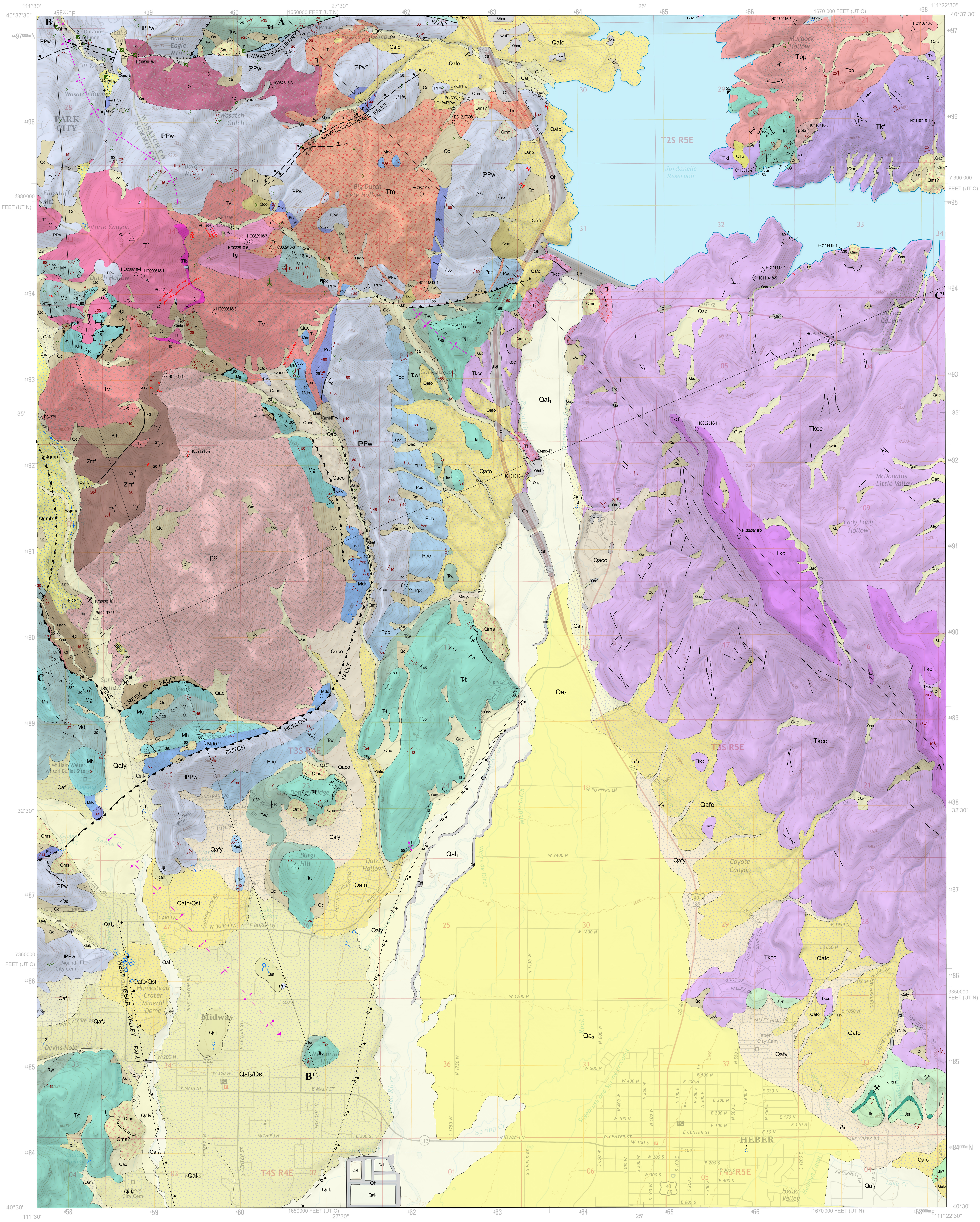
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

Plate 1
Utah Geological Survey Open-File Report 712DM
Interim Geologic Map of the Heber City Quadrangle



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

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APPROXIMATE MEAN DECLINATION, 2019

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

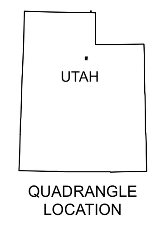
CONTOUR INTERVAL 40 FEET

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

by

Robert F. Biek

2019



QUADRANGLE LOCATION

Base from USGS Heber City 7.5' Quadrangle (2014)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1983
Spheroid: Clarke 1866

Mapping Program Manager: Grant C. Willis
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This map was created from geographic information system (GIS) data.

1	2	3
4		5
6	7	8

1. Park City West
2. Park City East
3. Kamas
4. Brighton
5. Francis
6. Aspen Grove
7. Charleston
8. Center Creek

ADJOINING 7.5' QUADRANGLE NAMES

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MAP SYMBOLS

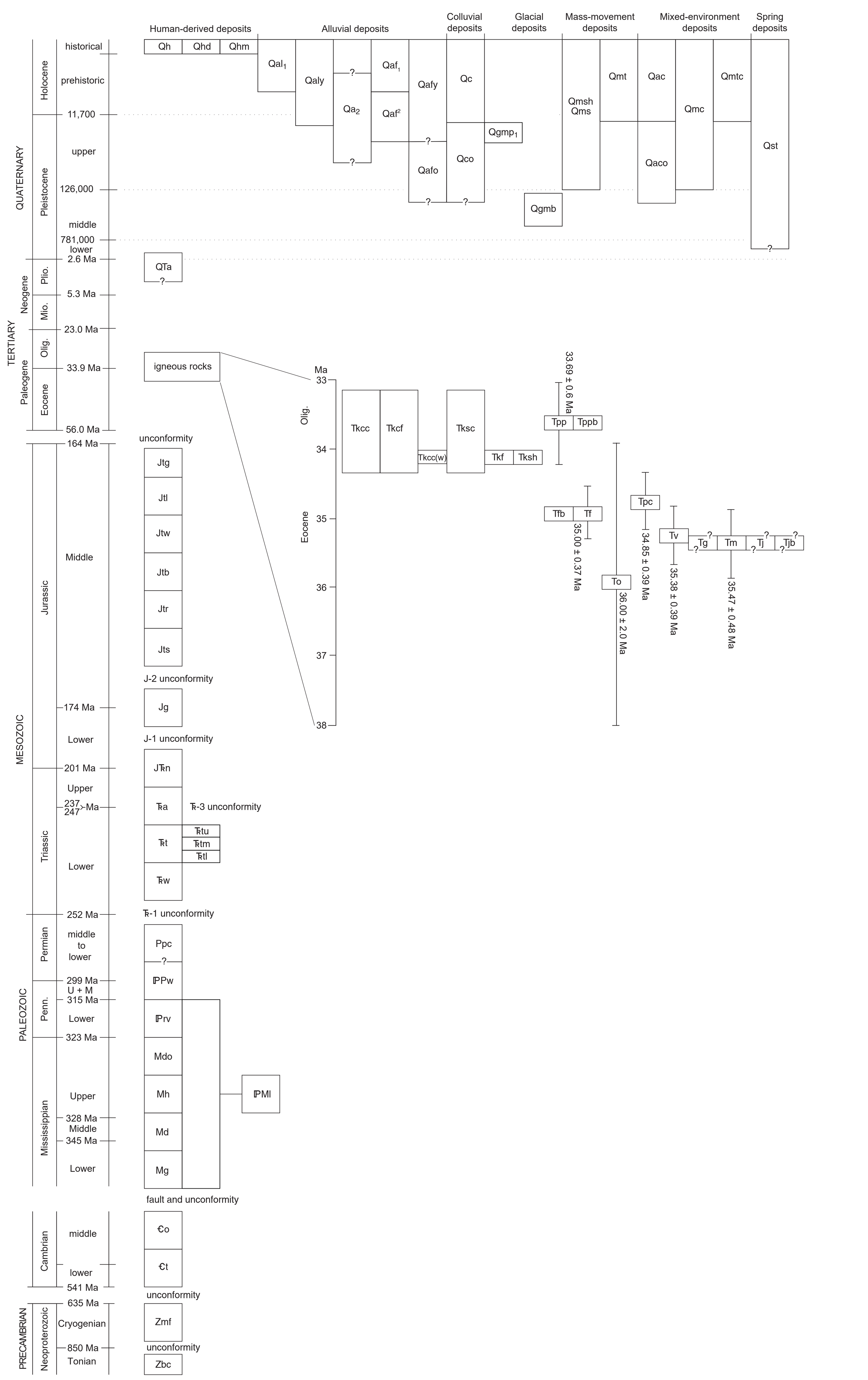
- Contact, dashed where approximately located
- Scratch contact, approximately located, between units that merge imperceptibly
- Normal fault – dashed where approximately located, dotted where concealed; queried where existence uncertain; bar and ball on down-thrown side
- Fault – uncertain origin and offset, dashed where approximately located, dotted where concealed
- Thrust fault – dashed where approximately located, dotted where concealed; saw teeth on upper plate
- Detachment fault – dashed where approximately located, dotted where concealed
- Axial trace of anticline; dashed where approximately located, dotted where concealed, arrow shows direction of plunge
- Axial trace of syncline; dashed where approximately located, dotted where concealed, arrow shows direction of plunge
- Lineament
- Igneous dike, dashed where approximately located
- Landslide scarp, hachures on down-dropped side
- Moraine crest
- 50 Strike and dip of inclined bedding; red symbols indicate attitudes from Bromfield and others (1970)
- 25 Strike and dip of inclined bedding determined photogrammetrically
- 45 Strike and dip of oveturned bedding; red symbols indicate attitudes from Bromfield and others (1970)
- Strike of vertical bedding
- Foliation from Bromfield and others (1970)
- Spring
- Quarry, inactive
- Sand and gravel or borrow pit, inactive
- Sample location and number (geochemistry, see table 1)
- Sample location and number (age, see table 2)
- Approximate location of selected water well (see table 3)
- Prospect; green symbols indicate prospects from Bromfield and others (1970) (see table 4)
- Prospect trench
- Paleoseismic trench (Sullivan and others, 1988)
- Adit, inaccessible; green symbols indicate adits from Bromfield and others (1970) (see table 4)
- Shaft, inaccessible; green symbols indicate shafts from Bromfield and others (1970) (see table 4)
- A——A' Line of cross section

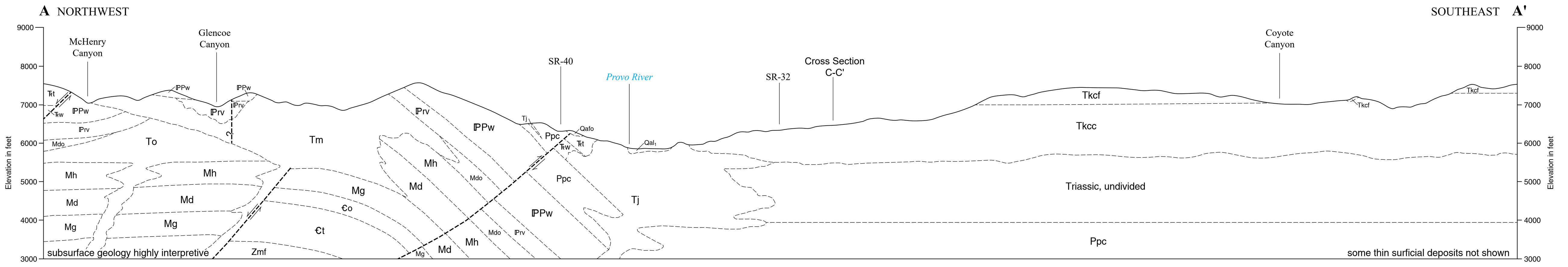
STRATIGRAPHIC COLUMN

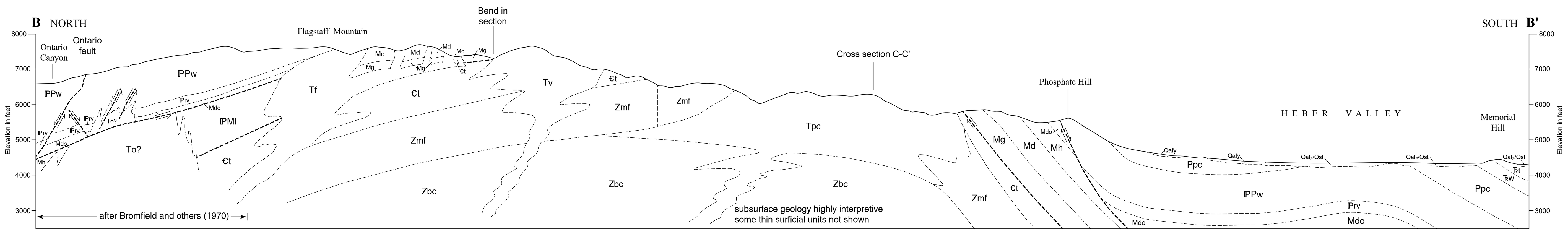
Ma	System	Series	Map Unit	Map Symbol	Thickness feet (meters)	Regional Tectonic Setting	Depositional Environment	Dominant Rock Type and Weathering Profile	Notes
.012	QUATERNARY	Holocene / Pleistocene	various surficial deposits see correlation of map units		variable	modern basin and range extention	alluvium and mass-wasting deposits in modern drainages and basins	unconsolidated gravel, sand, silt and clay	typically maximum thickness reported
2.6	NEO.	Plio.-Mio.							unconformity
33.9	TERTIARY PALEOGENE	Oligocene / Eocene	Keetley Volcanics: volc. mudflow breccia of Silver Creek; lava flows / volc. mudflow breccia of Coyote Canyon; lava flows	Tksc Tkf Tksh / Tkcc Tkcf	variable	early extension and start of volcanism	lahars sourced from stratovolcanoes that once towered over Wasatch intrusive belt	volcanic mudflow breccia and lave flows	Park City porphyries and Park Premier porphyry emplaced
									unconformity
	JURASSIC	Middle	Twin Creek Limestone: Giraffe Creek Member	Jtg	100-130 (30-40)	back bulge basin; Sevier orogeny	shallow marine: transgressive	limestone	
			Twin Creek Limestone: Leeds Creek Member	Jtl	400+ (120+)		shallow marine: transgressive	argillaceous limestone	not exposed
			Twin Creek Limestone: Watton Canyon Member	Jtw	250 (75)		shallow marine: transgressive	limestone	
			Twin Creek Limestone: Boundary Ridge Mbr.	Jtb	120 (35)		shallow marine: regressive	mudstone, siltstone, sandstone	
			Twin Creek Limestone: Rich Mbr.	Jtr	160 (50)		shallow marine: transgressive	argillaceous limestone	
			Twin Creek Limestone: Sliderock Mbr.	Jts	200 (60)		shallow marine: transgressive	limestone	J-2 unconformity
174			Gypsum Spring Fm.	Jg	20 (6)		shallow-marine transgression	silty sandstone	J-1 unconformity
		Lower	Nugget Sandstone	JŦn	900-1000 (275-300)	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							
237 / 247			Ankareh Fm.	Ŧa	1485 (453)		fluvial, floodplain and lake	mudstone, siltstone, sandstone	Ŧ-3 unconformity; not exposed
		Lower	Thaynes Fm.: upper unit	Ŧt: Ŧtu	1000 (300)	shallow-marine continental shelf	shallow marine	limestone calcareous sandstone shale	
			Thaynes Fm.: middle unit	Ŧt: Ŧtm					
			Thaynes Fm.: lower unit	Ŧt: Ŧtl					
			Woodside Fm.	Ŧw	315 (95)		tidal-flat and shallow marine	siltstone, sandstone	micaceous
252	PERMIAN	middle to lower	Park City and Phosphoria Fms., undivided	Ppc	870 (265)		shallow marine; phosphatic shale is deeper water, oxygen-starved basin	limestone; calcareous sandstone phos. shale, limestone; limestone	Ŧ-1 unconformity; phosphatic shale
299	PENN.	Upper to Middle	Weber Quartzite	ℙPw	1100-1500 (335-460)		coastal eolian dune field and shallow marine shelf	sandstone	indistinct bedding highly fractured
315		Lower	Round Valley Limestone (limestone)	ℙrv (ℙMl)	225-400 (70-120)		shallow marine	limestone and shale	
323	MISSISSIPPIAN	Upper	Doughnut Fm. (limestone)	Mdo (ℙMl)	430 (130)		shallow marine	limestone and shale at base	
			Humbug Fm. (limestone)	Mh (ℙMl)	700-750 (210-230)		shallow marine	calcareous sandstone, orthoquartzite, limestone	
328		Middle	Deseret and Gardison, undiv.: Deseret Limestone (limestone)	Md (ℙMl)	600-700 (180-210)		shallow marine	limestone	
345		Lower	Deseret and Gardison, undiv.: Gardison Limestone (limestone)	Mg (ℙMl)	600 (200)		shallow marine	limestone	Dell Phosphatic Mbr.
									unconformity and fault
	CAMBRIAN	middle	Ophir Formation	Ꞓo	40+ (12+)		shallow marine	shale and limestone	
497		lower	Tintic Quartzite	Ꞓt	500+ (150+)		beach and coastal plain	sandstone, pebbly sandstone	
541 / 645	NEOPROTEROZOIC	Cryogenian	Mineral Fork Formation	Zmf	1000+ (300+)		continental glaciers and shallow marine	diamictite, shale, sandstone	unconformity
850		Tonian	Big Cottonwood Fm.	Zbc	16,000+ (5000+)		shallow marine, tidal flat	orthoquartzite shale	unconformity; not exposed

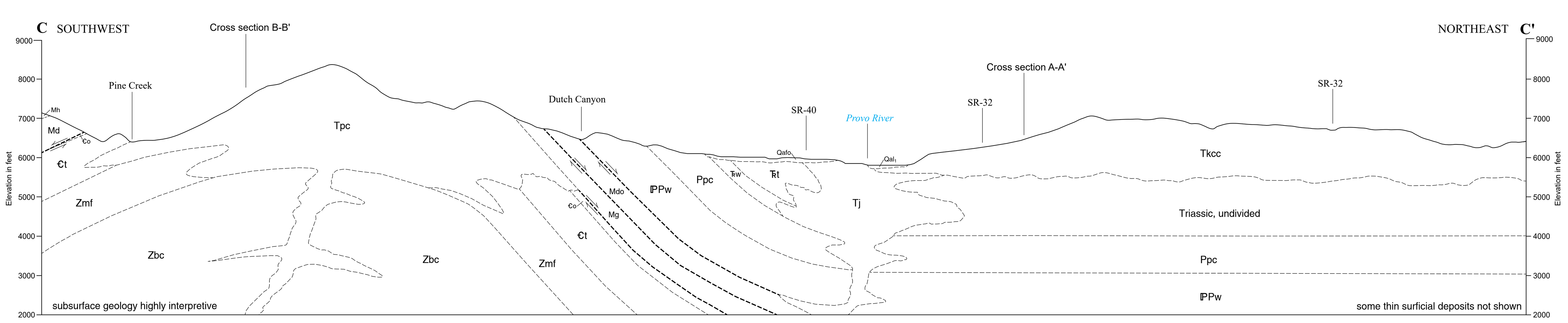
*ages from Cohen and others (2013, updated v.2018/08)

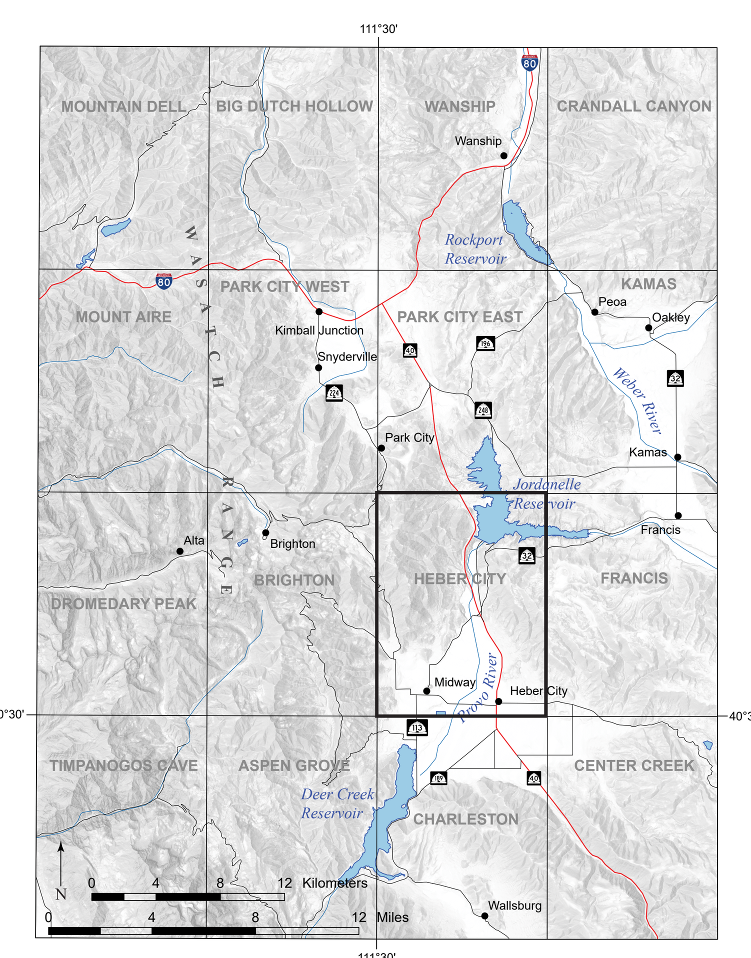
CORRELATION OF MAP UNITS



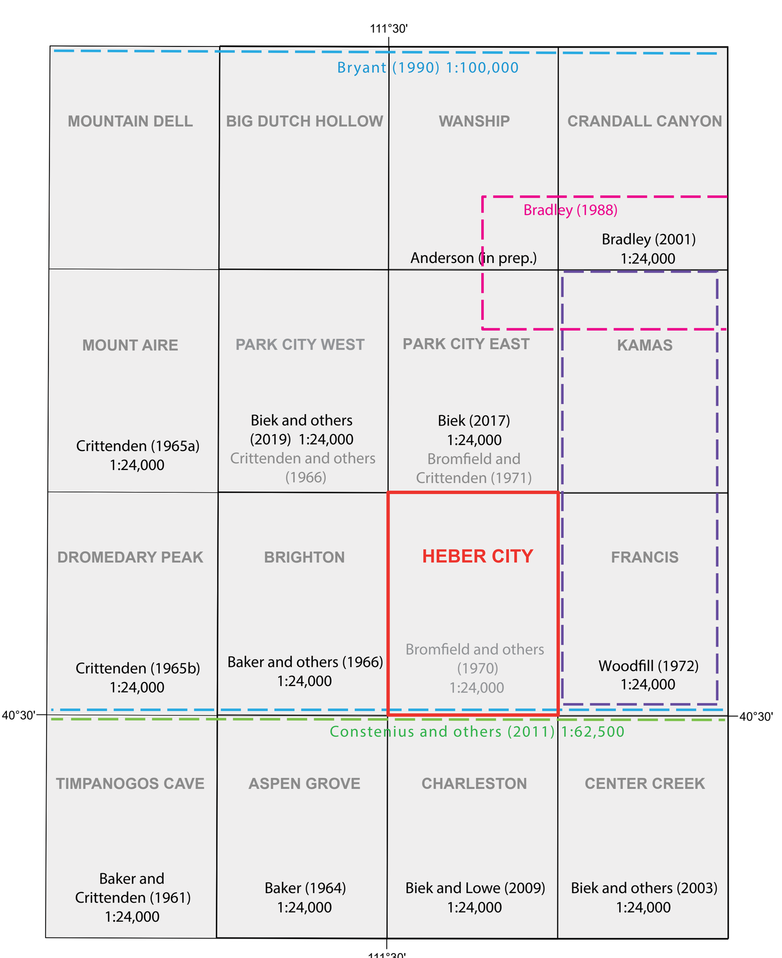








Location map showing U.S. Geological Survey 7.5' quadrangles.



U.S. Geological Survey 7.5' quadrangles and principal sources of geologic mapping.

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

by

Robert F. Biek

Suggested citation:

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Disclaimer

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey National Cooperative Geologic Mapping Program through USGS STATEMAP award number G18AC00202, 2018–2019. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. This map and explanatory information is submitted for publication with the understanding that the United States Government is authorized to reproduce and distribute reprints for governmental use.

UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 712DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2019

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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 and locally for small retention ponds; also used for the Jordanelle zoned-earth dam (Sullivan and others, 1988; Dow, 1995) and Heber Valley water treatment facility; 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.

Qhd **Disturbed land** (Historical) – Abandoned quarry in Jordanelle stock and gravel pit in younger fan alluvium and Pleistocene Provo River alluvium at the entrance to Cottonwood Canyon; also includes general borrow material from adjacent, colluvium-covered slopes used to smooth the cross sectional profile of valley bottoms once occupied by incised, intermittent streams and now occupied by ski runs at Deer Valley Resort; fill is generally less than 15 feet (5 m) thick.

Qhm **Mine dumps and waste piles** (Historical) – Waste rock from mining operations of the Park City mining district in the northern parts of the map area, once one of the West's most important silver-lead-zinc districts (see, for example, Phillips and Krahulec, 2006); smaller deposits and disturbed areas are shown with a symbol (quarry, prospect, adit, or shaft); thickness highly variable to several tens of feet.

Alluvial deposits

Qal_1 **Modern stream alluvium** (Holocene) – Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel along the Provo River, Snake Creek, and Lake Creek; includes river- and stream-channel and floodplain deposits, and low terraces several feet above current stream level; locally includes small alluvial-fan and colluvial deposits; extent is poorly constrained near Heber City due to subtle geomorphology and modification by agriculture and development; locally underlain by and interbedded with calcareous tufa along Snake Creek; boreholes indicate that alluvium at the location of the Jordanelle Dam, of which modern stream alluvium is only the uppermost part, is 30 to 100 feet (9–30 m) thick; 0 to about 30 feet (0–9 m) thick.

Qaly **Young stream alluvium** (Holocene to upper Pleistocene) – Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel mapped in major upland 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.

Qa_2 **Valley-fill deposits** (Holocene? to upper Pleistocene?) – Moderately sorted sand, silt, and pebble to boulder gravel that forms broad, planar, gently south-sloping surface of northern Heber Valley; has moderately well developed pedogenic calcium carbonate in upper part of deposit (Stage II to II+ carbonate of Birkeland and others, 1991) and is locally blanketed by loess veneer; likely 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; probably less than several tens of feet thick; these deposits form the upper part of basin-fill deposits of Heber Valley that locally exceed 450 feet (140 m) thick, based on water wells logs; based on a gravity survey, Peterson (1970) estimated slightly more than 800 feet (245 m) of basin fill in the southwest part of Heber Valley, just south of this map area.

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, mostly undissected 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 20 feet (6 m) thick.

Qaf_2 **Middle fan alluvium** (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; forms characteristic alluvial-fan morphology that is dissected by modern drainages; equivalent to the lower part of young and middle fan alluvium (Qafy); mapped in the southwestern corner of the map area; probably about 40 feet (12 m) thick.

Qafy **Young and middle fan alluvium, undivided** (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; colluvium locally constitutes a significant part adjacent to hillsides; forms both active depositional surfaces (Qaf_1 equivalent) and typically inactive surfaces incised by small streams (Qaf_2 equivalent); steeper, 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 along valley margins; 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 pedogenic calcium carbonate in upper part of deposit; exposed thickness as much as several tens of feet.

Map unit includes small area of apparently faulted, unconsolidated deposits immediately south of the west abutment of Jordanelle Dam originally interpreted to be pre-Keetley alluvium and colluvium (USBR, 1986; see also Sullivan and others, 1988; Dow, 1995). Exposures are poor in this area, and several trenches excavated during geotechnical investigations are backfilled. Still, I saw no evidence of pre-Keetley alluvium in this area—regionally this older unit is a distinctive, slope-forming unit with rounded quartzite cobbles and boulders, no volcanic clasts, and a reddish-brown mudstone and sandstone matrix (Toc of Bryant, 1990; Biek, 2017; Biek and others, 2019). If such pre-Keetley alluvial and colluvial strata were correctly identified in trenches, it is no longer apparent and appears to be buried by younger surficial deposits of locally derived, subangular quartzite and volcanic clasts that I interpret as late to middle Pleistocene fan alluvium.

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 are mapped; typically less than about 30 feet (0–9 m) thick.

Qco **Older colluvium** (upper to middle? Pleistocene) – Poorly to moderately sorted, clay- to boulder-size, locally derived sediment deposited on moderate slopes principally by slope wash and soil creep; forms mostly inactive surfaces incised by modern drainages, but uphill areas locally receive colluvium from adjacent hillsides; mapped in the greater Cottonwood Canyon area west of Jordanelle Dam; typically less than about 30 feet (0–9 m) thick.

Glacial deposits

Alpine glacial deposits in the Wasatch Range are of the Pinedale glaciation and an older glaciation of uncertain but likely Bull Lake age; relatively small post-Pinedale moraines are present in some cirque basins. Pinedale deposits in their type area in the Wind River Range of Wyoming are about 13 to 30 ka, with glacial maxima about 16 to 23 ka on the basis of cosmogenic ^{26}Al and ^{10}Be dating (Gosse and others, 1995; Chadwick and others, 1997; Phillips and others, 1997; Pierce and others, 2018), and are roughly coeval with the late Wisconsin glaciation, global Last Glacial Maximum (LGM, about 19.0 to 26.5 ka; Clark and others, 2009), and Marine Oxygen Isotope Stage 2 (MIS 2, 14 to 29 ka; data from 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 150 ka (Sharp and others, 2003; Pierce and others, 2011; Pierce and others, 2018) and are roughly coeval with the Illinoian glaciation or MIS 6 (130 to 191 ka; data from 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. In the Wasatch Range, maximum ice extent during the Pinedale glaciation occurred about 19 to 22 ka (Labbs and Munroe, 2016; Quirk and others, 2018) with deglaciation and minor moraine-building pauses lasting through about 13 ka (Labbs and others, 2011; Labbs and Munroe, 2016; Quirk and others, 2018). 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 ^{10}Be cosmogenic exposure ages and stratigraphic relationships between lake and glacial deposits, they reported that Pinedale terminal moraines at the entrances of Little Cottonwood and Bells Canyons were occupied near the time of or possibly before the Bonneville highstand around 18 ka and subsequently abandoned while the lake continued to overflow at the Provo level, consistent with stratigraphic studies of Godsey and others (2005). Quirk and others (2018) used coupled glacier energy-mass balance and ice-flow models to reconstruct glacier extents in Big and Little Cottonwood Canyons and American Fork Canyon and also showed that Pinedale glaciers reached and abandoned their maximum extent prior to the Bonneville highstand. Although undated, the proximity of the Park City-area Pinedale-age glacial deposits 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, possibly 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 lake) (Oviatt, 2014, 2015). However, the small cirque-floor moraines may be slightly older—Quirk and others (2018) reported a mean ^{10}Be exposure age for young moraines near Solitude Resort of 15.5 ± 0.8 ka, suggesting they may be coincident with the latter part of Heinrich Stadial 1, a period of disruption of global ocean circulation due to collapse of northern hemisphere ice shelves 18.0 to 14.5 ka (Álvarez-Solas and others, 2011).

$Qgmp_1$, $Qgmp_1$?

Glacial till of Pinedale age (upper Pleistocene) – Non-stratified, poorly sorted clay, silt, sand, gravel, cobbles, and boulders; clasts are matrix supported, subangular to subrounded; terminal moraine is poorly developed along Pine Creek at the western quadrangle boundary; Pinedale age is based on moderately well preserved morainal topography and weak soil development; map patterns suggest thickness in excess of 200 feet (60 m) near the western map boundary.

Two pulses of apparent Pinedale-age till are mapped in the nearby Park City West quadrangle, with $Qgmp_2$ being older and reaching farther down slope than $Qgmp_1$ (Biek and others, 2019); I continue that convention here although no $Qgmp_2$ deposits are apparent in this map area. No numerical age control is available for glacial deposits in the map area. The largest complex of Pinedale-age glacial sediment is along Pine Creek, which was fed by ice from cirque basins eroded into the east flank of Clayton Peak in the adjacent Brighton quadrangle. Two small deposits are also mapped in Ontario Canyon. Query indicates morainal deposits along Pine Creek that extend downslope of the main Pinedale deposits and that may be better assigned to the older ($Qgmp_2$) phase. The main mass of younger Pinedale-age glacial till ($Qgmp_1$) extends to an elevation of about 7400 feet (2255 m) in Pine Creek canyon.

Qgmb **Older glacial till of likely Bull Lake age** (middle Pleistocene) – Non-stratified, poorly sorted clay, silt, sand, gravel, cobbles, and boulders; similar to glacial till of Pinedale age, but glacial landforms are absent, clasts typically appear more weathered (especially clasts apparently derived from the Clayton Peak stock, which tend to be grussy), and soils tend to be better developed; map patterns suggest thickness in excess of 200 feet (60 m) near the western map boundary.

Also used for an unusual boulder deposit along Pine Creek just north of Springer Hollow that consists entirely of subrounded granitic boulders typically 3 feet (1 m) but as much as 20 feet (6 m) in diameter. Boulders are virtually all derived from a single intrusive source, possibly the Clayton Peak granodiorite, with rare boulders possibly from the Valeo porphyry. Boulders commonly have a well-developed Fe-Mn patina, but are not grussy weathering. This boulder field may have originated as a rock avalanche onto a Bull Lake-age glacier that subsequently carried the boulders to their present position. The boulder field is surrounded and nearly buried by young stream alluvium of Pine Creek.

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; "h" indicates two small landslides with documented historical movement in old fan alluvium on Highway 40 road cuts; thickness highly variable, but larger deposits exceed several tens of feet thick; most mapped landslides are newly recognized—just one is shown on the map of Bromfield and others (1970; the focus of their work was bedrock geology, as it was for most maps of that era) whereas several landslides and suspected slides are shown on the reconnaissance inventory map of Elliott and Harty (2010)—the result of newly available lidar data, 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 upland areas) 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.

Qmt **Talus** (Holocene to upper Pleistocene) – Very poorly sorted, locally derived, angular, boulder-size and lesser fine-grained interstitial sediment deposited by rockfall on and at the base of steep slopes; characterized by angular boulder fields that lack vegetation; about 0 to 30 feet (0–9 m) thick.

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; query indicates deposit in upper reaches of Dutch Hollow that is of higher elevation than adjacent mixed alluvium and colluvium, but offers no exposures—Bromfield and others (1970) mapped this area as the Valeo stock; probably about 20 to 30 feet (6–9 m) thick.

Qmc **Landslides and colluvium** (Holocene to upper Pleistocene) – Unsorted, locally derived, clay- to boulder-size material; mapped where possible landslide deposits are difficult to identify and possibly covered by colluvium; most deposits probably less than 30 feet (9 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 rockfall and slope wash; 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.

Spring deposits

Qst **Calcareous spring tufa deposits** (Holocene to Pleistocene) – Light-brown to pale-grayish-yellow, highly porous and vuggy calcareous spring tufa that forms mounds and broad terraces in the Midway area of northwestern Heber Valley; forms the largest concentration of calcareous hot spring tufa in Utah (Kohler, 1979; Carreón-Diazconti and others, 2003); Homestead Crater, shaped like an old-fashioned beehive, is the tallest mound at 55 feet (16 m) high; because it is relatively soft and easily worked, tufa is commonly used as a local building and landscape stone; tufa is derived from thermal spring waters whose average temperature is 88.2º to 113.9ºF (31.2º–45.5ºC), a result of deep circulation of precipitation and snowmelt in the nearby Wasatch Range (Mayo and Loucks, 1995); Carreón-Diazconti and others (2003) investigated subsurface mixing of thermal and non-thermal groundwater of the Midway system and reported deep circulation to a depth of about 1.2 miles (2 km) where temperatures are about 300ºF (150ºC); McBride and others (2010) used high-resolution ground-penetrating radar to map and understand the growth of tufa deposits northwest of Memorial Hill; tufa, interbedded with basin-fill sediments, is reported to depths of nearly 170 feet (52 m) in monitoring wells (Wallace, 2005) and to 392 feet (120 m) in a water well (Mayo and others, 2005) near the Midway fish hatchery immediately south of the map area.

Stacked-unit deposits

Qaf_2/Qst

Middle fan alluvium over calcareous spring tufa deposits (Holocene to upper Pleistocene/Holocene to Pleistocene) – Middle fan alluvium that forms a veneer over and interfingers with calcareous spring tufa deposits in the Midway area; forms a surface of slightly lower elevation with fewer tufa exposures than adjacent Qafo/Qst deposits; tufa is pale grayish yellow, weathers light brown, and is highly porous and vuggy; tufa is exposed at and near mapped springs and likely underlies much of the surrounding surface where it is concealed by and interbedded with fan alluvium; tufa, interbedded with basin-fill sediments, is reported to depths of nearly 170 feet (52 m) in monitoring wells (Wallace, 2005) and to 392 feet (120 m) in a water well (Mayo and others, 2005) near the Midway fish hatchery immediately south of the map area.

Qafo/Qst

Old fan alluvium over calcareous spring tufa deposits (Holocene to upper? Pleistocene/Holocene to Pleistocene) – Old fan alluvium that forms a discontinuous veneer over and interfingers with calcareous spring tufa deposits in northwestern Heber Valley; tufa is pale grayish yellow, weathers light brown, and is highly porous and vuggy; tufa is exposed at and near mapped springs and likely underlies much of the surrounding surface where it is concealed by and interbedded with fan alluvium; forms a slightly higher surface with more exposed tufa than Qaf_2/Qst deposits.

Qafo/ℙPw

Old fan alluvium over Weber Quartzite (Holocene to upper? Pleistocene/Upper Pennsylvanian) – Old fan alluvium that consists almost entirely of reworked Weber Quartzite debris; mapped near the old Mayflower mine; surficial cover probably less than about 20 feet (6 m) thick.

Qmt/ℙrv

Talus over Round Valley Limestone (Holocene to upper Pleistocene/Upper Pennsylvanian) – Talus derived from the Weber Quartzite that conceals upper Round Valley strata in the upper reaches of Dutch Hollow; surficial cover mostly less than about 15 feet (5 m) thick.

Unconformity

QUATERNARY AND TERTIARY

QTa **Old alluvial deposits** (lower Pleistocene to Pliocene?) – Pebble- to cobble-size, rounded, mostly quartzite gravels mapped in the northeastern corner of the map area nearly 400 feet (120 m) above Provo River floodplain, which is now flooded by Jordanelle Reservoir; interpreted to be deposits of the ancestral Provo River likely sourced from the Weber Quartzite and Uinta Mountain Group on the southwestern flank of the Uinta Mountains; probably less than about 20 feet (6 m) thick.

Unconformity

OLIGOCENE and EOCENE

The Keetley Volcanics are late Eocene to earliest Oligocene volcanic mudflow breccias, lava flows, fine-grained tuffaceous strata, conglomerate, and debris-avalanche deposits 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 sandstone and conglomerate at least locally deposited in a lake; a middle thick unit of volcanic mudflow breccia, debris-avalanche deposits, and lesser conglomerate known as the volcanic mudflow breccia of Silver Creek (northern exposures) and the volcanic mudflow breccia of Coyote Canyon (southern exposures; see note below); 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, 2001; Biek, 2017). Woodfill (1972) and Leveinen (1994) 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 igneous belt. As described by John (1987, 1989a), Hanson (1995), Feher (1997), Vogel and others (1997, 2001), Beno and others (2017), and Smyk and others (2018), the belt consists of nearly a dozen high-potassium, calc-alkaline Tertiary intrusions. From west to east these include three phaneritic stocks (Little Cottonwood, Alta, and Clayton Peak), six porphyry stocks (Flagstaff, Ontario, Mayflower, Glencoe, Valeo, and Pine Creek stocks collectively known as the Park City porphyries, to which I would add the Jordanelle porphyry), 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 stocks increases to the west, from less than 0.6 mile (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 east-west alignment of the Wasatch igneous belt is the latest manifestation of the long tectonic history of the building and ultimate demise of the Proterozoic supercontinent Rodinia (see, for example, Vogel and others, 2001; Dehler and Sprinkel, 2005; Biek, 2018; Sprinkel, 2018), which created an east-trending structural belt of weakened crust known as the Uinta-Cottonwood arch. The Wasatch igneous belt is between about 30 and 40 million years old (Crittenden and others, 1973; Bromfield and others, 1977; Vogel and others, 1997, 2001; Constenius and others, 2011; Smyk and others, 2018) (table 2). Nelson (1971, 1976) reported on early Oligocene vertebrate fossils in Keetley tuffaceous strata near Peoa, and these Keetley strata locally produce petrified tree stumps and fossil wood.

Keetley strata are intruded by both the Park Premier porphyry, which 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 have long been thought to be 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). However, Smyk and others (2018) reported U-Pb crystallization ages on zircon from the Wasatch igneous belt that are mostly younger than previous K-Ar and $^{40}Ar/^{39}Ar$ ages and so suggested that the Keetley Volcanics may have been sourced from the Valeo, Pine Creek, and Flagstaff stocks. Still, zircon ages record the crystallization age of a stock, whereas biotite, hornblende, and sanidine record the age of eruptive products, which are typically older than their parent stock. The preservation of the Indian Hollow vent area clearly shows it was one source of the Keetley Volcanics.

The Keetley Volcanics were deposited in an area of considerable pre-Keetley paleotopographic relief and lie unconformably over numerous mostly Paleozoic and Mesozoic units; the bulk of the formation fills paleotopography developed on comparatively non-resistant Triassic strata (Boutwell, 1912; Forrester, 1937; O'Toole, 1951; Woodfill, 1972; Feher, 1997). Near Heber City, the Keetley Volcanics are locally in excess of 2500 feet (760 m) thick (Bryant, 1992; Leveinen, 1994; Biek and others, 2003).

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 (between Park City and Morgan Valley) 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 in Morgan Valley to the north. Coogan and King (2016) speculated that the Wasatch igneous belt may be the source of volcanic material in the mostly finer grained Norwood strata.

The volcanic mudflow breccia of Silver Creek (Tksc) was named by Bromfield and Crittenden (1971) for exposures that border the valley of Silver Creek in the Park City East quadrangle. They noted that these strata are similar and in part equivalent to the volcanic breccia of Coyote Canyon (Tkcc), named for exposures at Coyote Canyon immediately north of Heber City (Bromfield and others, 1970). We now understand that the Coyote Canyon moniker pertains to volcanic mudflow breccias south of inferred vent areas at the Park Premier porphyry intrusions and the Indian Hollow plug, whereas the name Silver Creek was applied to similar deposits on the northern flanks of the vents. I follow this entrenched terminology, using the Provo River as an arbitrary divide between the two equivalent units.

Tkcf **Lava flows of Coyote Canyon** (lower Oligocene to upper Eocene) – Gray latite porphyry lava flows with 20% to 30% phenocrysts of plagioclase commonly 1 to 2 mm and as much as 5 mm in size, and less abundant and smaller phenocrysts of hornblende and biotite in a fine-grained groundmass; caps the volcanic breccia of Coyote Canyon north of Heber City; 200 to 250 feet (60–75 m) thick.

Tkcc **Volcanic mudflow breccia of Coyote Canyon** (lower Oligocene to upper Eocene) – Andesitic volcanic mudflow breccia similar to that of the volcanic breccia of Silver Creek; individual beds typically heterolithic, rarely monolithic; on the south side of Jordanelle Reservoir map unit includes mostly lava flows and lesser volcanic mudflow breccia, all dipping steeply and locally deeply altered; elsewhere, locally contains thin andesitic lava flows whose outcrop is discontinuous and impractical to map separately; weathers to rounded hills, typically with a deep regolith and poor exposure, and commonly covered with a lag of volcanic boulders; best exposures are in Highway 32 road cuts south of Jordanelle Reservoir; represents deposition as lahars (debris flows of volcanic material) and lava flows on the distal flanks of stratovolcanoes that once towered over the eastern stocks of the Wasatch igneous belt (Bromfield, 1968; Woodfill, 1972; John, 1989b; Bryant, 1992; Leveinen, 1994; Hanson, 1995; Feher and others, 1996; Feher, 1997; Smyk and others, 2018); as much as 1500 feet (460 m) thick northeast of Heber Valley.

Exposures in the northeastern corner of the map area—especially along the shoreline of Jordanelle Reservoir (sections 28, 32, and 33, T. 2 S., R. 4 E.) and in a Highway 32 road cut west of Charcoal Canyon—show vertical and steeply dipping lava flows and lesser mudflow breccias. Some exposures are cut by variously oriented shear zones characterized by fine-grained, reddish-brown fault gouge. Jigsaw clasts are locally common in matrix-supported volcanic mudflows. Hacker and others (2014) and Biek and others (in press) found such clasts to be characteristic of gigantic volcanic landslides. Deformed clasts such as these are absent in primary, undeformed volcanic mudflow deposits (broken clasts would be torn apart during flow movement), but are characteristic features of volcanic debris avalanches; the clasts appear to record brittle failure under high confining pressures (Pierson and others, 2018).

I interpret these steeply dipping strata as part of the Silver Creek chaos, which resulted from flank collapse of the volcano that once stood above the Park Premier porphyry stocks (see, for example, Biek, 2017, 2018). Bromfield and others (1970) mapped this area as volcanic mudflows of Coyote Canyon cut by inferred intrusive andesitic porphyries, some of which were interpreted to be near vertical. Rocks in this area are mostly poorly exposed and would have been even more so prior to erosion along the Jordanelle Reservoir shoreline and road cuts made for Highway 32. Even today, only a short distance from the shoreline or road cuts, it is virtually impossible to tell the orientation of beds in this area, rendering the southward extent of the chaos uncertain. It appears to be buried by subhorizontal (and thus post-collapse) volcanic mudflow breccia of Coyote Canyon (Tkcc) in sections 4 and 5 not far south of Highway 32.

Tkcc(w)

Brecciated Weber Quartzite block in volcanic mudflow breccia of Coyote Canyon (lower Oligocene to upper Eocene/lower Permian? to Middle Pennsylvanian) – Resistant, brecciated block of Weber Quartzite "floating" in volcanic mudflow breccia of Coyote Canyon; forms one house-sized block mapped near the base of the Keetley Volcanics south of Jordanelle Dam and east of SR40; Biek (2017) described a larger such block just to the north in the Park City East quadrangle.

Tksc **Volcanic mudflow breccia of Silver Creek** (lower Oligocene to upper Eocene) – Andesitic volcanic mudflow breccia similar to that of Coyote Canyon, but mapped only at the north edge of the quadrangle adjacent to Jordanelle Reservoir where it was intruded by the Park Premier porphyry stocks; hydrothermally altered, as shown by stippled pattern; like the volcanic breccia of Coyote Canyon, 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 igneous belt; as much as 1000 feet (300 m) thick in the adjacent Park City East quadrangle (Biek, 2017).

Tkf **Lava flows associated with Park Premier porphyry stocks** (lower Oligocene to upper Eocene) – Multiple, petrographically distinct lava flows of andesitic, dacitic, trachytic, and latitic composition; most are porphyritic with 5 to 30% phenocrysts of plagioclase and lesser hornblende, and some contain minor biotite; contains minor volcanic mudflow breccia, locally with deformed jigsaw clasts, suggesting this unit may also be part of the Silver Creek chaos; commonly hydrothermally altered, as described by Willes (1962), including widespread chloritization and iron-staining, and local silicification, alunitization, and clay alteration; may be roughly equivalent to the lava flows and volcanic mudflow breccia of Sage Hen Hollow (Tksh; Biek, 2017); most of this unit was mapped by Bromfield and others (1970) and John (1989b) as volcanic breccia of Coyote Canyon (Tkcb), but nearly all of these rocks appear to be a variety of andesitic, dacitic, and latite lava flows; thickness uncertain, but likely exceeds 1500 feet (450 m) thick.

Tksh **Lava flows and volcanic mudflow breccia of Sage Hen Hollow** (upper Eocene) – Small, poor exposure mapped north of the Hawkeye-McHenry fault zone at the north edge of the quadrangle; as described by Biek (2017), consists of multiple, petrographically distinct lava flows of andesitic, dacitic, and latitic 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; map patterns suggest a thickness of about 1300 feet (400 m) in the adjacent Park City East quadrangle.

Intrusive rocks

Where available, zircon U-Pb crystallization ages are reported below for the Park City and Park Premier porphyries. Smyk and others (2018) noted that U-Pb ages of these porphyries are generally younger than their K-Ar and $^{40}Ar/^{39}Ar$ ages on biotite, hornblende and feldspar (33 to 36 Ma vs. 32 to 42 Ma) (table 2). Because of zircon's higher closure temperature, U-Pb ages more closely reflect porphyry emplacement ages. Vogel and others (1997) and Smyk and others (2018) noted that many of the hornblende ages are anomalously old, possibly due to excess argon.

Using the classification scheme of LeBas and others (1986) the Park City and Park Premier porphyries are latites, dacites, and trachytes and form the eastern intrusions of the Wasatch igneous belt. These high-potassium, calc-alkaline intrusions were likely derived from partial melting of the lower crust (Vogel and others, 1997; Presnell, 1997; Vogel and others, 2001; Symk and others, 2018). Each porphyry has distinctive petrographic characteristics, but significant internal variation and typically poor exposure makes mapping porphyry-on-porphyry contacts difficult and commonly highly interpretative. I have largely followed the more detailed efforts of Bromfield and others (1970) while stripping away areas that appear to be of colluvial and alluvial origin.

Tia **Dikes of intermediate composition** (lower Oligocene to upper Eocene) – Medium- to dark-gray andesitic porphyry dikes typically containing 15% to 20% phenocrysts of plagioclase and minor hornblende; only a few dikes, intruded into the Valeo, Flagstaff, Glencoe, and Pine Creek stocks and adjacent country rock, are mapped due to limited, typically poor exposure; dikes are typically 1 to 10 feet (0.3–3 m) in width.

Tpp **Park Premier porphyry stock** (lower Oligocene to upper Eocene) – Medium-gray to greenish-gray porphyritic latite, dacite, andesite, and trachyte, subvolcanic porphyry intrusions containing about 25% phenocrysts (typically 1 to 3 mm in size) of plagioclase, hornblende, and biotite, and rare phenocrysts of pyroxene; as interpreted by John (1987, 1989b) and John and others (1997), the Park Premier stock comprises five small, granodiorite porphyry and andesite porphyry intrusions emplaced over a span of about 3 million years and that are the center of intense hydrothermal alteration, stockwork quartz veins, and low-grade copper-gold-molybdenum mineralization; the main, oldest phase of the Park Premier stock is a biotite-hornblende andesite to dacite porphyry intruded by two microaplitic granodiorite porphyries and by two dacite or andesite porphyries (John and others, 1997); hydrothermal alteration, as described and mapped by Willes (1962) and John (1987, 1989b), characterized by widespread chloritization and iron-staining, and local silicification, alunitization, and propylitic 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; because of widespread alteration and exceptionally poor exposure, I map the porphyry as a single unit, with a stippled pattern that shows more highly altered areas; mapped east of Jordanelle Reservoir in the northeast corner of the map area where it intrudes the volcanic mudflow breccia of Silver Creek (Tksc), lava flows associated with Park Premier porphyry stocks (Tkf), and Thaynes strata (ꞦTt) 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 main phase of the Park Premier stock in the adjacent Francis quadrangle; John and others (1997) reported K-Ar ages of 31.60 ± 0.39 Ma (biotite) and 32.38 ± 0.24 Ma (hornblende) from the Bone Hollow porphyry, and an $^{40}Ar/^{39}Ar$ age on hydrothermal biotite of 33.53 ± 0.09 Ma and on hypogene alunite of 31.42 ± 0.10 Ma, suggesting that high-sulfidation gold mineralization is about 2 million years younger than porphyry copper-gold mineralization and alteration; Smyk and others (2018) reported a U-Pb zircon crystallization age of 33.69 ± 0.60 Ma from a sample from the Park City East quadrangle.

Tppb **Park Premier porphyry, intrusive breccia phase** (lower Oligocene to upper Eocene) – Medium-gray to greenish-gray porphyritic dacite with abundant, angular, pebble- to cobble-size fragments of Thaynes strata; interpreted to be marginal breccia phase of the Park Premier porphyry intrusion; forms a near dip slope several tens of feet thick.

Tf **Flagstaff Mountain porphyry** (upper Eocene) – Granodiorite porphyry with 20% to 30% phenocrysts of plagioclase commonly 0.5 inch (1 cm) long and abundant smaller white plagioclase and lesser black hornblende and minor biotite phenocrysts in a greenish-gray, microcrystalline matrix; commonly altered with epidote, chlorite, and sericite; intrudes Valeo stock (Bromfield and others, 1970; Scales, 1972) and Weber Quartzite, Deseret and Gardison Limestones, and Tintic Quartzite; Smyk and others (2018) reported a U-Pb zircon crystallization age of 35.00 ± 0.37 Ma (table 2).

Tfb **Flagstaff Mountain porphyry, intrusive breccia phase** (upper Eocene) – Granodiorite porphyry breccia comprises autobrecciated Flagstaff and Valeo stocks and angular fragments of quartzite and limestone; poorly exposed and mapped following Bromfield and others (1970) along the east side of the intrusion where it intrudes the Valeo stock, but not observed in Ontario Canyon; likely several tens of feet thick.

To **Ontario porphyry** (upper Eocene) – Granodiorite porphyry with 30% to 35% phenocrysts of plagioclase commonly 0.5 inch (1 cm) long and abundant smaller white plagioclase and black hornblende and biotite phenocrysts in a light-gray, microcrystalline matrix; lacks quartz phenocrysts.

Tpc **Pine Creek porphyry** (upper Eocene) – Granodiorite porphyry with 25% to 30% phenocrysts of plagioclase commonly 0.5 inch (1 cm) long, and less abundant biotite and hornblende phenocrysts in a medium-gray, microcrystalline matrix; lacks obvious quartz, typically has fewer phenocrysts than the Valeo stock, and is typically lighter in color and more crystal-rich than the Flagstaff stock; Smyk and others (2018) reported a U-Pb zircon crystallization age of 34.85 ± 0.39 Ma from a sample from Pine Creek Canyon.

Tv **Valeo porphyry** (upper Eocene) – Granodiorite porphyry with 30% to 50% phenocrysts with abundant plagioclase phenocrysts and lesser amounts of quartz, biotite, and hornblende in a microcrystalline, medium- to dark-gray matrix; plagioclase phenocrysts are as much as 0.5 inch (1 cm) long; typically more phenocryst-rich than other stocks of the Park City porphyries; Scales (1972) noted that quartz phenocrysts are resorbed and thus appear rounded and about 2 mm in size; intrudes Glencoe stock (John and others, 1997); Smyk and others (2018) reported a U-Pb zircon crystallization age of 35.38 ± 0.39 Ma.

Tg **Glencoe porphyry** (lower Oligocene? to upper? Eocene) – Granodiorite porphyry with 20% to 30% phenocrysts of plagioclase and lesser amounts of hornblende, biotite, and quartz in a microcrystalline, medium- to dark-gray matrix; forms the smallest of the Park City porphyry stocks and typically contains fewer and smaller phenocrysts than the Valeo stock; age is poorly constrained, but Bromfield and others (1970, 1977) interpreted it as the oldest of the Park City porphyry stocks.

Tm **Mayflower porphyry** (upper Eocene) – Granodiorite porphyry with phenocrysts of plagioclase and minor hornblende and biotite in a medium-gray, microcrystalline groundmass; phenocryst abundance varies widely from a few percent to about 25% of the rock; Bromfield and others (1977) reported that in the Mayflower mine, the Mayflower stock is cut by dikes apparently of the Valeo stock; Smyk and others (2018) reported a U-Pb zircon crystallization age of 35.47 ± 0.48 Ma from a sample from near the Mayflower mine; Bromfield and others (1977) reported a K-Ar age on hornblende of 41.2 ± 1.6 Ma and a hornblende $^{40}Ar/^{39}Ar$ age of 32.7 ± 1.4 Ma, but noted that the Mayflower porphyry is intruded by poorly dated Ontario stock (Bromfield and others, 1977).

Tjb **Jordanelle porphyry, breccia phase** (lower Oligocene? to upper? Eocene) – Granodiorite porphyry breccia comprises autobrecciated Jordanelle stock and angular fragments of Woodside Formation sandstone and siltstone; poorly exposed and mapped south of the west abutment of Jordanelle Dam; likely several tens of feet thick.

Tj **Jordanelle porphyry** (lower Oligocene? to upper? Eocene) – Granodiorite porphyry with 25% to 45% phenocrysts of plagioclase and minor hornblende and biotite in a medium-gray, microcrystalline groundmass; mostly little altered and resistant, but locally deeply hydrothermally altered; forms most of the east and west abutments of Jordanelle Dam; drill-core samples from the dam site yielded K-Ar ages on hornblende of 36.5 ± 1.8, 36.3 ± 1.8, and 38.5 ± 1.9 Ma, and on biotite of 40.0 ± 1.6 Ma (Sullivan and others, 1988).

Unconformity

JURASSIC

Twin Creek Limestone (Middle Jurassic, Callovian to middle Bajocian) – Consists of six members following usage of Sprinkel and others (2011a), who reassigned the Gypsum Spring as a separate formation; only parts of the Sliderock and likely Rich Members are exposed in the southeastern corner of this map area. The Twin Creek Limestone was deposited in a 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).

Jtg **Twin Creek Limestone**, **Giraffe Creek Member** (Callovian) – Not exposed; probably about 100 to 130 feet (30–40 m) thick in the nearby Park City area (Biek and others, 2019).

Jtl **Twin Creek Limestone**, **Leeds Creek Member** (Callovian to Bathonian) – Not exposed; Imlay (1967, 1980) reported that the unit thickens westward from 776 feet (237 m) in outcrops near Peoa and Oakley, to 1520 feet (463 m) in Burr Fork near the top of Emigration Canyon; 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.

Jtw **Twin Creek Limestone, Watton Canyon Member** (Bathonian) – Not exposed; about 250 feet (75 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009).

Jtb **Twin Creek Limestone, Boundary Ridge Member** (Bathonian) – Not exposed; 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 (Biek and others, 2003).

Jtr? **Twin Creek Limestone, Rich Member** (Bajocian) – Medium-gray and light-brownish-gray, thin- to medium-bedded, variably clayey to silty, micritic limestone and poorly exposed calcareous mudstone; typically weakly bedded with closely spaced cleavage such that unit weathers to pencil-like fragments and small chips; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); query indicates uncertain designation of poor exposures a few tens of feet thick in the southeastern corner of the map area; about 300 to 400 feet (100–120 m) thick in the Park City West quadrangle (Biek and others, 2019); in the southern Heber Valley 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 the adjacent Center Creek quadrangle (Biek and others, 2003).

Jts **Twin Creek Limestone, Sliderock Member** (Bajocian) – Lower part comprises lenses of brownish-gray, light-gray-weathering, thick-bedded, oolitic to fossiliferous limestone with *Isocrinus* sp. crinoid columnals and fossil hash, whereas upper part (not exposed in this map area) comprises medium-gray weathering, medium-bedded, micritic limestone having moderately spaced tectonic stylolites; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); exposures are incomplete in this map area, but in the southern Heber Valley 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 (Biek and others, 2003); about 100 to 150 feet (30–45 m) thick in the Park City West quadrangle (Biek and others, 2019).

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

Jg **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, and sandy, calcareous siltstone, and chalcedony; resistant, yellowish-brown, reddish-brown, and black chalcedony occurs as a 3- to 6-foot thick (1–2 m) bed at the top of the formation; weathers to a poorly exposed slope between resistant slopes of Nugget and Sliderock strata; upper contact is sharp, corresponds to the J-2 unconformity, and marks a change from chalcedony to gray, aphanitic 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, nearly 40 miles (64 km) north of Heber Valley outcrops, older than the Temple Cap Formation of central and southern Utah to which it had long been correlated, which has 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); as mapped here, Gypsum Spring strata are about 20 feet (6 m) thick, but my upper contact is not the same as that used in the adjacent Center Creek quadrangle (Biek and others, 2003), where an unpublished measured section by Doug Sprinkel and Hellmut Doelling (UGS) reported 83 feet (25 m) of Gypsum Spring strata, the upper 57 feet (17 m) of which was brown to gray, dense, aphanitic limestone apparently similar to that of overlying Sliderock strata; 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; Gypsum Spring strata are about 60 feet thick (18 m) at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009).

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 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 fields (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 in northern Utah; only the upper part of the formation is exposed in the southeastern corner of the map area, but it is about 900 to 1000 feet (275–300 m) thick on the southwestern margin of Heber Valley, and about 1260 feet (385 m) thick in the West Daniels Land #1 well south of Heber Valley (Biek and others, 2003).

TRIASSIC

Ŧa **Ankareh Formation, undivided** (Upper and Lower Triassic) – Not exposed; comprises an upper member, the middle Gartra Grit Member, and the lower Mahogany Member collectively about 1485 feet (453 m) thick southwest of Heber Valley (Baker, 1964). The TR-3 unconformity of Pipiringos and O'Sullivan (1978) separates the Gartra Grit and Mahogany Members.

Thaynes Formation. In much of the central Wasatch Range, Thaynes strata are readily divisible into three unnamed members, but the middle member differs between upper plate rocks of the Mount Raymond thrust and those of the lower plate. Lower Thaynes strata are characterized by brown-weathering calcareous sandstone and sandy limestone, whereas the upper member, which contains similar brown sandy carbonate, is known for its medium-gray limestone. The middle member on the Mount Raymond thrust sheet is a thick, resistant limestone, whereas red siltstone and shale occupy this interval on the lower plate. On the north and west margins of Heber Valley, however, Thaynes strata are incompletely and commonly poorly exposed and thus mapped as a single unit (apart from a small exposure of upper Thaynes strata at the north edge of the map area). The Thaynes Formation intertongues eastward with the Mahogany Member of the Ankareh Formation (Kummel, 1954). Thaynes strata record deposition 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). Lower Triassic (Smithian to Spathian) age is from Kummel (1954) and Solien and others (1979). Map patterns suggest that Thaynes strata are 1300 to 1400 feet (400–425 m) thick in the upper reaches of Big Cottonwood Canyon (Biek and others, 2019); there, Boutwell (1912) reported a thickness of just 1190 feet (363 m). In Round Valley, northwest of Jordanelle Reservoir, map patterns suggest a thickness of about 1600 feet (490 m) (Biek, 2017), and southwest of Heber Valley, the formation is 950 feet (290 m) thick (Baker, 1964; see also Smith, 1969).

T̄Rt **Thaynes Formation, undivided** (Lower Triassic) – Light- to medium-gray, commonly 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; weathers to poorly exposed ledgy slopes in this map area; bedding attitudes are commonly variable across short distances, suggesting small-scale thrust faults and kink folds difficult to discern at map scale; upper contact not exposed, but is well exposed in the nearby Park City West quadrangle (Biek and others, 2019); likely about 1000 feet (300 m) thick.

T̄Rtu **Thaynes Formation, upper unit** (Lower Triassic) – 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; incompletely and poorly exposed and mapped only north of the Hawkeye-McHenry fault at the north edge of the map area; Biek (2017) reported a thickness of about 1100 feet (335 m) north of Silver Creek in the adjacent Park City East quadrangle.

T̄Rtm **Thaynes Formation, middle unit** (Lower Triassic) – Not mapped separately; see Biek (2017) and Biek and others (2019) for map unit description.

T̄Rtl **Thaynes Formation, lower unit** (Lower Triassic) – 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; Biek (2017) reported a thickness of about 300 feet (90 m) north of Silver Creek in the adjacent Park City East quadrangle.

T̄Rw **Woodside Formation** (Lower Triassic) – 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; upper contact appears conformable and corresponds to appearance of first ledge-forming, medium- to thick-bedded, dark-yellowish-brown-weathering, light-gray limestone; deposited in a tidal-flat and coastal-plain environment with clastic input from the Uncompahgre uplift in east-central Utah (Thomas and Krueger, 1946); locally served as a zone of weakness accommodating thrust faulting and so representative thicknesses are difficult to determine; Baker (1964) reported a thickness of 315 feet (95 m) southwest of Heber Valley; Biek and others (2019) reported a thickness of about 500 feet (150 m) north of Silver Fork and Brighton in Big Cottonwood Canyon, similar to the 450 to 600 feet (135–183 m) reported by Crittenden and others (1966); Biek (2017) estimated a thickness of about 450 feet (140 m) along Silver Creek in the adjacent Park City East quadrangle; Constenius and others (2011) noted that the Woodside 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 in the Ogden 30' x 60' quadrangle.

TR-1 unconformity (Pipiringos and O'Sullivan, 1978) spans 10 to 20 million years during the late Permian to Early Triassic. The TR-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 forming dramatic paleotopographic relief (Hayden, 2011).

PERMIAN

Park City and Phosphoria Formations. 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. 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). McKelvey and others (1959), Gordon and Duncan (1970) and Wardlaw and Collinson (1979) reported on the age of Park City and Phosphoria strata.

Park City and Phosphoria strata are remarkably poorly exposed in this map area, only locally forming ledgy outcrops. The best, though incompletely exposed, nearby section is Boutwell's (1912) section in Big Cottonwood Canyon, on the ridge north of Beartrap Fork; there, he inexplicably reported a thickness of 590 feet (180 m). However, his measured section (Boutwell, 1912, p. 50) totals just 466 feet (142 m) thick, though map patterns there suggest Park City and Phosphoria strata are about 1100 to 1200 feet (335–365 m) thick (Biek and others, 2019). Park City and Phosphoria strata are 1167 feet (356 m) thick in the upper reaches of Red Butte Canyon (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.

Ppc **Park City and Phosphoria Formations, undivided** (middle to lower Permian) – **Franson Member** is 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 appears conformable, as noted by Boutwell (1912) and Cheney (1957), but is a disconformity that corresponds to the TR-1 unconformity; map patterns suggest a thickness of about 400 feet (120 m) at Boutwell's (1912) type section in Big Cottonwood Canyon; 352 feet (107 m) thick west of Heber City (Baker, 1964). **Phosphoria Formation, Meade Peak Phosphatic Shale Tongue** is 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 Member** is 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; map patterns suggest a thickness of about 700 feet (210 m) at Boutwell's (1912) type section in Big Cottonwood Canyon (Biek and others, 2019); 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) – 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 thick limestone interval, thus including several thin limestone beds in upper Weber 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); widely considered correlative with much of the far thicker Pennsylvanian to Permian Oquirrh basin strata of western Utah (Hintze and Kowallis, 2009, and references therein); 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); Biek and others (2019) reported a thickness of about 1100 feet (335 m) in the upper reaches of Big Cottonwood Canyon; 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.

IPMl **Limestone** (Pennsylvanian to Mississippian) – Small masses of white and light-gray metamorphosed limestone (marble) as much as several tens of feet thick preserved as roof pendants or wall rocks of the Park City porphyry intrusions.

IPrv **Round Valley Limestone** (Lower Pennsylvanian) – Light-gray-weathering, gray to dark-gray, fossiliferous, locally cherty limestone and interbedded gray and greenish-gray shale, siltstone, and sandstone; pale-reddish-orange silicified fossils are characteristic; poorly and incompletely exposed on the eastern flanks of the Mayflower and Valeo stocks; Atokan and Morrowan age from Sadlick (1955); about 225 to 400 feet (70–120 m) thick west of Heber City (Baker, 1964) and about 400 feet (120 m) thick north of Silver Fork in Big Cottonwood Canyon (Biek and others, 2019); Bryant (1990) reported Round Valley strata are as much as 900 feet (300 m) thick in the Wasatch Range; Coogan and King (2016) summarized thicknesses in the Morgan area to the north of about 375 to 400 feet (115–120 m).

MISSISSIPPIAN

Mdo **Doughnut Formation** (Upper Mississippian) – Medium-gray, thin-bedded limestone and fossiliferous limestone, locally with black chert as nodules and in thin beds; a 30- to 100-foot-thick (10–30 m) zone of black, greenish, or locally reddish shale at the base contains thin beds of greenish-gray to rusty-weathering, silty limestone; poorly exposed on the eastern and southern flanks of the Pine Creek stock; Late Mississippian age from Baker and Crittenden (1961); about 430 feet (130 m) thick in the Wasatch Range and 210 feet (65 m) thick in the Uinta Mountains (Bryant, 1990); Coogan and King (2016) reported Doughnut strata are about 500 feet (150 m) thick at Durst Mountain.

Mh **Humbug Formation** (Upper Mississippian) – Interbedded calcareous quartz sandstone, orthoquartzite, and limestone that weather to ledgy slopes. Sandstone is light- to dark-brown weathering, pale yellowish brown to olive gray, medium to very thick bedded, variably calcareous or siliceous, locally with planar or low-angle cross-stratification. Limestone rarely contains dark-gray chert nodules and is: (1) light-gray weathering, medium dark gray, medium to thick bedded, and fine grained with local small white chert blebs; (2) dark gray, very thick bedded with small white calcite blebs; or (3) locally medium to coarse grained with sparse fossil hash. Regionally, though not observed in incomplete exposures in this map area, upper half contains several distinctive, ledge-forming, white to light-gray, medium- to thick-bedded sublithographic limestone beds up to 10 feet (3 m) thick; mapped in Pine Creek canyon at the west edge of the map area; upper contact is conformable and gradational and represents a change from interbedded sandstone and limestone to limestone; age from Morris and Lovering (1961); about 700 to 750 feet (210–230 m) thick; Bryant (1990) reported Humbug strata are 400 to 920 feet (120–280 m) thick in the central Wasatch Range and western Uinta Mountains; about 700 feet (210 m) thick at Durst Mountain (Coogan and King, 2006).

Md **Deseret Limestone** (Upper to Lower Mississippian) – Medium- to very thick bedded, light- to dark-gray, variably sandy and fossiliferous limestone and dolostone; contains distinctive white calcite nodules and blebs and local brown-weathering chert nodules; fossils include rugose corals, uncommon brachiopods, crinoids, bryozoans, and fossil hash; regionally, lower 20 to 30 feet (6–9 m) is marked by slope-forming, thin-bedded, black phosphatic chert likely of the Dell Phosphatic Member, but this was not observed in poor exposures in this map area; the best exposures are in Pine Creek Canyon, but also mapped as roof pendants in the Flagstaff and Valeo stocks; upper contact is conformable and gradational and corresponds to a change from fossiliferous limestone to predominantly sandstone; age from Morris and Lovering (1961) and Sandberg and Gutschick (1984); map patterns suggest a thickness of 600 to 700 feet (180–210 m) in Pine Creek Canyon, and Baker (1964) reported a thickness of about 585 feet (175 m) in the Wasatch Range; Bryant (1990) reported that Deseret strata are 460 to 970 feet (140–295 m) thick in the central Wasatch Range and western Uinta Mountains; about 500 feet (150 m) thick at Durst Mountain (Coogan and King, 2006).

Mg **Gardison Limestone** (Lower Mississippian) – Medium- to very thick bedded, medium- to dark-gray limestone, cherty limestone, and fossiliferous limestone; chert is present as black, irregularly shaped nodules and thin, discontinuous beds; fossils include rugose and colonial corals, brachiopods, gastropods, and bryozoans replaced by white calcite; the best exposures are in Pine Creek Canyon, but also mapped as roof pendants in the Flagsatff and Valeo stocks; upper contact appears conformable and gradational and generally corresponds to a break in slope, with slope-forming, thinner bedded, cherty limestone below and thicker bedded, ledge- and cliff-forming limestone above; age from Morris and Lovering (1961); Bryant (1990) reported that Gardison strata are about 600 feet (200 m) thick in the Wasatch Range.

Unconformity and Pine Creek fault

CAMBRIAN

Ꞓo **Ophir Formation** (middle Cambrian) – Yellowish-brown weathering, olive-green micaceous shale and minor gray, thin-bedded, fine-grained limestone; incomplete section is preserved but poorly exposed beneath the Pine Creek fault west of Pine Creek where it is as much as about 40 feet (12 m) thick; middle Cambrian age based on *Ehmaniella* sp., and *Glossopleura* sp. trilobites in Ogden Canyon (Rigo, 1968); complete formation is about 510 feet (155 m) thick to the west in American Fork Canyon (Baker, 1964).

Ꞓt **Tintic Quartzite** (middle and lower Cambrian) – White, light-gray, and light-brown, fine- to medium-grained orthoquartzite in medium to very thick beds with low-angle cross-stratification; locally medium to coarse grained with rounded white quartz pebbles; fracture surfaces commonly stained rusty brown and yellowish brown by iron oxides and hydroxides; forms ledgy slopes in Pine Creek canyon and as roof pendants of the Flagstaff and Valeo stocks; age from Baker (1964); deposited in beach and coastal-plain environments (Calkins and Butler, 1943); trace fossils in the upper part of the formation in the Ogden Canyon area include *Skolithus* tubes and *Plagiogmus* traces that indicate middle Cambrian age (Peterson and Clark, 1974); incomplete section is about 500 feet (150 m) thick, but the formation is 1170 feet (357 m) thick in Slate Canyon near Provo (Baker, 1972).

Unconformity

PRECAMBRAIN

Zmf **Mineral Fork Formation** (Neoproterozoic) – Dark-yellowish-brown, grayish-brown, and greenish-brown diamictite and interbedded, thin- to thick-bedded, poorly sorted sandstone and shale; diamictite is poorly sorted, nonstratified conglomerate with a dark-greenish-gray muddy and shaley matrix; pebble- to small boulder-size clasts are matrix-supported, rounded quartzite likely derived from the Big Cottonwood Canyon Formation, minor gneiss and granite from the Farmington Canyon Complex, and minor limestone; upper contact is poorly exposed but is a regional unconformity; deposited as ice from continental glaciers melted in a shallow ocean, dropping loads of poorly sorted sediment during one of three or more episodes of global or near-global glaciation between about 750 and 650 million years ago (Christie-Blick, 1983, 1985; Crittenden and others, 1983; also see Willis and Willis, 2010, 2012; Willis and others, 2010); only about the upper 1000 feet (300 m) exposed east of Pine Creek; Bryant (1990) reported a maximum thickness of 1300 feet (400 m) in the central Wasatch Range.

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Table 1. *Trace element- and whole-rock geochemistry of igneous rocks, Heber City quadrangle, Utah.*

Sample No.	Unit Name	7.5' Quadrangle	Map Symbol	Rock Type	Easting, NAD83	Northing, NAD83	Lab Used	Collected by	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
HC072016-5	Park Premier stock	Heber City	Tpp	andesite	466544	4497130	ALS Minerals	Biek	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
HC052518-1	lava flow	Heber City	Tkcf	latite	465367	4492396	ALS Minerals	Biek	16.31	0.17	5.25	<0.01	6.42	3.58	2.22	0.11	3.62	0.429		59.39	0.1	0.68	99.54	1.26	1420	96.2	50	3.09
HC052518-2	lava flow	Heber City	Tkcf	latite	465854	4491445	ALS Minerals	Biek	16.39	0.18	5.06	<0.01	6.19	3.47	1.87	0.1	3.72	0.381		60.77	0.1	0.69	100.05	1.11	1565	97.4	40	3.22
HC052518-3	dike, black glassy breccia	Heber City	NA	latite	466903	4493434	ALS Minerals	Biek	16.21	0.18	4.88	<0.01	6.07	3.65	2.15	0.1	3.44	0.403		59.98	0.11	0.68	99.9	2.05	1610	130.5	10	4.06
HC082818-3	Ontario stock	Heber City	To	dacite	460434	4496410	ALS Minerals	Biek	15.62	0.15	3.42	<0.01	4.47	3.66	1.68	0.07	3.64	0.25		65.11	0.07	0.53	99.39	0.72	1320	94.7	20	4.25
HC082918-1	Mayflower stock	Heber City	Tm	dacite	462182	4495150	ALS Minerals	Biek	15.82	0.19	3.45	<0.01	5.06	2.69	2.5	0.08	3.68	0.323		59.93	0.1	0.62	99.09	4.65	1780	102	50	1.36
HC082918-6	Glencoe stock	Heber City	Tg	latite	460190	4494609	ALS Minerals	Biek	17.36	0.34	5.22	0.02	5.99	4.39	3.17	0.08	3.31	0.361		58.64	0.15	0.7	99.9	0.17	3120	96.5	150	1.1
HC082918-7	Glencoe stock	Heber City	Tg	andesite	460310	4494601	ALS Minerals	Biek	15.79	0.25	4.89	<0.01	6.31	3.14	2.87	0.09	3.37	0.372		61.12	0.1	0.81	99.41	0.3	2310	132.5	40	2.9
HC082918-8	Mayflower stock	Heber City	Tm	latite	460428	4494528	ALS Minerals	Biek	16	0.21	4.8	<0.01	6.28	3.19	2.61	0.1	3.55	0.377		60.74	0.1	0.79	99.77	1.02	1865	117	20	2.22
HC083018-1	Ontario stock	Heber City	To	trachyte	458878	4496782	ALS Minerals	Biek	15.78	0.19	3.45	<0.01	4.98	3.92	2	0.11	5.05	0.343		62.28	0.08	0.61	99.66	0.87	1760	116.5	20	3.14
HC090618-1	Flagstaff stock	Heber City	Tf	dacite	458927	4494215	ALS Minerals	Biek	16.14	0.2	4.29	<0.01	4.72	2.6	2.09	0.08	3.82	0.306		62.92	0.11	0.56	99.69	1.85	1895	93.4	40	0.95
HC090618-3	Valeo stock	Heber City	Tv	dacite	459758	4493788	ALS Minerals	Biek	15.59	0.2	3.78	<0.01	4.32	2.71	2.14	0.07	3.68	0.259		63.11	0.1	0.52	99.56	3.08	1845	83.1	60	1.28
HC090618-4	Flagstaff stock	Heber City	Tf	dacite	458849	4494231	ALS Minerals	Biek	16.05	0.2	3.52	<0.01	4.54	2.79	2.32	0.08	4.12	0.281		62.17	0.09	0.56	100.05	3.31	1875	93.4	30	0.53
HC091218-5	Pine Creek stock	Heber City	Tpc	andesite	459185	4493062	ALS Minerals	Biek	15.68	0.2	4.56	0.02	5.67	2.63	3.86	0.09	3.66	0.336		60.18	0.1	0.66	99.82	2.17	1895	97.7	170	0.82
HC091218-9	Pine Creek stock	Heber City	Tpc	dacite	459437	4492131	ALS Minerals	Biek	16.46	0.2	4.36	<0.01	5.08	2.6	2.34	0.09	3.96	0.342		62.18	0.1	0.61	100.05	1.72	1805	104.5	30	1.34
HC091818-1	Mayflower stock	Heber City	Tm	dacite	462222	4494046	ALS Minerals	Biek	16.32	0.2	3.32	<0.01	4.6	3	1.63	0.06	3.79	0.298		63.94	0.1	0.57	100.15	2.33	1875	92.7	40	1.1
HC092618-1	Pine Creek stock	Heber City	Tpc	dacite	458304	4490447	ALS Minerals	Biek	16.4	0.19	4.56	<0.01	5.26	2.54	2.45	0.09	4.17	0.333		62.06	0.11	0.63	99.69	0.9	1845	102	80	1.81
HC101818-4	plag porphyry	Heber City	Tj	latite	463397	4491866	ALS Minerals	Biek	16.67	0.2	4.7	<0.01	5.46	3.14	2.44	0.07	3.71	0.338		61.35	0.1	0.66	100.2	1.36	1835	111.5	40	1.26
HC110718-1	lava flow?	Heber City	Tkf	latite	468139	4495940	ALS Minerals	Biek	16.26	0.16	4.98	<0.01	5.91	3.22	2.31	0.09	3.56	0.403		60.35	0.08	0.69	99.87	1.86	1440	112	20	1.47
HC110718-3	Park Premier stock breccia phase	Heber City	Tpp	dacite	466676	4495857	ALS Minerals	Biek	16.21	0.19	3.61	<0.01	4.44	3.53	1.36	0.07	3.7	0.428		63.66	0.1	0.49	99.52	1.73	1740	103	20	3.12
HC110718-7	Park Premier stock	Heber City	Tpp	dacite	467911	4497035	ALS Minerals	Biek	15.37	0.17	4.67	<0.01	4.67	2.46	2.03	0.07	3.07	0.3		62.86	0.09	0.63	99.78	3.39	1570	92.7	40	1.32
HC110818-2	lava flow	Heber City	Tkf	latite	466062	4495450	ALS Minerals	Biek	16.25	0.18	4.46	<0.01	6.34	3.47	2.49	0.11	3.72	0.419		60.01	0.09	0.7	100.05	1.8	1645	127.5	10	1.61
HC111418-1	prophyry sill?	Heber City	Tkcc	trachyte	467046	4494467	ALS Minerals	Biek	16.83	0.18	4.45	<0.01	5.49	3.86	1.76	0.1	3.63	0.359		61.6	0.09	0.63	100.2	1.21	1645	149	10	2.34
HC111418-4	lava flow?	Heber City	Tkcc	trachyte	466148	4494239	ALS Minerals	Biek	16.95	0.18	6.09	<0.01	7.18	3.05	2.11	0.09	3.74	0.634		57.1	0.11	0.92	99.97	1.82	1680	156	10	1.65
HC111418-5	lava flow?	Heber City	Tkcc	trachyte	466049	4494154	ALS Minerals	Biek	17.15	0.18	4.35	<0.01	5.25	3.87	1.2	0.06	3.86	0.381		61.91	0.1	0.65	100.15	1.2	1730	155.5	10	2.3

Notes: 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.

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

Map symbols are those used on plate 1.

NA = not applicable.

Table 1. *Continued*

Dy	Er	Eu	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
3.56	1.64	1.79	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
3.52	1.86	1.6	21.8	5.2	5.5	0.67	52.8	0.28	11	40.7	11.1	105	7.18	2	873	0.7	0.66	12.45	0.23	3.51	102	2	18.8	1.86	225	<0.5	6	<0.5	17	28	20	1	18	21	11	<10	77
3.99	2.05	1.78	22	5.25	6	0.72	57.9	0.34	11.3	46	12.15	110	7.31	1	870	0.7	0.73	12.65	0.27	3.82	173	2	20.7	1.9	248	<0.5	5	<0.5	14	29	20	2	15	19	10	<10	82
4.16	2.23	2.14	21.1	5.61	7.2	0.76	71.2	0.31	13.7	54.3	15.3	103.5	8.75	2	976	0.8	0.79	15	0.26	3.87	126	2	21.6	2.17	307	<0.5	5	<0.5	13	19	10	2	6	26	8	<10	88
2.65	1.32	1.34	20.7	3.98	5.4	0.56	54.2	0.24	12.2	36.3	10.5	120.5	5.95	1	607	1	0.48	19.7	0.22	4.62	89	3	15.7	1.37	206	<0.5	9	<0.5	10	69	20	2	11	29	7	<10	85
3.53	1.79	1.53	21.3	4.47	6.5	0.64	57.4	0.26	11.4	42.3	11.7	64	7.03	1	923	0.6	0.61	9.05	0.22	1.59	105	1	18.7	1.57	247	<0.5	8	<0.5	13	16	20	1	19	25	8	<10	91
3.45	1.91	1.61	23.8	5.03	6.4	0.65	51.7	0.26	12.4	42.1	11.45	83.2	7.03	1	1315	0.7	0.62	7.48	0.28	2.2	116	1	18.7	1.83	262	<0.5	5	<0.5	17	13	10	1	39	24	10	<10	92
4.33	2.29	1.82	21.8	5.91	7.4	0.77	74.2	0.32	11.8	53.3	15.15	78.5	8.2	1	923	0.8	0.75	15.9	0.35	3.38	132	2	21.4	2.23	294	<0.5	8	<0.5	14	22	10	2	18	24	11	<10	89
3.91	2.07	1.84	21.4	5.53	6.5	0.79	64.6	0.32	11.7	49	13.8	87.2	7.79	2	890	0.7	0.62	14.3	0.34	2.58	135	1	20.8	2.07	266	<0.5	12	<0.5	15	32	10	1	11	31	11	<10	90
3.01	1.46	1.43	20	4.27	5.7	0.53	67	0.2	13	44.3	12.85	132.5	6.9	2	694	0.9	0.52	18.3	0.23	4	93	2	15	1.18	222	<0.5	8	<0.5	12	33	30	1	14	34	8	<10	149
3.19	1.47	1.49	22	4.07	5.4	0.6	51.4	0.25	10.7	39	10.65	60.3	6.27	1	1025	0.7	0.51	7.92	0.22	1.97	88	1	16.1	1.45	220	<0.5	<5	<0.5	11	12	20	1	12	25	7	<10	81
2.9	1.48	1.39	21.4	3.65	4.9	0.53	45.4	0.21	10.6	33.9	9.83	65.5	6.1	1	929	0.6	0.46	6.77	0.18	1.73	82	1	14.6	1.48	193	<0.5	<5	<0.5	10	5	20	1	16	21	7	<10	72
2.69	1.75	1.38	20.3	4.24	5	0.6	51.6	0.23	10.8	38.1	11	67.6	6.41	1	806	0.6	0.58	7.69	0.24	1.84	81	1	15.4	1.52	205	<0.5	<5	<0.5	9	14	20	1	12	22	7	<10	82
3.36	1.79	1.45	20.4	4.43	5.8	0.63	55.8	0.29	10.5	42.5	11.5	62.6	6.64	1	903	0.5	0.6	7.87	0.24	2.04	136	1	16.8	1.58	224	<0.5	5	<0.5	18	31	20	1	77	22	10	<10	88
3.43	1.48	1.53	20.4	4.07	6	0.6	57.3	0.26	10.6	43.5	12.3	63	7.13	1	931	0.6	0.55	8.13	0.25	1.61	99	1	16.4	1.61	235	<0.5	<5	<0.5	12	12	20	1	13	23	7	<10	79
2.88	1.5	1.3	20.3	3.63	6.2	0.57	50.2	0.23	10.5	36.7	10.5	72.6	5.9	1	884	0.6	0.51	8.77	0.24	1.75	84	1	13.9	1.58	232	<0.5	<5	<0.5	11	16	20	1	16	26	8	<10	83
3.2	1.71	1.51	21.2	4.59	5.5	0.55	55.8	0.26	10.9	45.1	11.95	60.2	6.83	2	947	0.6	0.61	7.55	0.23	1.19	94	1	16.8	1.58	216	<0.5	8	<0.5	11	13	20	1	13	20	8	<10	80
3.24	1.81	1.47	21.5	4.85	6.2	0.64	62	0.2	9.8	48	13	71.8	7.78	1	868	0.6	0.61	10.9	0.24	2.08	99	1	16.4	1.72	237	<0.5	<5	<0.5	13	23	20	1	18	25	9	<10	92
3.55	1.9	1.69	20.1	4.61	6.8	0.66	62.5	0.24	12.6	45.2	12.7	83.5	7	1	707	0.7	0.58	13.3	0.25	3.1	102	2	18.1	1.65	261	<0.5	<5	<0.5	15	29	30	1	14	20	9	<10	91
3.32	1.64	1.66	19.9	4.65	5.9	0.56	58.7	0.25	11.5	47.7	12.85	115	7.31	1	821	0.7	0.54	12.45	0.22	2.73	74	1	15.4	1.39	226	<0.5	<5	<0.5	9	20	20	1	12	22	7	<10	76
2.86	1.49	1.39	18.2	4.08	6.2	0.55	49.8	0.25	11.2	39	10.5	59.5	6.16	1	781	0.6	0.53	8.58	0.22	1.63	90	1	15	1.3	235	<0.5	<5	<0.5	10	19	20	1	16	24	8	<10	92
4.41	2.51	1.93	20.6	5.61	7.3	0.82	70.3	0.36	13.4	56.6	15.15	96.4	9.41	2	759	0.8	0.76	15	0.31	3.41	114	2	23.1	2.28	312	<0.5	<5	<0.5	14	21	10	1	6	18	9	<10	97
3.88	2.02	1.97	21.1	5.76	9.1	0.78	83.5	0.28	14.8	60.6	17.05	107.5	9.06	2	792	0.8	0.72	17.65	0.33	4.23	102	3	20.3	1.91	361	<0.5	<5	<0.5	11	24	10	2	8	26	8	<10	91
5.18	2.67	2.59	23.6	7.99	8.7	0.88	89.7	0.32	15.5	72.3	19.7	72.1	12.1	2	996	0.8	1.03	16.15	0.34	3.71	168	1	25.1	1.93	349	<0.5	<5	<0.5	15	34	20	2	8	22	12	<10	108
4	2.25	2.02	21.5	6.17	9.3	0.78	88.5	0.31	16.6	61.9	17.8	108	9.88	2	843	0.8	0.78	18.35	0.29	4.17	100	3	20.8	1.96	388	<0.5	<5	<0.5	11	22	20	2	4	26	7	<10	87

Notes: 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.

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

Map symbols are those used on plate 1.

NA = not applicable.

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
Flagstaff stock	BC12LZ522		35.0 ± 0.37		zircon	NA	NA	NA	NA	Smyk and others (2018)
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)
Jordanelle stock	A-7482	36.5 ± 1.8			hornblende	Heber City	NA	NA	Geochron	Sullivan and others (1988)
Jordanelle stock	A-7481	36.3 ± 1.8			hornblende	Heber City	NA	NA	Geochron	Sullivan and others (1988)
Jordanelle stock	A-7480	38.5 ± 1.9			hornblende	Heber City	NA	NA	Geochron	Sullivan and others (1988)
Jordanelle stock	A-7480	40.0 ± 1.6			biotite	Heber City	NA	NA	Geochron	Sullivan and others (1988)
Keetley Volc., lava flows of Richardson Flat	PC-398	36.4 ± 1.3			hornblende	Park City East	463216	4503449	USGS	Bromfield and others (1977)
Keetley Volc., lava flows of Richardson Flat	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	Peoa area	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 Summit	495055	4479557	USGS	Crittenden and others (1973)
Keetley Volcanics, ignimbrite	BC12DC656		34.94 ± 0.44		zircon	NA	NA	NA	NA	Smyk and others (2018)
Keetley Volcanics, clast	BC12MB470		35.27 ± 0.45		zircon	NA	NA	NA	NA	Smyk and others (2018)
Keetley Volcanics	NA			38.5 ± 2.1	hornblende	NA	NA	NA	NA	Vogel and others (1997)
Keetley, basal tuff unit	KNC92799-6			37.25 ± 0.14	hornblende	Co-op Creek	485384	4469018	NMGRL	Constenius and others (2011)
Keetley Volcanics, flow	BC12DC658		34.68 ± 0.39		zircon	NA	NA	NA	NA	Smyk and others (2018)
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	BC12JT608		35.47 ± 0.48		zircon	Heber City	462704	4495981	NA	Smyk and others (2018)
Mayflower stock	NA			32.7 ± 1.4	hornblende	Heber City	NA	NA	NA	Vogel and others (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	NA	NA	USGS	Bromfield and others (1977)
Ontario stock	NA		36 ± 2.0		zircon	Heber City	NA	NA	NA	Constenius and others (1997)
Ontario stock	2380-1	33.3 ± 1.3			biotite	Heber City	NA	NA	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	NA	NA	BGC	John and others (1997)
Park Premier stock	PPr-10	32.38 ± 0.24			hornblende	Park City East	NA	NA	BGC	John and others (1997)
Park Premier stock	BC12DC657		33.69 ± 0.6		zircon	Park City East	466434	4498681	NA	Smyk and others (2018)
Park Premier stock	81-PP-2			33.53 ± 0.09	biotite	Heber City	NA	NA	BGC	John and others (1997)
Park Premier stock, Bone Hollow phase	PPr-23			31.42 ± 0.10	alunite	Park City East	NA	NA	BGC	John and others (1997)
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	BC12JT607		34.85 ± 0.39		zircon	Heber City	458357	4490240	NA	Smyk and others (2018)
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	NA	NA	USGS	Crittenden and others (1973)
Pine Creek stock	81-PC-4	36.04 ± 0.30			biotite	Heber City	NA	NA	BGC	John and others (1997)
Pine Creek stock	81-PC-4	41.28 ± 0.49			hornblende	Heber City	NA	NA	BGC	John and others (1997)
Pine Creek stock	NA			38.0 ± 0.9	hornblende	Heber City	NA	NA	NA	Vogel and others (1997)
Pine Creek stock	NA	38.5 ± 0.7			hornblende	Heber City	NA	NA	NA	Vogel and others (1997)
Pine Creek stock	NA			38.5 ± 0.7	hornblende	Heber City	NA	NA	NA	Vogel and others (1997)
Valeo stock	BC12LZ526		35.38 ± 0.39		zircon	Heber City	NA	NA	NA	Smyk and others (2018)
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)

Notes:

Age uncertainty = 2 standard deviations
NMGRL = New Mexico Geochronology Research Laboratory
BGC = Berkeley Geochronolgy Center
General location of John and others (1997) samples shown in their figure 2
Jordanelle stock ages are from cores under Jordanelle Dam
NA = not available

Table 3. *Selected water wells and exploration drill holes in the Heber City quadrangle.*

Map Number	Well Identification # (WIN)	Well Name	Latitude NAD83	Longitude NAD83	Total Depth (feet)	Completed	Owner	PLS Coordinates
1		Mahogany Springs Well	40.5416	-111.4852	500		Midway City	N 1890 W 980 S4 S22 T3S R4E SL
2	437261	Alpenhof-Weber Well	40.5172	-111.4989	1010	12/2/2013	Midway City	S 1710 E 471 N4 S33 T3S R4E SL
3	4257	Heber City Hospital Well	40.5059	-111.4026	550	10/23/1996	Heber City	S 543 W 2026 NE S5 T4S R5E
4	429659	Best Ranch Well	40.5734	-111.4256	1508	4/30/2007	Jordanelle Special Service District	N 2853 W 389 S4 S7 T3S R5E SL

Table 4. *Main mines of the Park City mining district.*

Map Number	Mine Name
1	Ontario mine, shaft 3
2	Ontario mine, shaft 2
3	Parleys Park shaft
4	Wabash mine
5	Nail Driver tunnel
6	Nail Driver mine
7	New York shaft
8	Superior mine, lower tunnel
9	Superior mine, middle tunnel
10	Superior mine shaft
11	Hawkeye mine
12	Wasatch mine
13	Liberty tunnel
14	Star tunnel
15	Glencoe mine, main tunnel
16	Glencoe mine, upper tunnel
17	Valeo mine, upper tunnel
18	Valeo mine, middle tunnel
19	Valeo mine, main tunnel
20	Dutch Canyon tunnel
21	Dutch Canyon incline
22	East Valeo
23	Sunnyside
24	Mayflower mine
25	Park Premier mine