Wasatch Range and Uinta Mountains. The Keetley Volcanics are regionally subdivided into three lithologic units: a basal unit of fine-grained tuff, lapilli tuff, thin lahar deposits, and volcaniclastic sandstone and conglomerate at least locally deposited in a lake; a middle thick unit of volcanic mudflow breccia and lesser volcaniclastic conglomerate; and an upper unit of lava flows and lesser volcanic mudflow breccia (Bryant, 1992; Leveinen, 1994). Keetley strata are andesite and rhyodacite by field classification, but most samples chemically range from basaltic trachyandesite and latite to andesite using the classification of LeBas and others (1986) (table 1) (Bromfield and others, 1977; Hanson, 1995; Feher, 1997; Vogel and others, 1997; this report). Woodfill (1972) provided petrographic descriptions of many of the Keetley units described below.

The Keetley Volcanics lie at the east end of the east-west-trending, 28-mile-long (45 km) Wasatch intrusive belt. As described by John (1987, 1989a), Hanson (1995), Feher (1997), and Vogel and others (1997, 2001), the belt consists of several high-potassium, calc-alkaline Tertiary intrusions. From west to east these include three phaneritic stocks (Little Cottonwood, Alta, and Clayton Peak), six porphyritic stocks (Flagstaff, Ontario, Mayflower, Glencoe, Valeo, and Pine Creek stocks collectively known as the Park City porphyries), the Park Premier porphyry, and the Indian Hollow plug. With the exception of the more mafic Clayton Peak stock, the silica content of the plutons generally increases to the west (Hanson, 1995). The depth of emplacement of the exposed portion increases to the west, from less than 0.6 mile (less than 1 km) for the porphyritic Park Premier and Indian Hollow intrusions to about 6.5 miles (11 km) for the phaneritic Little Cottonwood stock due to uplift and rotation on the Wasatch fault (John, 1987, 1989a). The entire belt is between about 30 and 40 million years old (table 2) (Crittenden and others, 1973; Bromfield and others, 1977; Vogel and others, 1997, 2001; Constenius and others, 2011). Nelson (1971) reported on early Oligocene vertebrate fossils in Keetley tuffaceous strata near Peoa, and Keetley strata locally produce petrified tree stumps and fossil wood.

Keetley strata are intruded both by the Park Premier porphyry, which consists of five granodiorite to rhyodacite or dacite porphyry intrusions and is the center of a several-square-kilometer area of hydrothermal alteration and precious-metal mineralization (Willes, 1962), and the Indian Hollow plug, a volcanic neck surrounded by a radial dike swarm (Bromfield, 1968; Woodfill, 1972; Hanson, 1995). The Indian Hollow plug and Park Premier porphyry may be the remnants of the magmatic source of most of the Keetley Volcanics (Bromfield, 1968; Woodfill, 1972; John, 1989b; Bryant, 1992; Leveinen, 1994; Hanson, 1995; Feher and others, 1996; Feher, 1997).

South of this map area, the Keetley Volcanics are in excess of 1650 feet (500 m) thick north of Heber City (Bryant, 1992; Leveinen, 1994) and locally in excess of 2500 feet (760 m) thick southeast of Heber City (Biek and others, 2003). The Keetley Volcanics were deposited in an area of considerable pre-Keetley topographic relief (Boutwell, 1912; Forrester, 1937; O'Toole, 1951; Woodfill, 1972; Feher, 1997).

The Keetley Volcanics are roughly time-equivalent to the Norwood Formation preserved in northern Utah back valley areas (Coogan and King, 2016), and to the Moroni Formation preserved in central Utah's back valleys (Constenius and others, 2011). Bryant (1990; see also Eardley, 1944; Bryant and others, 1989) noted that the East Canyon graben (northwest of this map area) contains a facies that is transitional between mudflow breccia of the Keetley Volcanics to the south and finer grained tuff and tuffaceous sediment of the type Norwood Tuff in Morgan Valley to the north. Coogan and King (2016) speculated that the Wasatch intrusive belt may be the source of volcanic material in the mostly finer grained Norwood strata.

Tku **Keetley Volcanics, undivided** (lower Oligocene to upper Eocene) – Shown on cross section only.

Tkn **Lava flows of Neel Hollow** (lower Oligocene) – Medium-gray, brownish-gray, and commonly grayish-red shoshonite porphyry lava flows (high-potassium basaltic trachyandsite) and minor volcanic mudflow breccia; contains 20 to 30% phenocrysts of plagioclase and pyroxene (to 1 mm in size) in a fine-grained groundmass; forms resistant ridgetops northeast of Jordanelle Reservoir on the west flank of the Indian Hollow vent area where it consists of multiple lava flows each several tens of feet thick; overlies volcanic mudflow breccia of Silver Creek (Tksc); collectively, the lava flows and mudflow breccia are as much as about 300 feet (90 m) thick.

Tkt **Lava flows of Todd Hollow** (lower Oligocene) – Medium-gray andesite porphyry lava flows and minor volcanic mudflow breccia; contains 20 to 30% phenocrysts of plagioclase as much as 5 mm in size and minor small hornblende phenocrysts in a fine-grained groundmass; north of Todd Hollow, upper part includes pale-red latite porphyry lava flow with plagioclase, pyroxene, and hornblende phenocrysts (1–2 mm in size) and medium-gray, finer grained andesite porphyry with conspicuous hornblende phenocrysts (as much as 1 mm in size); interfingers with volcanic mudflow breccia of Silver Creek (Tksc); map patterns suggest a thickness of as much as 1000 feet (300 m), but it appears to thin and pinch out northward.

Tkrf **Lava flows of Richardson Flat** (lower Oligocene to upper Eocene) – Medium-gray andesitic and trachytic porphyry lava flows and minor volcanic mudflow breccia; contains 20 to 30% phenocrysts of plagioclase 1 to 2 mm in size and abundant small hornblende phenocrysts in a fine- to medium-grained groundmass; samples are commonly magnetic; similar to lava flows of Todd Hollow but with more abundant hornblende; interfingers with volcanic mudflow breccia of Silver Creek (Tksc); Bromfield and others (1977) reported K-Ar ages of 36.4 ± 1.3 Ma (hornblende) and 33.9 ± 1.3 Ma (biotite) for their sample PC-398 near the junction of Utah Highway 248 and Browns Canyon Road; map patterns indicate a thickness of at least 200 feet (60 m) northwest of Jordanelle Reservoir, thinning to the north.

Tksc **Volcanic mudflow breccia of Silver Creek** (lower Oligocene to upper Eocene) – Andesitic to rhyodacitic volcanic mudflow breccia and minor interbedded lava flows and ash-flow tuff; typically heterolithic, but locally monolithic, the reverse of that reported in Woodfill's (1972) otherwise good work; clasts are andesite and rhyodacite by field classification but chemically range from latite and trachyte to andesite and dacite (Bromfield and others, 1977); weathers to rounded hills, typically with a deep regolith and poor exposure, and commonly covered with a lag of volcanic boulders; locally exhibits prominent lineaments on aerial photographs, the larger ones of which are mapped; some of the best exposures are in Threemile Canyon near the north edge of the map area; similar to and at least in part correlative with the volcanic breccia of Coyote Canyon east of Heber City (Biek and others, 2003); represents deposition as lahars (debris flows of volcanic material) on the distal flanks of stratovolcanoes that once towered over the eastern stocks of the Wasatch intrusive belt; map patterns suggest thicknesses of as much as 1000 feet (300 m) in the southeast part of this map area and at least 1400 feet (430+ m) thick southeast of Heber City (Biek and others, 2003).

Silver Creek chaos:

Large, extensively brecciated blocks of mostly Mesozoic strata (mapped separately as listed below and as shown by "+" symbol in the northeast corner of the map) are interbedded within volcanic mudflow breccia of Silver Creek in The West Hills, roughly between Wanship and the Jordanelle Reservoir (Mount, 1952; Bromfield and Crittenden, 1971). The largest exposure, composed of a mélange of Nugget and Ankareh strata, stretches nearly a mile (1.6 km) in length on a northeast-trending ridge south of Utah Highway 196, just north of the upper reaches of Browns Canyon. Most blocks, however, are several meters to several tens of meters in length.

The largest single block, of Nugget Sandstone, is about 1500 feet (475 m) in length and 30 to 200 feet (10–70 m) in width and forms a rounded ridge crest in the north-central part of section 29, T. 1 S., R. 5 E. Breccia fragments are angular to subangular and mostly pebble to small cobble size encased in a matrix of structureless fine quartz sand. About 1500 feet (500 m) to the southwest of this Nugget block, a block of the Gartra Grit is about 525 feet (160 m) in length and 20 feet (6 m) in width. Both large blocks are apparently encased in a very poorly exposed, chaotic mix of mostly reddish-brown mudstone of the Ankareh Formation and lesser resistant small blocks of brecciated Nugget and Gartra strata. Some areas, particularly the thin band that apparently connects the two larger parts of this block, may be debris-flow deposits sourced from the same Mesozoic strata.

The blocks are widely dispersed, but cluster in two broad areas: (1) a northeast-trending zone from Richardson Flat to Lost Creek, and (2) a broad, northeast-trending zone that reaches from just west of Silver Creek Junction to Wanship. The position of these blocks in basal strata of the Silver Creek breccia is intriguing in that southward, in the Center Creek quadrangle, this interval is occupied by the quartzite clast unit of the Keetley Volcanics, which was likely deposited in an alluvial-fan environment shed principally northeast off the Charleston thrust sheet (Biek and others, 2003). Due to poor exposures, kinematic data suggestive of source areas for the exotic blocks is lacking, but the blocks appear to be debris-avalanche deposits that traveled as semi-coherent slabs with runouts of 6 miles (10 km) or more across tuffaceous strata of the lower Keetley Volcanics. They may have resulted from collapse of the stratovolcano vent that once towered over the Park Premier porphyry stock, which intruded the Triassic Ankareh Formation; blocks of Ankareh and overlying Nugget strata are preserved as roof pendants above that intrusion. A local source at Mesozoic outcrops near Utah Highway 196 is not plausible because: (1) these rocks are likely to have been buried by Keetley strata, (2) Ankareh strata are not exposed, and (3) the chaos lacks blocks from the Twin Creek Formation.

Tksc(n-ag) **Nugget Sandstone and Gartra Grit Member of the Ankareh Formation**.

Tksc(n) **Nugget Sandstone**.

Tksc(ag) **Gartra Grit Member of the Ankareh Formation**.

Tksc(a) **Ankareh Formation, undivided**, mostly reddish-brown mudstone and fine-grained silty sandstone.

Tksc(w) **Weber Quartzite**.

Tkp **Tuffaceous unit** (upper Eocene) – Non-resistant, white to light-gray and yellowish-gray, fine-grained ash-flow tuff, tuffaceous mudstone, and tuffaceous sandstone with minor interbedded thin mudflow breccia and volcaniclastic sandstone and conglomerate; likely intertongues and is gradational with overlying coarser mudflow breccia of Silver Creek, and the contact between the two is almost everywhere poorly exposed and expressed and thus difficult to pick (the contact shown here mostly follows that of Bromfield and Crittenden [1971]); generally lacks a lag of volcanic boulders characteristic of the volcanic mudflow breccia of Silver Creek; typically poorly exposed and covered by colluvium, but even so, soils developed on the tuffaceous unit tend to be white and poorly drained; $^{40}Ar/^{39}Ar$ ages show that lowest Keetley tuffs in the Strawberry Reservoir area and at Current Creek Peak, to the southeast in the Co-op Creek quadrangle, are 37.25 ± 0.14 Ma (hornblende) and 37.73 ± 0.28 Ma (biotite) (Constenius and others, 2011); contains early Oligocene vertebrates near Peoa (Nelson, 1971); part of the basal fine-grained unit of the Keetley Volcanics and equivalent at least in part to the Peoa tuff of Mount (1952) and Willes (1962) and the tuffaceous unit of Biek and others (2003); as much as about 600 feet (180 m) thick in this map area, and at least 720 feet (220+ m) thick in the Center Creek quadrangle east of Heber Valley (Biek and others, 2003).

Tksh **Lava flows and volcanic mudflow breccia of Sage Hen Hollow** (upper Eocene) – Multiple, petrographically distinct lava flows of andesitic, dacitic, and trachyandesitic composition; most are porphyritic with 5 to 30% phenocrysts of plagioclase and lesser hornblende, and some contain minor biotite; includes distinctive hornblende latite porphyry with 10 to 15% hornblende phenocrysts 1 to 5 mm in length in a greenish-gray, fine-grained matrix; also includes distinctive lithic ash-flow tuff with light-greenish-gray, fine-grained andesitic hornblende porphyry lithic fragments in a darker, grayish-red fine-grained matrix; as mapped here, most of this unit was inexplicably mapped by Bromfield and Crittenden (1971) as their breccia of Silver Creek, but nearly all of these rocks appear to be a variety of andesitic, dacitic, and trachyandesite lava flows; map patterns suggest a thickness of about 1300 feet (400 m), pinching out to the north.

Tksh(pc-w)

Exotic block of Park City Formation and Weber Sandstone – Brecciated, white quartzitic sandstone and light-gray cherty limestone with white and black chert nodules near the base of the volcanic section west of U.S. Highway 40, near the northeast part of Deer Crest subdivision; Bromfield and Crittenden (1971) interpreted this exposure as Thaynes Formation poking through Keetley Volcanics, but its pervasive brecciation and lithology suggest that it is a landslide block of lower Park City Formation and Weber Sandstone incorporated in the lower Sage Hen Hollow map unit; outcrop is as much as 800 feet (245 m) wide.

Tksh(w)

Exotic blocks of Weber Sandstone – Brecciated, white quartzitic sandstone near the base of the volcanic section in Pocatello Gulch west of U.S. Highway 40, near the southern map boundary; outcrops are less than a few hundred feet wide.

Intrusive rocks

Tia **Andesitic dikes** – Includes medium-gray to olive-gray hornblende porphyry (shoshonite) dike in lower Bone Hollow containing about 10% hornblende phenocrysts as much as 1.5 cm in length; dike is 5 to 10 feet (2–3 m) wide and intrudes volcanic mudflow breccia of Silver Creek; a larger dike, possibly related to the Indian Hollow plug, is present in upper Murdock Hollow; two other dikes or sills that are similar but with smaller phenocrysts, are poorly exposed west of U.S. Highway 40—one intrudes Thaynes strata on the north wall of Pocatello Gulch, and the other intrudes an exotic block of Park City and Weber strata.

Tkpp **Park Premier porphyry stock** (lower Oligocene to upper Eocene) – Medium-gray to greenish-gray porphyritic latite or trachyte containing about 25% phenocrysts (typically 1 to 3 mm in size) of plagioclase, hornblende, and biotite, and rare phenocrysts of pyroxene; commonly hydrothermally altered, as described by Willes (1962), including widespread chloritization and iron-staining, and local silicification, alunitization, and clay alteration; includes rhyodacite of Bone Hollow, which Bromfield and Crittenden (1971) reported is characterized by larger phenocrysts than the Park Premier stock but which is likely only a poorly expressed textural variety of that intrusion; mapped east of Jordanelle Reservoir in the southeast corner of the map area where it intrudes the volcanic mudflow breccia of Silver Creek and Nugget and Ankareh strata (which exhibit little or no alteration) now exposed as discordant roof pendant blocks; Bromfield and others (1977) reported K-Ar ages of biotite (33.9 ± 1.2 Ma) and hornblende (35.2 ± 1.0 Ma) from the Park Premier stock in the adjacent Francis quadrangle.

Tki **Latite porphyry stock** – Light-brownish-gray latite porphyry stock with 20 to 30% phenocrysts of plagioclase, hornblende, and minor biotite in a microcrystalline groundmass; possibly related to the Mayflower stock; exposed in U.S. Highway 40 road cut in the upper reaches of Sage Hen Hollow.

unconformity

Ta **Tertiary alluvial deposits** (Eocene?) – Very poorly exposed pebble- to boulder-conglomerate with subrounded to rounded clasts that weathers to form rounded slopes mostly blanketed by colluvium and regolith; given weathering habit, likely contains nonresistant, finer grained mudstone and sandstone interbeds, but these are not exposed; an excavation in this map unit west of Silver Creek Junction in the adjacent Park City West quadrangle revealed an apparently old, well-developed pedogenic carbonate (stage III+ of Birkeland and others, 1991) unrelated to the modern soils; clasts are principally Pennsylvanian-Permian orthoquartzite (likely Weber Quartzite) and Nugget Sandstone as much as 3 feet (1 m) in diameter; locally, as at the north end of Round Valley, includes rare limestone clasts from Paleozoic and Twin Creek strata; host to several previously unrecognized landslides of mostly subdued morphology; lower contact is unconformable over Paleozoic and Mesozoic strata, and this unit appears to partially fill paleotopographic depressions on and immediately south of thrust sheets of the Wyoming salient; upper contact with the Keetley Volcanics is not exposed but appears to be conformable and likely gradational as reported by Bryant (1990) in the Porcupine Ridge area about 20 miles (30 km) to the northeast; as mapped here, upper contact corresponds to a break in slope, with lower slopes of Tertiary alluvial deposits (Ta) covered with Weber and Nugget sandstone clasts, above which are steeper slopes and abundant resistant volcanic clasts of the Silver Creek breccia (Tksc); Bryant (1990) reported a maximum thickness of about 1000 feet (300 m) for this map unit in the Salt Lake City 30′ x 60′ quadrangle; in this map area, the unit is only as much as about 50 feet (15 m) thick.

unconformity

CRETACEOUS

Kfl **Frontier Formation, lower members, undivided** (Upper Cretaceous, Turonian) – Interbedded sandstone, siltstone and mudstone; sandstone is medium to thick bedded, very pale orange to light gray to yellowish brown, calcareous, fine- to medium-grained quartz sand that weathers to resistant ledges; mudstone and siltstone are commonly mottled dark reddish brown and light olive gray and are slightly swelling; consists of sandstone equivalent to the basal Longwall Sandstone Member, carbonaceous shale of the Spring Canyon Member, and the lower half of the Chalk Creek Member as described by Molenaar and Wilson (1990) in the nearby Coalville area; the lower two members record deposition in shoreline and brackish-water environments as part of the overall eastward progradation of the Mowry shoreline, whereas the Chalk Creek Member records continued eastward progradation of coastal plain environments (Ryer, 1975, 1977); dips moderately north as part of para-autochthonous strata on the northwest nose of the Uinta uplift; the Utelite quarry, which produces expanded shale for light-weight aggregate, is located immediately north of the map area in black carbonaceous shale of the Allen Hollow Shale Member of Molenaar and Wilson (1990); Ryer (1975, 1977) reported earliest Turonian fossils about 3300 feet (1000 m) above the base of the formation and early middle Turonian fossils in its upper part in the Coalville area; south of this map area, on the south flank of the Uinta uplift, Biek and others (2003) reported abundant gastropods and bivalves indicative of an early Turonian age, uncommon fish scales, and a middle to late Cenomanian to Turonian palynomorph and dinoflagellate assemblage in a fine-grained silty sandstone and shale near the top of the lower member and under a prominent ledge-forming oyster-bearing limestone; incomplete section is as much as about 2000 feet (600 m) thick in the northeast corner of the map area; Bryant (1990) reported that lower Frontier strata are 5000 feet (1370 m) thick in the Coalville area and about 5900 feet (1800 m) thick to the west along East Canyon Creek.

The correlation of north- and south-flank Cretaceous strata is complicated by rapid facies changes and the absence of outcrops across the western projection of the Uinta uplift. Still, Molenaar and Wilson (1990) clearly showed that the entire Frontier Formation thickens greatly to the northwest, from about 760 feet (230 m) at Currant Creek to 7800 feet (2380 m) near Coalville in the heart of the foreland basin. They also noted, however, that the Frontier Formation in the Coalville area includes strata both somewhat older and younger than that of Frontier Formation strata on the south flank of the Uinta uplift.

unconformity

Kma **Aspen Shale** (Upper Cretaceous, lower Cenomanian) – Dark-gray siliceous shale and silty shale; fossil fish scales and bones are locally common; equivalent to the Mowry Shale of eastern Utah and adjacent areas and was deposited in the first marine transgression of the Western Interior Seaway (Molenaar and Wilson, 1990); incomplete section is about 400 feet (120 m) thick in this map area although the base is not exposed; Bryant (1990) reported maximum thickness of about 525 feet (160 m) north of Peoa and that it thins to west and north.

Kk **Kelvin Formation, undivided** (upper Lower Cretaceous) – Shown on cross section only. Sandstone, siltstone, and conglomerate of the upper member thins to the west and south, from about 4260 feet (1300 m) thick in Turner Hollow area east of Coalville to about 1540 feet (470 m) thick near head of Parleys Canyon, and limestone, sandstone, siltstone, and conglomerate of the underlying Parleys Member is about 165 feet (50 m) thick in this area (Bryant, 1990).

unconformity

JURASSIC

Jms **Morrison and Stump Formations** (Upper and Middle Jurassic) – Subsurface only. Bryant (1990) reported that colorful sandstone, silty sandstone, limestone and pebble conglomerate of the Morrison Formation is about 260 feet (80 m) thick, and that shale, sandstone and basal glauconitic limestone of the underlying Stump Formation is about 200 feet (60 m) thick in this area.

Jp **Preuss Sandstone** (Middle Jurassic) – Subsurface only. Bryant (1990) reported that silty sandstone, sandstone, and silty shale, with local anhydrite and salt in the subsurface, is about 1000 feet (300 m) thick in this area.

Twin Creek Limestone (Middle Jurassic, Callovian to middle Bajocian) – Consists of six members, the lower five of which are exposed in this map area; usage follows Sprinkel and others (2011a), who reassigned the Gypsum Springs as a separate formation; thicknesses in this quadrangle are calculated from the map; thicknesses reported from the nearby Center Creek quadrangle (Biek and others, 2003) were measured by Doug Sprinkel and Hellmut Doelling (UGS unpublished data, June 22, 1999), who also measured a section near Peoa and Oakley; deposited in warm, shallow, inland sea that occupied a broad back-bulge basin in front of the Sevier orogenic belt (Imlay, 1967, 1980); Middle Jurassic age is from Imlay (1967, 1980), Sprinkel and others (2011a), and Doelling and others (2013).

Jtc **Twin Creek Limestone, undivided** – Shown on cross section only. Imlay (1967) reported a total thickness (less their Gypsum Spring Member) of Twin Creek strata exposed near Peoa and Oakley of 1357 feet (414 m); in their unpublished measured section of the same area, Sprinkel and Doelling reported that Twin Creek strata are 1558 feet (475 m) thick.

Jtcl **Twin Creek Limestone, Leeds Creek Member** (Callovian to Bathonian) – Light-gray, splintery, thin-bedded to laminated, slope-forming, argillaceous limestone; deposited in a shallow-marine environment during the second major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, an incomplete section of Leeds Creek strata is about 350 feet (105 m) thick; Imlay (1967) reported that the unit thickens westward from 776 feet (237 m) in outcrops near Peoa and Oakley, 1520 feet (463 m) in Burr Fork near the top of Emigration Canyon, and 1289 feet (393 m) at Devils Slide; at the northwest side of Deer Creek Reservoir, Biek and Lowe (2009) reported an incomplete and attenuated section of about 400 feet (120 m) exposed beneath the Charleston thrust fault along the west side of the reservoir.

Jtcw **Twin Creek Limestone, Watton Canyon Member** (Bathonian) – Yellowish-gray to medium-gray, thin- to thick-bedded, ledge-forming, oolitic limestone, and dense, very fine grained limestone commonly with a conchoidal or rectilinear fracture; locally exhibits well-developed stylolites; upper contact is gradational and placed at a change from ledge-forming dense limestone to slope-forming argillaceous limestone; deposited in a shallow-marine environment during the second major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Watton Canyon strata are about 300 to 350 feet (90–105 m) thick; Imlay (1967) reported that the unit thickens westward from 220 feet (68 m) thick in outcrops near Peoa and Oakley, 348 feet (106 m) thick in Burr Fork near the top of Emigration Canyon, and 380 feet (116 m) at Devils Slide; southeast of Heber Valley, about 10 miles (16 km) south of this map area, Watton Canyon strata are about 250 feet (75 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009).

Jtcb **Twin Creek Limestone, Boundary Ridge Member** (Bathonian) – Non-resistant, reddish-brown mudstone, siltstone, and fine-grained sandstone with two resistant intervals of light-gray argillaceous limestone and oolitic limestone; overall weathers to form poorly exposed saddles and slopes between more resistant enclosing limestone members; thin bedded to laminated; Imlay (1967) noted that thicker, western exposures are characterized by more limestone and less siltstone and sandstone red beds; in this map area and in western exposures generally, the upper contact is difficult to pick but is placed at the top of a light-brown calcareous sandstone typically overlain by light-gray, thick-bedded oolitic and fossiliferous limestone; deposited in a shallow-marine environment during the first major regression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Boundary Ridge strata are about 100 feet (30 m) thick; Imlay (1967) reported that regionally the unit thickens irregularly westward, but in the greater Wasatch back valley area it is 97 feet (30 m) thick at Devils Slide, 102 feet (31 m) thick in Burr Fork near the top of Emigration Canyon, and 107 feet (33 m) thick in outcrops near Peoa and Oakley; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Boundary Ridge strata are about 120 feet (35 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 145 feet (44 m) thick in adjacent Center Creek quadrangle.

Jtcr **Twin Creek Limestone, Rich Member** (Bajocian) – Medium-gray and light-brownish-gray, thin- to medium-bedded, finely crystalline, ledge- and slope-forming limestone and argillaceous limestone that weathers to pencil-like fragments and small chips, and very light gray, very fine grained calcareous sandstone with ripple marks; upper contact placed at a change from ledgy slopes of grayish, argillaceous limestone to reddish-brown siltstone slopes; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Rich strata are about 200 feet (60 m) thick; Imlay (1967) reported that the unit is 125 feet (38 m) thick in outcrops near Peoa and Oakley, but thickens to the northwest to 391 feet (119 m) in Burr Fork near the top of Emigration Canyon and 540 feet (165 m) at Devils Slide; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Rich strata are about 160 feet (50 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 116 feet (35 m) thick in adjacent Center Creek quadrangle.

Jtcs **Twin Creek Limestone, Sliderock Member** (Bajocian) – Brownish-gray, light-gray-weathering, slope- and ledge-forming, thin- to medium-bedded, dense limestone with a conchoidal fracture, light-gray micritic limestone that weathers to pencil-like fragments, and medium-gray, dense, finely crystalline to very fine grained limestone with *Isocrinus* sp. crinoid columnals and fossil hash near the top; upper gradational contact typically corresponds to a break in slope between more resistant Sliderock limestone and less resistant argillaceous Rich limestone; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Sliderock strata are about 100 feet (30 m) thick; Imlay (1967) reported that the unit is 47 feet (14 m) thick in outcrops near Peoa and Oakley, but thickens to the northwest to 150 feet (46 m) in Burr Fork near the top of Emigration Canyon and 100 feet (30 m) at Devils Slide; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Sliderock strata are about 200 feet (60 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 209 feet (64 m) thick in adjacent Center Creek quadrangle.

J-2 unconformity (Pipiringos and O'Sullivan, 1978)

Jgs **Gypsum Spring Formation** (Lower to Middle Jurassic, upper Pliensbachian to lower Bajocian) – Slope-forming, dark-reddish-brown, fine- to medium-grained silty sandstone with few coarse sand grains; best exposures are near Browns Canyon quarries at the center of section 20, T. 1 S., R. 5 E., where lower 3 to 6 feet (1–2 m) is yellowish-brown clayey sandstone; elsewhere weathers to a poorly exposed slope or strike valley between resistant slopes of Nugget and Sliderock strata; southward, in the greater Heber Valley area, also contains sandy, calcareous siltstone, minor jasperoid, pinkish-brown sideritic limestone, and brown to gray, dense, very fine grained limestone with a conchoidal fracture (Biek and others, 2003; Biek and Lowe, 2009), and near Peoa the basal foot is a chert pebble sandstone (Doug Sprinkel, written communication, February 7, 2017); usage follows Sprinkel and others (2011a); upper contact is sharp, corresponds to the J-2 unconformity, and marks a change from dominantly reddish-brown siltstone slopes to gray, ledgy limestone; Sprinkel and others (2011a) reported an $^{40}Ar/^{39}Ar$ sanidine age of 184.6 ± 0.2 Ma and a U-Pb zircon age of 183.2 ± 0.49 Ma for ash beds in the lower Gypsum Spring at Devils Slide, 23 miles (37 km) north-northwest of this map area, and fossils indicate that it is in part equivalent to and slightly older than the Temple Cap Formation of central and southern Utah, with a preferred age of about 173 to 170 Ma (Sprinkel and others, 2011a; see also Imlay, 1967); deposited in a south- and eastward-prograding shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Gypsum Spring strata are about 30 feet (9 m) thick near Browns Canyon quarries and likely of similar thickness at the north end of Round Valley; Imlay (1967) reported that the unit is 22 feet (7 m) thick in outcrops near Peoa and Oakley, but thickens greatly to the northwest to about 140 feet (43 m) in Burr Fork near the top of Emigration Canyon and 208 feet (63 m) at Devils Slide; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Gypsum Spring strata are about 60 feet thick (18 m) at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 83 feet (25 m) thick east of Heber Valley (Biek and others, 2003).

J-1 unconformity (Pipiringos and O'Sullivan, 1978) formed prior to about 185 million years ago in northern Utah, but possibly as late as about 173 million years ago in southwest Utah (Sprinkel and others, 2011a).

JURASSIC-TRIASSIC

JŦn **Nugget Sandstone** (Lower Jurassic to Upper Triassic) – Moderate-reddish-orange, moderate-orange-pink and very pale orange, cross-bedded, moderately well-cemented quartz sandstone composed of well-rounded, fine- to medium-grained, frosted quartz grains; bedding consists of high-angle, large-scale cross-bedding in tabular planar, wedge planar, and trough shaped sets 10 to 45 feet or more (3–14+ m) thick; upper unconformable contact is sharp and planar and corresponds to a prominent lithologic and topographic change, with ledge-forming, massively cross-bedded sandstone below and slope-forming, dark-reddish-brown or locally yellowish-brown, fine- to medium-grained silty sandstone with minor coarse sand grains above; deposited principally by north winds in a vast coastal and inland dune field (Kocurek and Dott, 1983; Blakey, 1994; Marzolf, 1994; Peterson, 1994), part of one of the world's largest coastal and inland paleodune field (Milligan, 2012); much of the sand may originally have been transported to areas north and northwest of Utah via a transcontinental river system that tapped Grenvillian-age (about 1.0 to 1.3 Ga) crust involved in Appalachian orogenesis of eastern North America (Dickinson and Gehrels, 2003, 2009a, 2009b; Rahl and others, 2003; Reiners and others, 2005); correlative with the entire Glen Canyon Group of the Colorado Plateau (Wingate Sandstone/Moenave Formation, Kayenta Formation, and Navajo Sandstone) (Sprinkel and others, 2011b); Sprinkel and others (2011b) also summarized age control, primarily aetosaur and dinosaur tracks, indicating that the Triassic-Jurassic boundary is within the Nugget Sandstone and that the J-0 unconformity of Pipiringos and O'Sullivan (1978) probably does not exist; incomplete section immediately north of Utah Highway 196 is about 1000 feet (300 m) thick, but the base is not exposed; Bryant (1990) reported Nugget thicknesses of about 1300 feet (400 m) near Parleys Canyon and about 900 feet (280 m) near Peoa; about 900 to 1000 feet (275–300 m) thick on the saddle west of Soldier Hollow, and about 1260 feet (385 m) thick in the West Daniels Land #1 well (Biek and others, 2003).

TRIASSIC

Ŧa **Ankareh Formation, undivided** (Upper and Lower Triassic) – Shown on cross section only. Regionally consists of three members, with a major regional unconformity, the Ŧ-3 unconformity of Pipiringos and O'Sullivan (1978), separating the middle and lower members (Kummel, 1954); 1485 feet (453 m) thick southwest of Heber Valley (Baker, 1964) and of comparable thickness near Devils Slide (Coogan and King, 2016).

Ŧau **Ankareh Formation, upper member** (Upper Triassic) – Reddish-brown mudstone, siltstone, and very fine to fine-grained sandstone that weathers to poorly exposed slopes; deposited in fluvial, floodplain, and lacustrine environments of an interior basin drained by north- and northwest-flowing rivers (see, for example, Dubiel, 1994); upper contact not exposed, but appears sharp, corresponding to the base of ledge-forming, moderate-reddish-orange, massively cross-bedded, quartz sandstone of the Nugget Sandstone; map patterns suggest a thickness of 600 to 700 feet (180–210 m) at the southwest side of Round Valley; Kummel (1954) reported that the upper member is 390 feet (120 m) thick on Red Butte Creek northeast of Salt Lake City; Coogan and King (2016) reported that equivalent beds at Devils Slide are 600 to 680 feet (180–210 m) thick, and Baker (1964) reported this unit is about 450 feet (135 m) thick southwest of Heber City.

Ŧag **Ankareh Formation, Gartra Grit Member** (Upper Triassic) – White, light-brown, and pinkish-gray, fine- to coarse-grained, locally pebbly and gritty, feldspathic quartz sandstone; clasts are rounded quartzite and chert; resistant and so weathers to support ridge crests; at the Hideout development, east of Jordanelle Reservoir, and northwest of Kimball Junction, in the Park City West quadrangle, consists of a thick lower sandstone and thinner upper sandstone separated by poorly exposed reddish-brown mudstone comparable in thickness to the two combined sandstones; upper contact corresponds to a change from ledge-forming gritty sandstone to slopes of reddish-brown mudstone and fine-grained sandstone; deposited in north- and northwest-flowing braided river channels of an interior basin (see, for example, Dubiel, 1994); map patterns suggest a thickness of about 250 feet (75 m) at Round Valley; Kummel (1954) reported that the Gartra Grit is 60 feet (18 m) thick on Red Butte Creek northeast of Salt Lake City, and Baker (1964) reported that it is about 40 feet (12 m) thick southwest of Heber City.

Ŧ-3 *unconformity of Pipiringos and O'Sullivan (1978)*

T̵ram **Ankareh Formation, Mahogany Member** (Lower Triassic) – Reddish-brown, grayish-purple, and grayish-red, locally mottled, mudstone, siltstone, and fine-grained sandstone that weathers to poorly exposed slopes; upper contact is sharp, concordant and unconformable as exposed in new road cuts at the Hideout development east of Jordanelle Reservoir; deposited in fluvial, floodplain, and lacustrine environments of an interior basin drained by north- and northwest-flowing rivers (see, for example, Dubiel, 1994); Thomson and Loveless (2014) reported on swim tracks from exposures near Thistle, Utah, and evidence for Early Triassic age; map patterns suggest a thickness of about 1300 to 1500 feet (400–460 m) at Round Valley; Coogan and King (2016) reported that equivalent beds at Devils Slide are 600 to 725 feet (180–220 m) thick; Kummel (1954) reported that the lower member is 850 feet (260 m) thick on Red Butte Creek northeast of Salt Lake City and thickens eastward into the Uinta Mountains as Thaynes strata pinch out; Baker (1964) reported lower Ankareh strata are about 1000 feet (300 m) thick southwest of Heber City whereas Smith (1969) reported a thickness of 1372 foot (420 m) in this same area.

T̵rt **Thaynes Formation, undivided** (Lower Triassic, Spathian to Smithian) – Shown on cross section only. In the central Wasatch Range, Thaynes strata are readily divisible into three parts: a lower brown calcareous sandstone and sandy limestone, a middle red siltstone and shale, and an upper medium-gray limestone, with a composite thickness in Big Cottonwood Canyon of 1190 feet (363 m) (Boutwell, 1912); regionally, map unit intertongues eastward with Mahogany Member of Ankareh Formation (Kummel, 1954); deposited in a warm, shallow sea with repeated eastward-prograding shallow-marine limestone tongues separated by westward-prograding clastic intervals of the Ankareh Formation, such that the formation thins eastward into the Uinta Mountains (Kummel, 1954; Blakey and Gubitosa, 1983); Solien and others (1979) recognized seven informal lithologic units that totaled 2296 feet (700 m) thick north of Red Butte Creek east of Salt Lake City and Coogan and King (2016) estimated a thickness of 1835 feet (560 m) south of Devils Slide; the formation is 950 feet (290 m) thick southwest of Heber Valley (Baker, 1964; see also Smith, 1969), but here map patterns suggest a thickness of about 1600 feet (490 m) at Round Valley.

T̵rtu **Thaynes Formation, upper limestone member** (Lower Triassic, Spathian) – Light- to medium-gray, thin- to thick-bedded limestone and fine-grained calcareous sandstone interbedded with light-gray, light-brown, and olive-gray, thin-bedded calcareous siltstone and shale; locally fossiliferous with pelecypods, gastropods, and ammonites; upper contact corresponds to the top of light-gray limestone, above which are poorly exposed slopes of reddish-brown Ankareh mudstone, siltstone, and fine-grained sandstone; deposited in a warm, shallow sea (Kummel, 1954; Blakey and Gubitosa, 1983); age from Solien and others (1979); map patterns suggest a thickness of about 1100 feet (335 m) north of Silver Creek.

T̵rtm **Thaynes Formation, middle shale member** (Lower Triassic, Spathian to Smithian) – Reddish-brown, micaceous siltstone and fine-grained sandstone; typically laminated or thin- to medium-bedded with planar and ripple cross stratification; bedding surfaces commonly reveal symmetrical and interference ripple marks; well exposed in a West Harmony Drive road cut at Deer Crest and along a service road immediately to the southeast; upper contact, exposed along this service road, is conformable and gradational and placed at the base of the first thick series of gray to brownish-gray limestone beds; likely equivalent to the middle red shale of Boutwell (1912); this red bed interval is likely a tongue of Mahogany Member of Ankareh Formation, with which the Thaynes interfingers eastward into the Uinta Mountains (Kummel, 1954); deposited in tidal-flat and distal fluvial environments of a coastal plain (Kummel, 1954; Blakey and Gubitosa, 1983); map patterns suggest a thickness of about 200 feet (60 m) north of Silver Creek.

T̵rtl **Thaynes Formation, lower limestone member** (Lower Triassic, Smithian) – Light- to medium-gray, conspicuously dark-yellowish-brown-weathering, thin to thick-bedded limestone and fine-grained calcareous sandstone interbedded with light-gray, light-brown, and olive-gray, thin-bedded calcareous siltstone and shale; locally fossiliferous with pelecypods, gastropods, and ammonites; well exposed north of Silver Creek and in numerous road cuts in the Deer Crest development west of Jordanelle Reservoir; Deer Crest exposures reveal multiple, short-wavelength, generally north-trending fold axes and accompanying east- and west-directed small-displacement thrust faults on what is otherwise a near dip-slope of Thaynes strata; upper contact, exposed in service road below West Harmony Drive (Deer Crest development), is conformable and gradational and corresponds to the first appearance of reddish-brown micaceous siltstone and fine-grained sandstone; deposited in a warm, shallow sea (Kummel, 1954; Blakey and Gubitosa, 1983); map patterns suggest a thickness of about 300 feet (90 m) north of Silver Creek.

T̵rw **Woodside Shale** (Lower Triassic, Scythian) – Moderate- to dark-reddish-brown, laminated to thin-bedded or rarely medium-bedded, micaceous and feldspathic siltstone and fine-grained sandstone with planar and small-scale cross stratification; bedding surfaces commonly reveal symmetrical and interference ripple marks; non-resistant and so weathers to form strike valleys and colluvium-covered slopes; uppermost beds typically include yellowish-brown, fine- to medium-grained sandstone; lower part well exposed in Snow Top Road cut in Deer Crest development where it is light-yellowish-brown, light-gray, and minor reddish-brown, laminated to thin-bedded, fine-grained calcareous sandstone, siltstone, and mudstone about 50 feet (15 m) thick; upper and middle part of classic reddish-brown micaceous siltstone and fine-grained sandstone is well exposed in Highway 248 (Kearns Boulevard) road cut and locally in road cuts of Deer Crest development; upper contact appears conformable and corresponds to appearance of first ledge-forming, medium- to thick-bedded, dark-yellowish-brown-weathering, light-gray limestone; probably deposited in a tidal-flat and coastal-plain environment with clastic input from the Uncompahgre uplift in east-central Utah; locally served as a zone of weakness accommodating thrust faulting and so representative thicknesses are difficult to determine; map patterns near Silver Creek suggest a thickness of about 450 feet (140 m), but early geologic maps of the Park City mining district (e.g., ASARCO, 1929) interpreted a northeast-striking, down-to-the-northwest normal fault (their Silver Creek fault, for which I see no evidence) and thus an anomalous thickness of about 750 feet (230 m); it is about 450 to 600 feet (135–183 m) thick north of Silver Fork and Brighton in Little Cottonwood Canyon (Crittenden and others, 1966; Baker and others 1966); Baker (1964) reported a thickness of 315 feet (95 m) southwest of Heber Valley, and (Constenius and others, 2011) noted that the Woodside Shale may be tectonically thinned or thickened from less than 200 to over 700 feet (60–215 m) in the Provo 30′ x 60′ quadrangle; Coogan and King (2016) reported that the Woodside is 500 to 600 feet (150–180 m) thick at Devils Slide.

₮-1 *unconformity (Pipiringos and O'Sullivan, 1978), spans 10 to 20 million years during Late Permian to Early Triassic. The* ₮-1 *unconformity represents an episode of dramatic, worldwide sea-level drop and the largest global extinction event in Earth's history (see, for example, Ward, 2004). Sheldon and others (1967b) noted that in northern Utah the transition from Permian to Triassic is not marked by significant erosion, unlike in southwesternmost Utah, where such erosion locally cuts out 500 feet (150 m) of Permian strata (Hayden, 2011).*

PERMIAN

Ppc **Park City and Phosphoria Formations, undivided** (Middle to Lower Permian, Leonardian to Wordian) – Boutwell (1912, p. 49; see also Boutwell, 1907) named and defined the Park City Formation for its importance as the principal host for lead-silver-zinc replacement deposits in the Park City mining district. In the central Wasatch Range, Park City strata are divisible into the lower Grandeur and upper Franson Members, which are separated by the Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation (McKelvey and others, 1959); they are undivided here due to structural complications and limited exposure. In this map area, Park City strata record warm, shallow-marine deposition (Sheldon and others, 1967b) east of the Utah hingeline, a long-lived boundary between a stable continental shelf to the east and a subsiding marine basin to the west, when southwest Utah lay just north of the equator on the western margin of the supercontinent Pangea. Phosphoria strata, however, were deposited in a deep-water, oxygen- and sediment-starved part of the basin (Sheldon and others, 1967a). Gordon and Duncan (1970) and Wardlaw and Collinson (1979) reported on the age of Park City and Phosphoria strata.

The most complete section of Park City and Phosphoria strata in this map area is at Masonic Hill, with possible Meade Peak strata involved in a small landslide along Deer Valley Drive immediately west of the map boundary, but structural complications and poor exposure preclude accurate thickness estimates. The best nearby section, 590 feet (180 m) thick, is Boutwell's (1912) section in Big Cottonwood Canyon in the southwest corner of the Park City West quadrangle. Park City and Phosphoria strata are 1167 feet (356 m) thick in the upper reaches of Red Butte Creek (Cheney and others, 1953) and 870 feet (265 m) thick west of Heber City (Baker, 1964); Coogan and King (2016) reported that these strata are 857 and 675 feet (260 and 205 m) thick at Devils Slide and Durst Mountain, respectively, but the former may be structurally thickened.

Franson strata: thin- to thick-bedded, typically medium bedded, light- to medium-gray to pinkish-gray limestone, cherty limestone, and calcareous sandstone; limestone locally contains brachiopods, crinoid stems, gastropods, and bryozoans; upper contact well exposed in Snow Top Road road cut in Deer Crest development, where it corresponds to the top of a light-gray, medium- to thick-bedded limestone overlain by light-yellowish-brown, light-gray, and minor reddish-brown, laminated to thin-bedded, fine-grained calcareous sandstone, siltstone, and mudstone; upper contact appears conformable, noted by Boutwell (1912) and Cheney (1957), but here is a disconformity that corresponds to the ₮-1 unconformity; 352 feet (107 m) thick west of Heber City (Baker, 1964); Franson (and Rex Chert) strata are about 240 to 300 feet (75–90 m) thick in the Ogden 30′ x 60′ quadrangle (Coogan and King, 2016).

Meade Peak strata: not exposed but scattered float suggests a lithologically diverse unit of typically thin-bedded, dark-gray limestone, laminated to thin-bedded, dark-brown to black phosphatic siltstone and shale, and brownish-gray calcareous sandstone that weathers to poorly exposed slopes; regionally consists of upper and lower phosphatic shale units split by a tongue of the Franson Member; about 60 feet (18 m) thick west of Heber City (Baker, 1964).

Grandeur strata: thin- to thick-bedded, typically medium-bedded, light- to medium-gray limestone, cherty limestone, sandy limestone, and calcareous sandstone; locally contains thin lenses and irregularly shaped nodules of black chert; locally fossiliferous, especially basal beds, with common brachiopods, crinoid stems, gastropods, and bryozoans; 458 feet (140 m) thick west of Heber City (Baker, 1964) and about 220 to 310 feet (65–95 m) thick in the Ogden 30′ x 60′ quadrangle (Coogan and King, 2016); Cheney (1957) reported that Grandeur strata are 290 feet (88 m) thick northeast of Salt Lake City and that the member thins and becomes sandy eastward into the Uinta Mountains where it pinches out east of Duchesne.

PERMIAN-PENNSYLVANIAN

IPPw **Weber Quartzite** (Lower Permian? to Middle Pennsylvanian, Desmoinesian) – Very pale orange, grayish-orange, and yellowish-gray, typically thick- to very thick bedded, fine-grained, well-cemented quartzitic and less commonly calcareous sandstone with uncommon, thin, light-gray limestone, cherty limestone, and dolomite interbeds; commonly bleached white and locally iron-stained; typically highly fractured and indistinctly bedded and so bedding attitudes are surprisingly difficult to obtain; weathers to steep, rounded, colluvium-covered hillsides; upper contact is conformable and gradational, thus difficult to consistently pick, and corresponds to the base of the first limestone beds, thus including significant quartzitic sandstone in basal Grandeur strata; Middle Pennsylvanian age in the Wasatch Range from Van Horn and Crittenden (1987), but includes Lower Permian (Wolfcampanian) strata in the northern Wasatch Range and Uinta Mountains (Baker, 1964; Bissell, 1964); correlative with much of the far thicker Pennsylvanian to Permian Oquirrh basin strata of western Utah; deposited on a shallow continental shelf east of the Utah hingeline in a westward-prograding coastal eolian dune field and adjacent shallow-marine environments (Bissell, 1964; Hansen, 1965; Fryberger, 1979); structural complications preclude accurate thickness estimates in the greater Park City area, but Bromfield (1968) estimated that the formation is 1300 to 1500 feet (400–460 m) thick and that westward in Big Cottonwood Canyon, limestone interbeds make up about 15 to 20% of the formation; Coogan and King (2016) estimated Weber strata are 2600 feet (790 m) thick near Morgan.

IPrv **Round Valley Limestone** (Lower Pennsylvanian) – Shown on cross section only. About 225 to 400 feet (70–120 m) thick west of Heber City (Baker, 1964).

MISSISSIPPIAN

Mississippian, undivided – Combined Doughnut, Humbug, Deseret, and Gardison strata, collectively about 2500 feet (760 m) thick in Big Cottonwood Canyon (Crittenden, 1965a; Bryant, 1990), shown on cross section.

MISSISSIPPIAN-NEOPROTEROZOIC

Mississippian-Neoproterozoic, undivided – Combined Fitchville, Maxfield, Ophir, Tintic, and Mutual strata, collectively as much as several thousand feet thick, shown on cross section.

ACKNOWLEDGMENTS

I appreciate the strong support of Bill Loughlin (Loughlin Water Associates, LLC), long an ardent supporter of geologic mapping, who organized several meetings with local officials and others with knowledge of local geology and mining history. Andy Armstrong, Doug Evans, and Brian Davenport of the Mountain Regional Water District shared well data and facilitated access to several developments throughout the map area. Truce Steele pointed out several interesting exposures and facilitated access to the Promontory development where he works. Consulting engineering geologist Harry Audell shared his preliminary mapping of landslides in the greater Park City area and provided an insightful review of the map and supporting materials. Doug Sprinkel (UGS) and Hellmut Doelling (UGS, retired) provided an unpublished measured section of Gypsum Springs and Carmel strata near Peoa. Colleagues Grant Willis, Zach Anderson, Mike Hylland, and Stephanie Carney

(UGS) reviewed the map and supporting materials, and I am grateful for their collective wisdom. Basia Matyjasik (UGS) created the ArcGIS files and Lori Steadman, Jay Hill, and Martha Jensen (UGS) drafted plate 2 figures. This geologic map was funded by the Utah Geological Survey and U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number G16AC00191, 2016.

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Table 1. Trace-element and whole-rock geochemistry of igneous rocks, Park City area, Utah.

Sample No.	Unit Name	7.5' Quadrangle	Map Symbol	Rock Name	Easting, NAD83	Northing, NAD83	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SO_3	SiO_2	SrO	TiO_2	Total	LOI	Ba	Ce	Cr	Cs	Dy	Er	Eu
PCE111016-2	latite porphyry intrusion	Park City East	Tki	latite	461698	4499015	16.73	0.2	3.91	0.01	6.22	3.32	2.74	0.09	4.07	0.33	0.01	59.73	0.11	0.78	100.1	1.75	1995	106	50	0.46	3.83	2	1.8
PCE052416-5	lava flows and breccias of Sage Hen Hollow	Park City East	Tksh	benmorite	461772	4500366	17.82	0.2	5.29	0.01	6.66	2.45	1.64	0.09	4.89	0.42	0.01	59.15	0.11	0.86	100.05	0.36	1885	129	50	1.13	4.1	2.04	2.07
PCE052416-11	lava flows and breccias of Sage Hen Hollow	Park City East	Tksh	latite	461978	4499051	16.52	0.15	5.05	<0.01	7.56	2.85	3.83	0.12	3.69	0.42	0.01	56.66	0.1	0.93	99.68	1.7	1370	115	20	0.55	4.48	2.39	2.13
PCE052416-15	lava flows and breccias of Sage Hen Hollow	Park City East	Tksh	dacite	462159	4499557	15.17	0.17	4.07	<0.01	5.92	3.16	2.37	0.09	3.15	0.34	0.01	63.69	0.09	0.7	99.95	0.94	1630	113	30	1.18	3.48	1.7	1.8
PCE111016-1	lava flows and breccias of Sage Hen Hollow	Park City East	Tksh	andesite	461766	4498820	16.66	0.16	3.65	<0.01	5.85	2.48	4.74	0.1	3.48	0.35	0.01	57.51	0.12	0.78	99.99	4	1455	127.5	40	0.85	3.71	1.91	1.91
PCE062816-6	lava flows of Neel Hollow	Park City East	Tkn	shoshonite	467051	4503027	16.61	0.12	8.34	<0.01	10.33	3.18	3.61	0.13	3.32	0.68	0.01	51.59	0.11	1.17	99.86	0.54	1060	125	30	1.35	5.73	2.68	3.01
PCE062816-7	lava flows of Neel Hollow	Park City East	Tkn	shoshonite	467129	4502274	17.1	0.16	6.98	<0.01	9.33	3.65	2.97	0.14	3.94	0.82	0.02	53.11	0.14	1.08	99.97	0.38	1465	216	10	1.46	6.27	2.79	4.25
PCE052316-4	lava flows of Richardson Flat	Park City East	Tkrf	trachyte	463186	4499693	15.88	0.15	3.57	<0.01	5.01	3.88	1.42	0.07	3.88	0.34	0.02	64.78	0.09	0.57	100.1	0.34	1345	126.5	10	2.81	3.78	1.88	2.16
PCE052316-6	lava flows of Richardson Flat	Park City East	Tkrf	trachyte	463105	4500673	16.37	0.15	3.54	<0.01	5.15	4.04	1.56	0.09	3.86	0.34	0.01	63.33	0.09	0.59	99.89	0.68	1395	135.5	10	3.05	4.27	2.08	2.27
PCE060216-6	lava flows of Richardson Flat	Park City East	Tkrf	andesite	463448	4503790	17.57	0.17	4.7	<0.01	7.91	2.79	1.56	0.08	3.48	0.45	0.01	58.28	0.1	0.99	99.85	1.65	1685	111	30	1.63	4.11	2.12	2.29
PCE050416-4	lava flows of Todd Hollow	Park City East	Tkt	andesite	463106	4501152	16.72	0.22	5.81	<0.01	7.13	2.78	3.36	0.11	3.07	0.4	0.09	58.18	0.09	0.83	100.2	1.32	2150	104.5	30	2.57	4.34	2.28	1.93
PCE050416-6	lava flows of Todd Hollow	Park City East	Tkt	andesite	464977	4501673	17.08	0.13	5.21	<0.01	7.46	2.71	2.85	0.11	3.38	0.36	<0.01	59.35	0.08	0.85	100.5	0.8	1165	103.5	30	1.83	4.2	2.25	2.04
PCE062816-3	lava flows of Todd Hollow	Park City East	Tkt	andesite	465206	4503471	16.16	0.19	5.32	<0.01	6.68	2.82	2.99	0.1	3.2	0.37	0.11	59.23	0.09	0.77	99.8	1.69	1850	110.5	30	2.1	4.22	2.29	1.89
PCE062816-4	lava flows of Todd Hollow	Park City East	Tkt	latite	465625	4503853	15.67	0.15	5.54	0.01	7.03	3.31	3.64	0.11	3.44	0.45	0.01	58.9	0.1	0.91	99.7	0.32	1495	134	90	2.38	4.72	2.66	2.33
PCE062816-9	lava flows of Todd Hollow	Park City East	Tkt	andesite	465651	4500121	17.13	0.14	4.7	<0.01	6.64	2.73	1.92	0.08	3.74	0.34	0.01	60.77	0.08	0.76	99.78	0.63	1240	111	40	1.65	3.68	2.05	1.8
PCE072016-3	hornblende porphyry dike	Park City East	Tia	shoshonite	466403	4497656	15.33	0.11	7.65	<0.01	10.21	2.91	4.64	0.16	3.02	0.65	0.01	49.42	0.09	1.26	99.81	4.22	997	134.5	20	0.82	5.95	2.84	2.89
PCE070815-1	Park Premier stock	Park City East	Tkpp	trachyte	466381	4498926	15.38	0.17	4.37	0.01	4.93	3.8	2.6	0.09	3.56	0.42	0.01	62.26	0.11	0.75	99.1	0.53	1665	161.5	50	2.99	3.76	1.81	2.31
PCE062816-10	Park Premier stock	Park City East	Tkpp	latite	466688	4499840	16.93	0.15	4.4	<0.01	6.08	3.44	2.2	0.09	3.76	0.41	0.01	61.02	0.09	0.66	100.05	0.72	1330	123.5	10	1.65	3.81	1.9	2.31
HC072016-5	Park Premier stock	Heber City	Tkpp	latite	466544	4497130	14.68	0.17	5.65	0.05	6.98	3	5.49	0.17	2.95	0.35	0.03	56.25	0.08	0.73	99.73	3.02	1695	108	390	0.73	3.56	1.64	1.79
PCE071916-2	volcanic mudflow breccia of Silver Creek	Park City East	Tksc	mugearite	465589	4497305	16.96	0.14	4.57	<0.01	6.26	2.69	2.42	0.11	4.58	0.44	0.03	58.12	0.09	0.68	99.54	2.35	1265	114	10	0.94	3.68	1.83	2.16
PCE072016-2	volcanic mudflow breccia of Silver Creek	Park City East	Tksc	trachyte or trachydacite	466410	4497646	15.58	0.18	3.94	<0.01	5.15	3.74	2.69	0.09	3.44	0.35	0.05	60.84	0.09	0.59	100.1	3.27	1645	120	30	0.85	3.37	1.63	1.99

Ga	Gd	Hf	Ho	La	Lu	Nb	Nd	Pr	Rb	Sm	Sn	Sr	Ta	Tb	Th	Tm	U	V	W	Y	Yb	Zr	Ag	As	Cd	Co	Cu	Li	Mo	Ni	Pb	Sc	Tl	Zn
21.7	5.11	6.2	0.73	56.5	0.27	10.7	43.8	12.05	76.9	6.91	1	994	0.5	0.67	8.93	0.26	1.72	83	1	19.8	1.78	226	<0.5	<5	<0.5	15	21	10	<1	17	22	11	<10	71
20.8	5.71	6.7	0.76	68	0.27	11.9	52.2	14.4	60	8.05	1	968	0.6	0.75	11.35	0.27	2.23	113	1	20.1	1.79	251	<0.5	<5	<0.5	14	11	10	1	19	21	12	<10	75
22.5	6.29	6.1	0.81	60	0.32	10.7	49.8	13.4	67.6	8.33	2	908	0.5	0.81	9.95	0.33	2.19	164	1	22.6	2.02	226	<0.5	<5	<0.5	19	34	10	1	10	12	14	<10	91
20.8	5.05	6.4	0.66	62.2	0.27	11.3	44.7	12.55	82.4	7.13	1	818	0.7	0.66	14.7	0.26	3.92	114	1	18.3	1.79	225	<0.5	<5	<0.5	14	30	20	1	14	11	11	<10	76
21.3	5.38	7.1	0.72	68	0.28	11.3	50.7	14.05	70.8	7.94	1	1065	0.6	0.69	11.85	0.29	2.76	116	1	19.6	1.78	261	<0.5	<5	<0.5	16	19	20	<1	18	22	11	<10	78
23.5	8.83	6.4	0.99	64.8	0.32	9.5	65.5	16.35	91.6	11.85	2	996	0.4	1.04	12.05	0.36	2.82	256	1	26.9	2.06	226	<0.5	<5	<0.5	27	62	10	1	21	17	22	<10	107
24	11.05	12.1	1.04	106	0.33	19.5	97.1	25.4	93	16.55	2	1250	0.8	1.3	17.2	0.37	4.07	188	2	28.6	2.25	486	<0.5	<5	<0.5	22	41	10	2	10	27	15	<10	112
21.2	5.86	6.8	0.69	68.3	0.24	12.3	52	14.45	114.5	8.54	1	800	0.7	0.68	15.05	0.24	3.44	83	1	18.8	1.77	241	<0.5	<5	<0.5	9	12	10	1	5	19	7	<10	70
22.2	6.58	7.3	0.77	73.8	0.28	13.1	56.8	15.85	125.5	9.19	1	805	0.7	0.83	16.8	0.27	4.08	87	1	21.2	1.83	265	<0.5	<5	<0.5	10	9	10	1	5	20	7	<10	74
23.2	6.09	6.5	0.79	65.1	0.27	11.3	53.1	14.15	76.3	8.73	1	843	0.6	0.77	10.75	0.3	2.54	166	1	20.3	1.85	240	<0.5	<5	<0.5	18	40	10	1	13	14	15	<10	97
22.3	5.73	6.3	0.83	59.3	0.33	10.3	46.3	12.7	77.5	7.66	1	815	0.6	0.78	12.15	0.33	3	142	1	23.7	2.12	232	<0.5	<5	<0.5	19	23	<10	2	17	18	12	<10	93
22.1	5.94	6.2	0.81	59.6	0.28	10.2	47.7	12.9	74.8	8.16	1	651	0.6	0.77	11.7	0.28	2.72	143	1	21.7	2.01	231	<0.5	<5	<0.5	20	25	10	1	19	17	14	<10	93
22.2	5.84	6.4	0.81	61.8	0.33	10.7	48	13.1	73.9	7.86	1	857	0.6	0.76	11.75	0.33	2.88	113	1	22.8	2.09	239	<0.5	<5	<0.5	16	20	10	2	19	18	11	<10	86
22.5	7.1	9.9	0.89	71.3	0.33	16.8	58	15.65	88.9	9.58	2	893	0.9	0.88	14.5	0.34	3.33	117	1	25.5	2.22	375	<0.5	<5	<0.5	19	33	10	1	28	15	14	<10	86
22.4	5.32	6.4	0.76	60.5	0.27	11	44.5	12.45	80.4	7.32	1	696	0.7	0.68	13.9	0.26	3.31	111	2	19.3	1.84	235	<0.5	<5	<0.5	17	28	10	1	21	18	11	<10	79
22.3	9.07	8.2	1.09	64.9	0.35	13.3	64.5	16.5	80.1	11.8	2	782	0.6	1.14	11.65	0.39	2.8	266	1	29.2	2.29	314	<0.5	<5	<0.5	26	40	10	1	13	13	22	10	102
21	6.13	10.3	0.69	82.4	0.24	16.2	64.4	18.1	131	9.37	2	956	0.8	0.74	13.85	0.26	3.3	84	1	18.9	1.62	402	<0.5	<5	<0.5	13	20	10	1	16	22	7	<10	71
21.9	6.3	6.3	0.75	65.9	0.25	10.5	53.1	14.5	100.5	8.62	1	804	0.6	0.74	12.95	0.26	3.34	100	1	19.2	1.65	231	<0.5	<5	<0.5	12	11	10	1	6	18	8	<10	77
20.6	4.88	5.2	0.63	58.2	0.24	11.6	44.1	12.35	86.6	6.85	1	757	0.7	0.64	12.3	0.22	3.42	134	3	17.3	1.55	195	<0.5	8	<0.5	20	53	10	1	112	18	13	<10	132
21.7	5.69	5.8	0.67	58.6	0.25	9.2	50.2	13.35	71.5	8.4	1	862	0.5	0.69	10.85	0.25	3.04	100	1	18	1.67	219	<0.5	<5	<0.5	12	10	10	1	5	29	8	<10	107
20.3	5.4	6.1	0.63	65.4	0.23	10.5	47.7	13.45	98.3	7.79	1	728	0.6	0.65	13.2	0.22	3.58	92	1	16.3	1.44	219	<0.5	<5	<0.5	12	19	10	1	11	20	8	<10	76

Notes:

Samples collected by Biek; analyses by ALS Geochemistry.

Major oxides reported in weight percent by X-Ray Florescence; minor and trace elements by Inductively Coupled Plasma-Mass Spectrometry in parts per million.

LOI = Loss on ignition in weight percent.

Rock names based on the TAS classification diagram of LeBas and others (1986).

Map symbols are those used on the interim geologic map of the Park City East quadrangle.

Samples from the volcanic mudflow breccia of Silver Creek appear to be lava flows or flow breccias.

Table 2. Isotopic ages of Keetley Volcanics and eastern porphyry stocks of Wasatch intrusive belt.

Formation	Sample number	K-Ar age (Ma)	U/Pb (Ma)	$^{40}Ar/^{39}Ar$ age (Ma)	Mineral	7.5' quadrangle	Easting NAD83	Northing NAD83	Lab used	Reference
Clayton Peak stock	83-PC-175			32.0 ± 0.2	biotite	Brighton			BGC	John and others (1998)
Flagstaff stock	PC-384	39.7 ± 1.2			hornblende	Heber City	458806	4494646	USGS	Bromfield and others (1977)
Flagstaff stock, dike	PC-12	37.8 ± 1.5			hornblende	Heber City	459202	4493996	USGS	Bromfield and others (1977)
Indian Hollow plug	PC-386	36.2 ± 1.3			hornblende	Francis	470079	4499625	USGS	Bromfield and others (1977)
Indian Hollow plug	PC-385	36.1 ± 1.3			hornblende	Francis	470055	4499626	USGS	Bromfield and others (1977)
intrusion	KNC90299-1			34.70 ± 0.16	biotite	Twin Peaks	472164	4463060	NMGRL	Constenius and others (2011)
Keetley Volc., lava flows of Richardson Fla	PC-398	36.4 ± 1.3			hornblende	Park City East	463216	4503449	USGS	Bromfield and others (1977)
Keetley Volc., lava flows of Richardson Fla	PC-398	33.9 ± 1.3			biotite	Park City East	463216	4503449	USGS	Bromfield and others (1977)
Keetley Volcanics	KNC6901-1			38.20 ± 0.11	sanidine	Kamas	470651	4510107	NMGRL	Constenius and others (2003)
Keetley Volcanics	KNC92799-5			40.45 ± 0.18	hornblende	Co-op Creek	485396	4469144	NMGRL	Constenius and others (2011)
Keetley Volcanics	63-mc-47	35.1 ± 1.1			biotite	Heber	463513	4492070	USGS	Crittenden and others (1973)
Keetley Volcanics	62-mc-12	32.7 ± 1.0			biotite	Francis	474972	4494921	USGS	Crittenden and others (1973)
Keetley Volcanics	62-mc-15	34.0 ± 1.0			biotite	Wolf Mountain Summi	495055	4479557	USGS	Crittenden and others (1973)
Keetley Volcanics				38.5 ± 2.1	hornblende					Flood (1997)
Keetley, basal tuff unit	KNC92799-6			37.25 ± 0.14	hornblende	Co-op Creek	485384	4469018	NMGRL	Constenius and others (2011)
Little Cottonwood stock	KNC62695-2		30.5 ± 0.6		zircon	Dromedary Peak	442094	4486069	UALCC	Constenius (1998)
Mayflower stock	PC-388	74.90 ± 4.8			plagioclase	Heber City	463113	4494968	USGS	Bromfield and others (1977)
Mayflower stock	PC-388	41.2 ± 1.6			hornblende	Heber City	463039	4494963	USGS	Bromfield and others (1977)
Mayflower stock				32.7 ± 1.4	hornblende	Heber City				Flood (1997)
Ontario stock	PC-392	34.3 ± 1.3			biotite	Heber City	457712	4497250	USGS	Bromfield and others (1977)
Ontario stock	93718-2		36.00 ± 2.0		zircon	Heber City	465412	4497987	USGS	Vogel and others (2001)
Ontario stock	PC-393	34.00 ± 1.1			biotite	Heber City	462612	4496225	USGS	Bromfield and others (1977)
Ontario stock	PC-392	33.40 ± 1.3			biotite	Heber City	468225	4483322	USGS	Bromfield and others (1977)
Ontario stock	DDH-37-1490	34.5 ± 1.4			biotite	Heber City			USGS	Bromfield and others (1977)
Ontario stock			36 ± 2.0		zircon	Heber City				Constenius and others (1997)
Ontario stock	2380-1	33.3 ± 1.3			biotite	Heber City			USGS	Bromfield and others (1977)
Ontario stock, dike	PC-389	35.6 ± 1.3			plagioclase	Heber City	459747	4494764	USGS	Bromfield and others (1977)
Ontario stock, dike	PC-389	35.7 ± 1.3			plagioclase	Heber City	459747	4494764	USGS	Bromfield and others (1977)
Park Premier stock	PPr-10	31.60 ± 0.39			biotite	Park City East			BGC	John and others (1998)
Park Premier stock	PPr-10	32.38 ± 0.24			hornblende	Park City East			BGC	John and others (1998)
Park Premier stock	81-PP-2			33.53 ± 0.09	biotite	Heber City			BGC	John and others (1998)
Park Premier stock, Bone Hollow phase	PPr-23			31.42 ± 0.10	alunite	Park City East			BGC	John and others (1998)
Park Premier stock, main phase	PC-387	33.9 ± 1.2			biotite	Kamas	468441	4500897	USGS	Bromfield and others (1977)
Park Premier stock, main phase	PC-387	35.2 ± 1.0			hornblende	Kamas	468441	4500897	USGS	Bromfield and others (1977)
Pine Creek stock	PC-27	35.20 ± 1.3			biotite	Heber City	458181	4490398	USGS	Bromfield and others (1977)
Pine Creek stock	LSH-4a	36.8 ± 1.1			biotite	Heber City			USGS	Crittenden and others (1973)
Pine Creek stock	81-PC-4	36.04 ± 0.30			biotite	Heber City			BGC	John and others (1998)
Pine Creek stock	81-PC-4	41.28 ± 0.49			hornblende	Heber City			BGC	John and others (1998)
Pine Creek stock				38.5 ± 0.7	hornblende	Heber City				Flood (1997)
Tibble Fm., lower	KNC61093-2T			36.56 ± 0.15	biotite	Timpanogos Cave	445725	4481568	UA-F	Constenius and others (2011)
Tibble Fm., lower	KNC61093-2T			36.56 ± 0.15	biotite	Timpanogos Cave	445725	4481568	UA-F	Constenius and others (2003)
Tibble Fm., lower	KNC61093-2T			36.1 ± 1.7	zircon	Timpanogos Cave	445725	4481568	UALCC	Constenius and others (2011)
Valeo stock	PC-383	34.6 ± 1.6			biotite	Heber City	458678	4492673	USGS	Bromfield and others (1977)
Valeo stock	PC-379	40.3 ± 1.6			hornblende	Heber City	457737	4492555	USGS	Bromfield and others (1977)
Valeo stock	PC-383	39.8 ± 1.2			hornblende	Heber City	458678	4492673	USGS	Bromfield and others (1977)
volcanic rocks of east Traverse Mtns	KNC060407-14		35.7 ± 0.6		zircon	Timpanogos Cave	443890	4482205	UALCC	Constenius and others (2011)
volcanic rocks of east Traverse Mtns	L33103-9			35.25 ± 0.13	biotite	Lehi	428761	4479912	NMGRL	Biek (2005)
volcanic rocks of east Traverse Mtns	63-mc-66	37.3 ± 1.1			biotite	Lehi	430088	4482903	USGS	Crittenden and others (1973)
volcaniclastic rocks of Strawberry Valley	KNC92899-2			37.73 ± 0.28	biotite	Co-op Creek	482446	4456898	NMGRL	Constenius and others (2011)

Notes:

age uncertainty = 2 standard deviations

UALCC = University of Arizona LaserChron Center

NMGRL = New Mexico Geochronology Research Laboratory

UA-F = University of Alaska, Fairbanks

BGC = Berkeley Geochronolgy Center

General location of John and others (1998) samples shown in their figure 2

Table 3. Selected water well and exploration drill holes.

Map Number	DWR Well Number	Well Name	Easting NAD83*	Northing NAD83*	Total Depth (feet)	Completed	Status	Notes	PLS Coordinates
1		Bison Bluffs well	460678	4509365	1005	12/22/15	water well	base surficial deposits 175 feet; volcanics to 625 feet; TD in Kelvin Fm.?	North 150 feet, East 2110 feet, from W 1/4 corner Section 14, T. 1 S., R. 4 E.
2		Star Pointe Ranch well	460678	4509365	750	10/15/96	water well	base surficial deposits 147 feet; volcanics to 627 feet; TD in Kelvin Fm.?	North 150 feet, East 2110 feet, from W 1/4 corner Section 14, T. 1 S., R. 4 E.
3	00-35-002-P-00	#1 new well	462577	4510289	1050	6/2/93	capped	base volcanics 800 feet; TD in red mudstone, conglomerate	North 1600 feet, East 2710 feet, from SW corner Section 12, T. 1 S., R. 4 E.
4	00-35-002-P-01	#1 new well	462678	4509760	900	8/13/00		TD in volcanics	South 1185 feet, West 924 feet, from NE corner Section 13, T. 1 S., R. 4 E.
5	00-35-001-P-02	Mid valley test well	462585	4506054	1560	9/10/00	plugged and abandoned	base volcanics 1025 feet	South 2700 feet, West 2100 feet, from NE corner Section 25, T. 1 S., R. 4 E.
6	00-55-003-P-01	Butte #1	463480	4502275	900	6/30/00	plugged and abandoned	TD in volcanics	South 4500 feet, East 650 feet, from NW corner Section 6, T. 2 S., R. 5 E.
7	99-35-008-M-02	Hidden Meadow	459536	4501373	2380	2/1/00	plugged and abandoned	TD in Weber Quartzite?	South 2160 feet, West 1690 feet, from NE corner Section 10, T. 2 S., R. 4 E.

Notes:

DWR, Utah Division of Water Rights