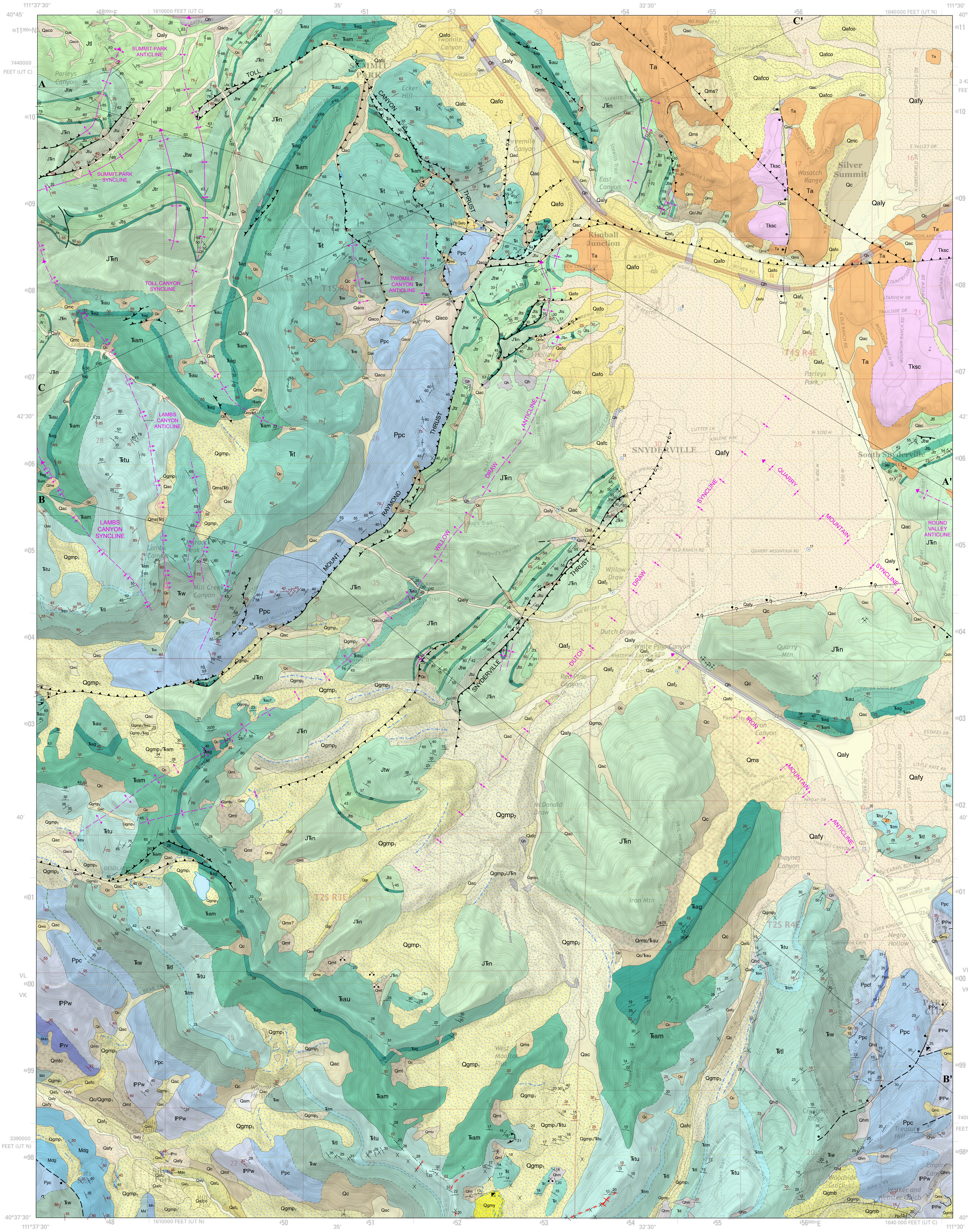
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources



This open-file release makes information available to the public during the review and production period necessary for a formal UGS publication. The map may be incomplete, and inconsistencies, errors, and omissions have not been resolved. While the document is in the review process, it may not conform to UGS standards; therefore, it may be premature for an individual or group to take actions based on its contents. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

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

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 G17AC00266, 2017-18. The views and conclusions contained in this document are those of the authors 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.

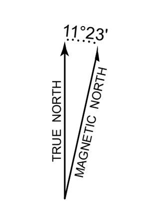
SCALE 1:24,000

1 0.5 0 1 MILE

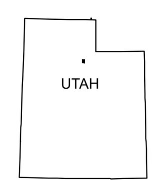
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET



APPROXIMATE MEAN DECLINATION, 2019



QUADRANGLE LOCATION

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

by

Robert F. Biek[1], W. Adolph Yonkee[2], and William D. Loughlin[3]

[1] Utah Geological Survey
[2] Department of Geosciences, Weber State University, Ogden, UT 84408-2507
[3] Loughlin Water Associates, LLC, 3100 W. Pinebrook Road, Ste. 1100, Park City, UT 84098

2019

Base from USGS Park City West 7.5' Quadrangle (2017)
Projection: UTM Zone 12
Datum: NAD 1983
Spheroid: Clarke 1866

Mapping Program Manager: Grant C. Willis
Project Manager: Zachary W. Anderson
GIS and Cartography: Basia Matyjasik

Utah Geological Survey
1594 West North Temple, Suite 3110
P.O. Box 146100, Salt Lake City, UT 84114-6100
(801) 537-3300
geology.utah.gov

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

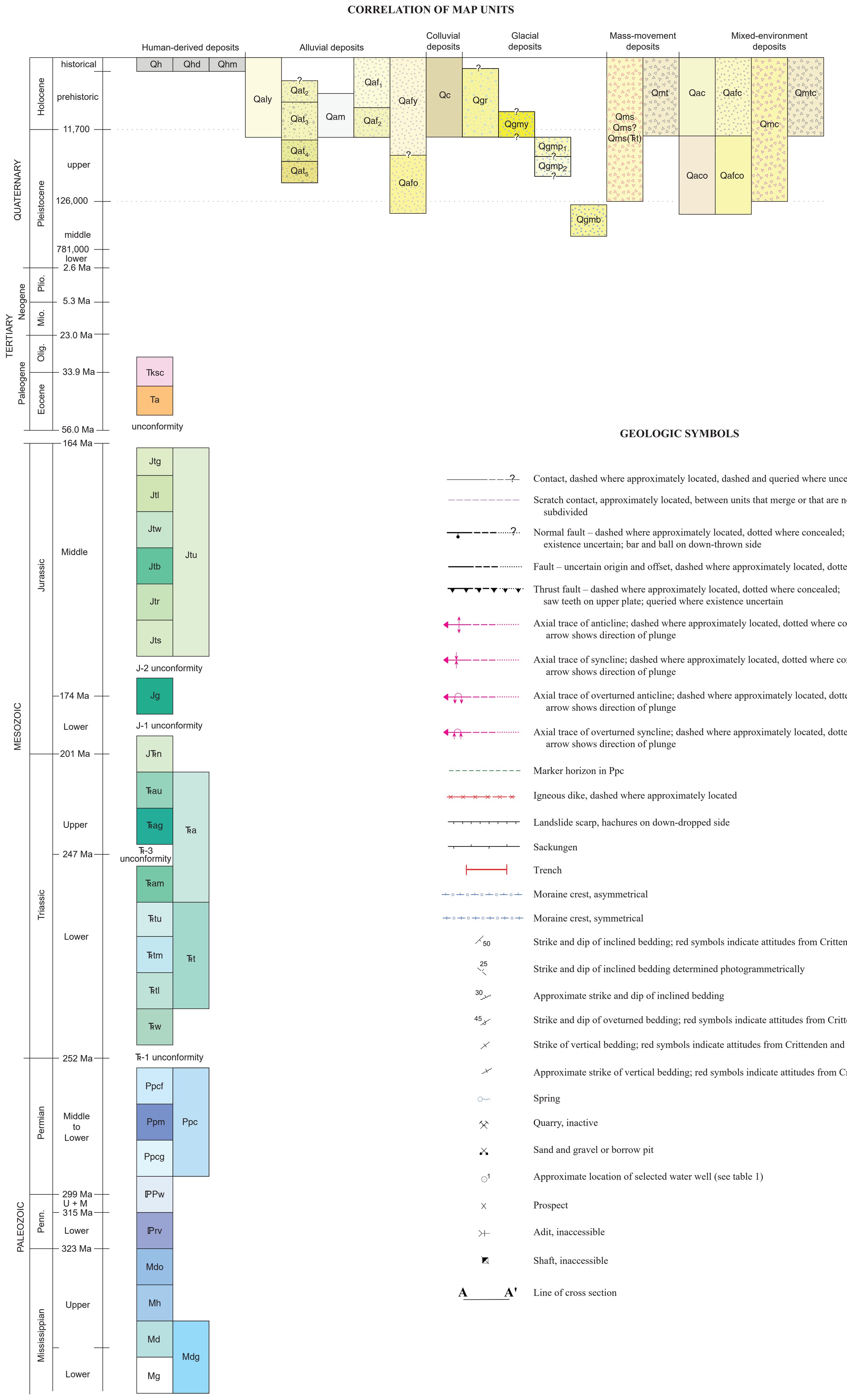
1	2	3
4		5
6	7	8

1. Mountain Dell
2. Big Dutch Hollow
3. Wanship
4. Mount Aire
5. Park City East
6. Dromedary Peak
7. Brighton
8. Heber City

ADJOINING 7.5' QUADRANGLE NAMES

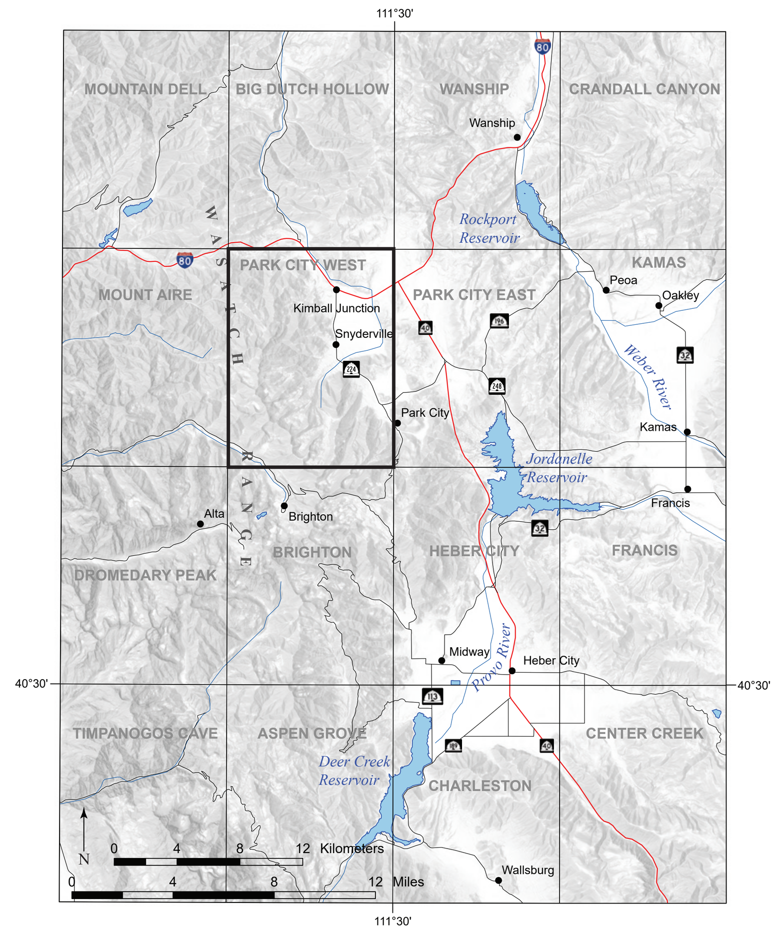
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

CORRELATION OF MAP UNITS

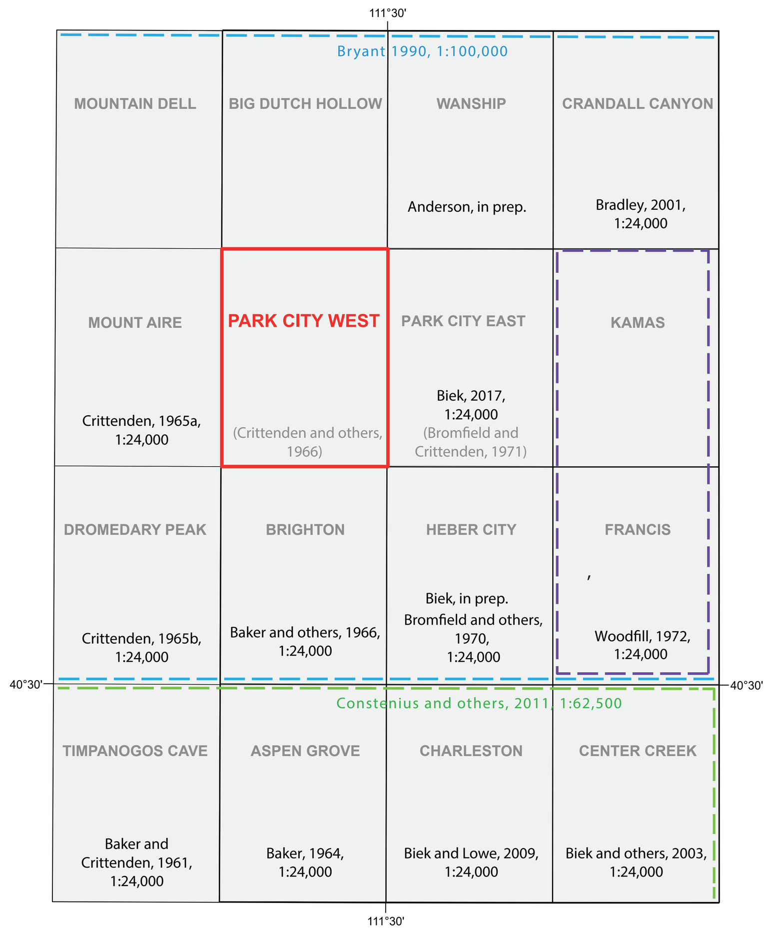


GEOLOGIC SYMBOLS

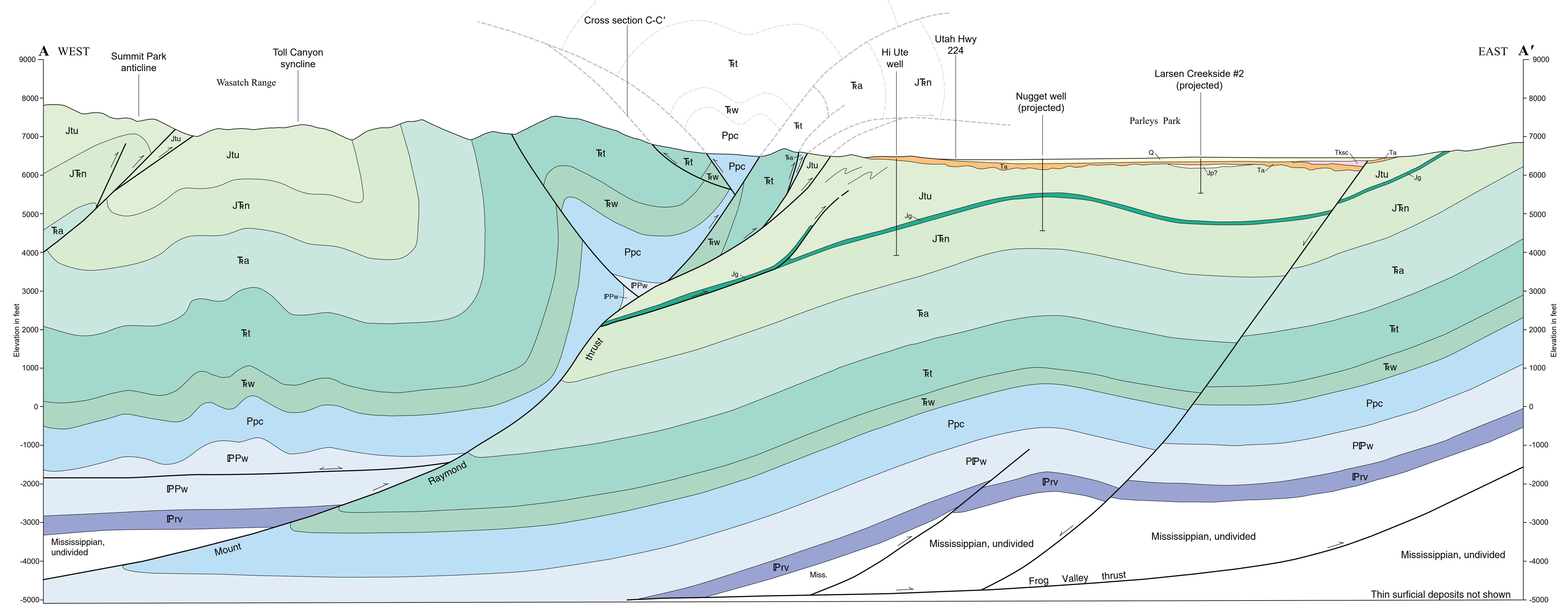
- Contact, dashed where approximately located, dashed and queried where uncertain
- Scratch contact, approximately located, between units that merge or that are no longer subdivided
- Normal fault – dashed where approximately located, dotted where concealed; queried where existence uncertain; bar and 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; queried where existence uncertain
- 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
- Axial trace of overturned anticline; dashed where approximately located, dotted where concealed; arrow shows direction of plunge
- Axial trace of overturned syncline; dashed where approximately located, dotted where concealed; arrow shows direction of plunge
- Marker horizon in Ppc
- Igneous dike, dashed where approximately located
- Landslide scarp, hachures on down-dropped side
- Sackungen
- Trench
- Moraine crest, asymmetrical
- Moraine crest, symmetrical
- 50 Strike and dip of inclined bedding; red symbols indicate attitudes from Crittenden and others (1966)
- 25 Strike and dip of inclined bedding determined photogrammetrically
- 30 Approximate strike and dip of inclined bedding
- 45 Strike and dip of oveturned bedding; red symbols indicate attitudes from Crittenden and others (1966)
- Strike of vertical bedding; red symbols indicate attitudes from Crittenden and others (1966)
- Approximate strike of vertical bedding; red symbols indicate attitudes from Crittenden and others (1966)
- Spring
- Quarry, inactive
- Sand and gravel or borrow pit
- 1 Approximate location of selected water well (see table 1)
- Prospect
- Adit, inaccessible
- Shaft, inaccessible
- A A′ Line of cross section

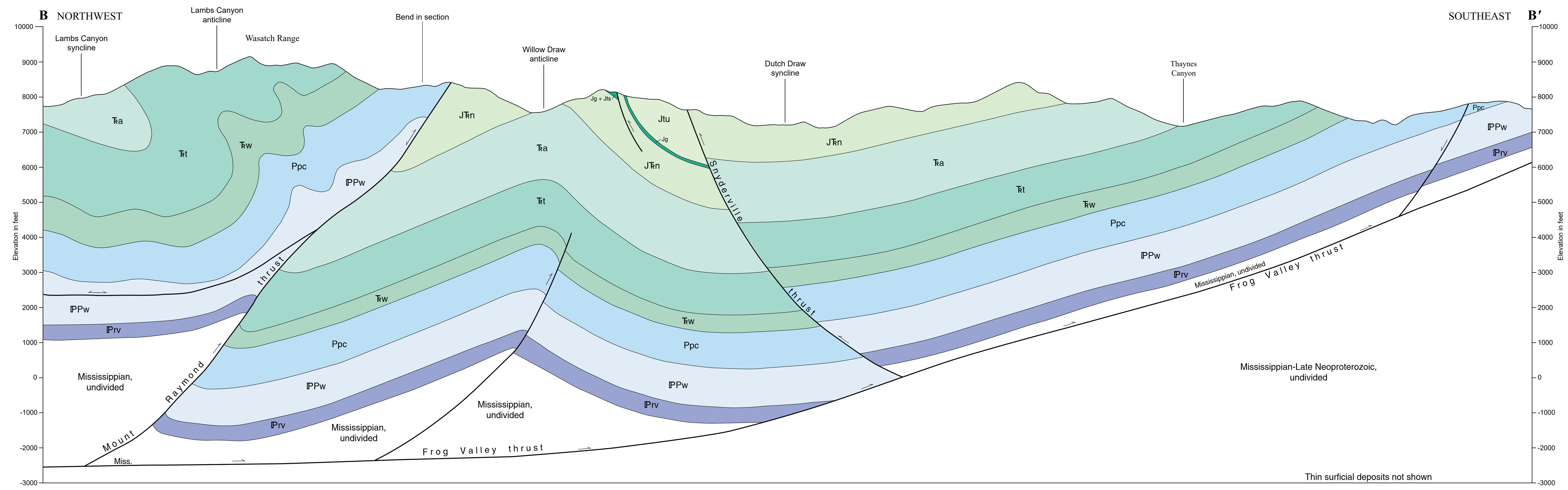


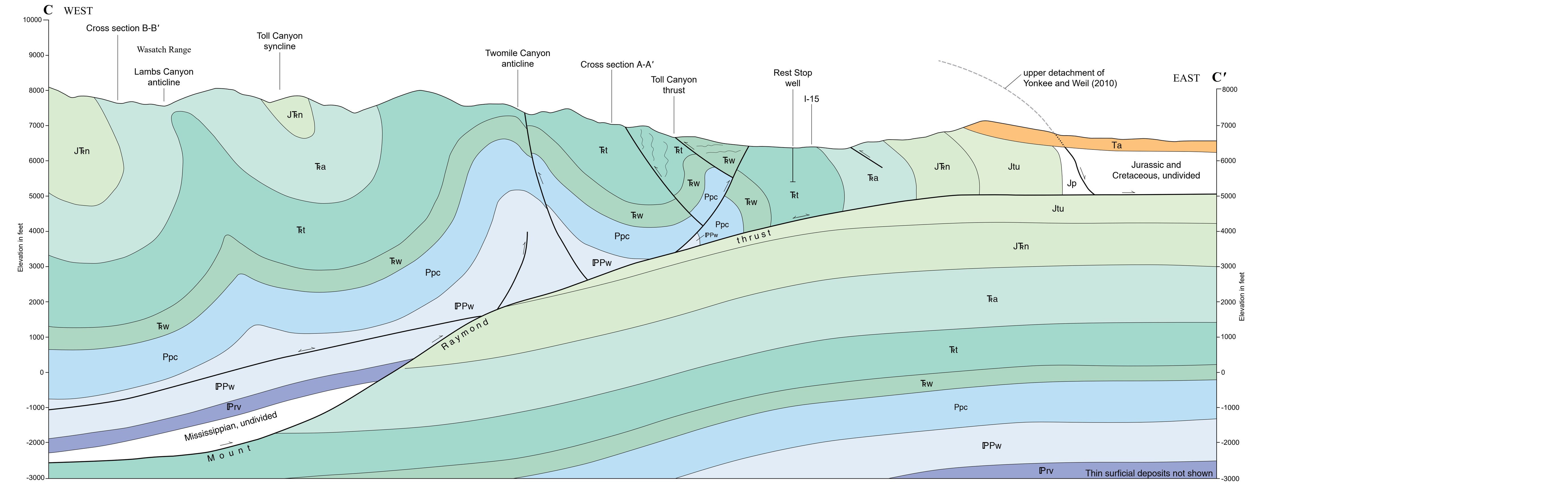
Location map with U.S. Geological Survey 7.5′ quadrangles.



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







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.							
33.9	TERTIARY PALEOGENE	Oligocene	Keetley Volcanics: volc. mudflow breccia of Silver Creek	Tksc	200+ (60+)	early extension and start of volcanism	lahars sourced from stratovolcanoes that once towered over Wasatch intrusive belt	volcanic mudflow breccia	volcanic clasts
		Eocene	Tertiary alluvial deposits	Ta	200 (60)		river channel and floodplain	conglomerate, sandstone, mudstone	no volcanic clasts
	JURASSIC	Middle	Twin Creek Limestone: Giraffe Creek Member	Jtu: Jtg	1357 (414) lower plate, 2700 (823) upper plate: 100-130 (30-40)	back bulge basin; Sevier orogeny	shallow marine: transgressive	limestone	
			Leeds Creek Member	Jtl	1300 (400)		transgressive	argillaceous limestone	
			Watton Canyon Member	Jtw	300-360 (90-110)			limestone	
			Boundary Ridge Mbr.	Jtb	100 (30)		regressive	mudstone, siltstone, sandstone	Jtb is oolitic limestone in upper plate
			Rich Mbr.	Jtr	300-400 (100-120)		transgressive	argillaceous limestone	
			Sliderock Mbr.	Jts	100-150 (30-45)			limestone	J-2 unconformity
174			Gypsum Spring Fm.	Jg	20-40 (6-12)		shallow marine transgression	silty sandstone	J-1 unconformity
		Lower	Nugget Sandstone	JTRn	1300 (400)	low-relief continental interior of a back-arc basin	vast eolian dune field of arid west coast subtropical desert	sandstone	large cross-beds
201	TRIASSIC	Upper	Ankareh Fm.: upper member	TRa: TRau	1700–2000 (520–600): 600-700 (180-210)		fluvial, floodplain and lake	mudstone, siltstone, sandstone	
			Gartra Grit Mbr.	TRag	150-200 (45-60)		braided river	pebbly sandstone	TR-3 unconformity
247		Lower	Mahogany Member	TRam	1000–1300 (300–400)		fluvial, floodplain and lake	mudstone, siltstone, sandstone	
			Thaynes Fm.: upper limestone member	TRt: TRtu	1300-2000 (400-600): 750 (230)		shallow marine	limestone calcareous sandstone shale	
			middle shale mbr.	TRtm	150-200 (45-60)		tidal flat	siltstone, sandstone	micaceous
			lower limestone mbr.	TRtl	300 (90)		shallow marine	limestone calcareous sandstone shale	
			Woodside Fm.	TRw	500 (150)		tidal flat and shallow marine	siltstone, sandstone	micaceous TR-1 unconformity
252	PERMIAN	Middle to Lower	Park City and Phosphoria Fms., undivided: Franson Mbr.	Ppc: Ppcf	1100-1200 (335-365): 400 (120)	shallow-marine continental shelf	shallow marine	limestone	
			Meade Peak	Ppm	100 (30)		phosphatic shale is deeper water, oxygen-starved basin	calcareous sandstone phos. shale, limestone	phosphatic shale
			Grandeur Mbr.	Ppcg	700 (210)			limestone	
299 ?	PENN.	Upper to Middle	Weber Quartzite	IPPw	1100-1500 (335-460)		coastal eolian dune field and shallow-marine shelf	sandstone	indistinct bedding highly fractured
315		Lower	Round Valley Limestone	IPrv	400 (120)		shallow marine	limestone and shale	
323	MISSISSIPPIAN	Upper	Doughnut Fm.	Mdo	430 (130)			limestone and shale at base	
			Humbug Fm.	Mh	700-750 (210-230)			calcareous sandstone, orthoquartzite, limestone	
		Lower	Deseret and Gardison, undiv.: Deseret Limestone	Mdg: Md	1185 (375): 585 (175)			limestone	Dell Phosphatic Mbr.
			Gardison Limestone	Mg	600 (200)			limestone	

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

by Robert F. Biek[1], W. Adolph Yonkee[2], and William D. Loughlin[3]

[1] Utah Geological Survey, P.O. Box 146100, Salt Lake City, UT 84114-6100

[2] Department of Geosciences, Weber State University, Ogden, UT 84408-2507

[3] Loughlin Water Associates, LLC, 3100 W. Pinebrook Road, Ste. 1100, Park City, UT 84098

Disclaimer

This open-file release makes information available to the public during the review and production period necessary for a formal UGS publication. The map may be incomplete, and inconsistencies, errors, and omissions have not been resolved. While the document is in the review process, it may not conform to UGS standards; therefore, it may be premature for an individual or group to take actions based on its contents. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product. Geology intended for use at 1:24,000 scale.

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 G17AC00266, 2017–18. The views and conclusions contained in this document are those of the authors 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 697DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2019

Blank pages are intentional for printing purposes.

MAP UNIT DESCRIPTIONS

QUATERNARY

Human-derived deposits

Qh **Artificial fill** (Historical) − Engineered fill and general borrow material used mostly for major highways and secondary roads that cross small drainages; includes large areas of fill derived from the Nugget Sandstone at Olympic Park; 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) – 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 Park City Mountain Resort; generally less than 10 to 15 feet (3–5 m) thick.

Qhm **Mine dumps and aggregate pit** (Historical) – Waste rock from mining operations of the Park City mining district, in the southeastern corner of the map area, once one of the West's most important silver-lead-zinc districts (see, for example, Phillips and Krahulec, 2006); includes pit for crushed limestone in Thaynes Formation in upper reaches of Iron Canyon; a large excavation in talus at the head of McDonald Draw, not mapped separately but shown with a gravel pit symbol, supplied aggregate and large blocks of Nugget Sandstone; 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

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

$Qat_{2,3,4,5}$

Stream-terrace alluvium (middle? Holocene to upper Pleistocene) – Moderately to well-sorted sand, silt, clay, and pebble to boulder gravel that forms level to gently sloping surfaces above, and incised by, East Canyon Creek and Big Cottonwood Creek; deposited in a stream-channel environment, but locally includes colluvium and small alluvial fans derived from adjacent slopes; each terrace represents the elevation of stream base level prior to incision; subscript denotes relative age and height above modern drainage: Qat_2 is less than about 20 feet (6 m), Qat_3 ranges from about 20 to 30 feet (6–9 m), Qat_4 ranges from about 30 to 40 feet (9–12 m), and Qat_5 is generally more than 40 feet (12 m) above adjacent creeks; as much as about 30 feet (0–9 m) thick.

Qam **Alluvial marsh deposits** (Holocene to upper Pleistocene) – Not exposed but inferred to be moderately sorted sand, silt and mud impounded by main-stem, Big Cottonwood Canyon Pinedale-age glacial deposits; may contain interbedded debris-flow deposits; mapped at Willow Heights in Big Cottonwood Canyon; probably less than 30 feet (9 m) thick.

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, as where small fans spill onto the floodplain of East Canyon Creek; 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 locally along margins of Snyderville basin; probably about 40 feet (12 m) thick.

Qafy **Young and middle fan alluvium, undivided** (Holocene to upper Pleistocene) – Similar to young fan alluvium (Qaf_1) in composition, but forms both active depositional surfaces (Qaf_1 equivalent) and typically inactive surfaces incised by small streams (Qaf_2 equivalent); deposited principally as debris flows and debris floods, but colluvium locally constitutes a significant part adjacent to hillsides; steeper, upper parts of fans are commonly incised; probably less than 40 feet (12 m) thick.

Map unit forms the broad, planar, gently sloping, undissected surfaces of Parleys Park and Park Meadows, where it is inferred to have been deposited as glacial outwash in braided-stream channels and is thus principally late Pleistocene in age, but likely includes veneer of Holocene alluvial deposits; these deposits form the upper part of basin-fill deposits that, based on water well data, are about 250 feet (75 m) thick at Parleys Park (Snyderville basin) and less than 80 feet (25 m) thick at Park Meadows (Ashland and others, 2001).

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

Colluvial deposits

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

Glacial deposits

Alpine glacial deposits in the Wasatch Range are of the Pinedale glacial advance and an older glaciation of uncertain but likely Bull Lake advance; 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 12 to 24 ka (Imbrie and others, 1984) (with glacial maxima about 16 to 23 ka on the basis of cosmogenic ^{26}Al and ^{10}Be dating; Gosse and others, 1995; Chadwick and others, 1997; Phillips and others, 1997), and are roughly coeval with the late Wisconsin glaciation, global Last Glacial Maximum (LGM, about 26.5 to 19.0 ka; Clark and others, 2009), and Marine Oxygen Isotope Stage 2 (MIS 2, 26 to 14 ka; Lisiecki and Raymo, 2005). In contrast, deposits of the Bull Lake alpine glacial advance in their type area in the Wind River Range are about 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 (167 to 132 ka; Lisiecki and Raymo, 2005).

Glaciation in the map area has not been studied in detail, but it probably followed patterns of Wasatch Front glaciation and was influenced by late Pleistocene Lake Bonneville. Laabs and Munroe (2016) described the problems of relative timing of glacial advances and retreats and the rise and fall of Lake Bonneville. Based on new ^{10}Be cosmogenic exposure ages, they reported that Pinedale terminal moraines at the entrances of Little Cottonwood and Bells Canyons were occupied near the time of the Bonneville highstand 18 ka and subsequently abandoned while the lake continued to overflow at the Provo level, consistent with stratigraphic studies of Godsey and others (2005). Further, based on stratigraphic relationships between lake and glacial deposits, Laabs and Munroe (2016) reported that glaciers extended to the mountain front more than once during the last glaciation and that the youngest moraines were abandoned near the time of, or possibly before, the Bonneville flood 18 ka. 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 LGM 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) (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 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 18.0-14.5 ka (Alvarez-Solas and others, 2011).

Qgr **Relic rock glaciers** (Holocene to upper Pleistocene) – Poorly sorted, angular, cobble- to boulder-size blocks and minor fine-grained interstitial sediment that forms a rumpled surface that extends downslope from talus deposits in three areas in the upper cirque basins of Red Pine Canyon and Dutch Draw; characterized by a lack of vegetation and subdued but distinctive surface morphology owing to flow through deformation of interstitial ice; subdued morphology, relative abundance of lichen-covered surfaces, and lack of late summer meltwater suggest these rock glaciers are dormant, now lacking interstitial ice; possibly as young as the Little Ice Age (A.D. 1500 to 1800); about 20 feet (6 m) thick.

Qgmy **Younger glacial till** (lower Holocene? to upper Pleistocene?) – Non-stratified, poorly sorted till consisting of clay, silt, sand, gravel, cobbles, and boulders; clasts are matrix supported, subangular to subrounded and reflect a source in the upper Thaynes Formation, in a cirque at the head of Iron Canyon on the southern map boundary; terminal and recessional moraines are well developed; maximum thickness is about 60 feet (18 m).

Younger glacial till likely resulted from a post-Pinedale minor glacial advance, possibly associated with a period of global cooling 12,800 to 11,500 years ago called the Younger Dryas. Other cirque basins in the map area, for example southeast of Red Pine Lake, may hold deposits from this cold period, but, lacking full lidar coverage, are not readily differentiated on standard aerial imagery.

Qgmp$_1$, Qgmp$_2$

Glacial till of Pinedale age (upper Pleistocene) – Non-stratified, poorly sorted till consisting of clay, silt, sand, gravel, cobbles, and boulders; clasts are matrix supported, subangular to subrounded and reflect sources in their respective drainage basins; terminal moraines are well developed below cirque basins eroded into relatively resistant Nugget and Thaynes strata, but poorly developed or nonexistent where mostly nonresistant Ankarah strata provided the bulk of glacial sediment; recessional and lateral moraines and hummocky, stagnant-ice topography are locally well developed, as is ice-sculpted bedrock on cirque basin floors; Pinedale age is based on moderate to sharp morainal topographic expression and weak soil development; well-developed terminal and recessional moraines, as in Red Pine Canyon and below Dry Lake in Big Cottonwood Canyon, are locally in excess of 200 feet (60 m) thick, but till is thinner elsewhere and, in upper cirque basins, locally consists only of scattered boulders or a veneer of melt-out till on bedrock.

Two pulses of apparent Pinedale-age till are mapped, with Qgmp$_2$ being older and reaching farther down canyon than Qgmp$_1$. No numerical age control is available for glacial deposits in the map area. The largest complex of Pinedale-age glacial sediment is that of Dutch Draw, which was fed by ice from six separate cirque basins eroded into the crest of the range. Older Pinedale-age glacial till (Qgmp$_2$) of Red Pine Canyon extends to an elevation of about 7350 feet (2240 m), that of the larger Dutch Draw/White Pine Canyon complex to about 6880 feet (2100 m), and that of Thaynes Canyon to about 7100 feet (2165 m). Younger Pinedale-age glacial till (Qgmp$_1$) extends to about 7540 feet (2300 m) in Red Pine Canyon and to 8200 to 8530 feet (2500–2600 m) in the Dutch Draw/White Pine Canyon complex and in Thaynes Canyon. Terminal moraines in Red Pine Canyon are moderately well developed, but the Dutch Draw/White Pine complex lacks terminal moraines, as do deposits in Thaynes Canyon, possibly because non-resistant Ankareh strata contributed a greater proportion of sediment compared to deposits in Red Canyon (the Qgmp$_1$ moraine in Iron Canyon, sourced in large part from Thaynes strata, is moderately well developed). Pinedale-age glacial deposits in the Silver Fork area of Big Cottonwood Canyon show that glacial ice there was about 650 feet (200 m) thick, part of the large Big Cottonwood glacier whose terminal moraine is two miles (3 km) down canyon near Reynolds Flat.

Qgmb **Older glacial till of likely Bull Lake age** (middle Pleistocene) – Non-stratified, poorly sorted clay, silt, sand, gravel, cobbles, and boulders; clasts are typically matrix supported, subangular to subrounded and reflect sources in upstream drainage basins; similar to glacial till of Pinedale age, but glacial landforms are poorly preserved or absent, clasts typically appear more weathered (especially monzonite porphyry clasts), and soils tend to be better developed; as mapped here in the southeast corner of the quadrangle, forms deposits that stand at a higher level than those of Pinedale age and that appear to grade to older glacial deposits that cap Ontario Ridge in the adjacent Park City East quadrangle (Biek, 2017); thickness uncertain, but may be in excess of 200 feet (60 m) capping the ridge south of Walker and Webster Gulch.

Mass-movement deposits

Qms, Qms? Qms(TRt)

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; thickness highly variable, but larger deposits exceed several tens of feet thick; most mapped landslides are newly recognized—none are shown on the map of Crittenden and others (1966) (the focus of their work was bedrock geology, as it was for most maps of that era) and just one (a slide in the lower reaches of Iron Canyon) is shown on the reconnaissance inventory map of Elliott and Harty (2010)—the result of newly available lidar data and aerial imagery, more detailed and accurate map production techniques, and our modern attention given to understanding surficial deposits and their relationship to the built environment; Qms(TRt) denotes two large blocks of Thaynes strata in uppermost Lambs Canyon that appear out-of-place with respect to nearby bedrock ridges; 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 westernmost Summit County) 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 rock fall 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; probably about 20 to 30 feet (6–9 m) thick.

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

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

Qmc **Landslides and colluvium** (Holocene to upper Pleistocene) – Unsorted, locally derived, clay- to boulder-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 rock fall 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.

Stacked-unit deposits

$Qc/Qgmp_1$

Colluvium over glacial till of Pinedale age (Holocene to upper Pleistocene/upper Pleistocene) – Mapped in Big Cottonwood Canyon where colluvium appears to mostly conceal underlying Pinedale-age glacial till; surficial cover likely less than 20 feet (6 m) thick.

Qc/Jtu **Colluvium over Twin Creek Limestone, undivided** (Holocene to upper Pleistocene/Middle Jurassic) – Mapped northeast of Kimball Junction where colluvium derived from Tertiary alluvial deposits (Ta) apparently conceals underlying upper members of the Twin Creek Limestone; surficial cover may exceed 20 feet (6 m) thick.

Qc/TRau

Colluvium over Ankareh Formation, upper member (Holocene to upper Pleistocene/Upper Triassic) – Mostly fine-grained colluvium that conceals upper Ankareh strata in a swale on the south side of Iron Mountain; surficial cover mostly less than about 10 feet (3 m) thick.

Qmtc/TRau

Talus and colluvium over Ankareh Formation, upper member (Holocene to upper Pleistocene/Upper Triassic) – Mixed talus and colluvium derived from the Nugget Sandstone that conceals upper Ankareh strata along the south and east sides of Iron Mountain; surficial cover mostly less than about 10 feet (3 m) thick.

$Qgmp_1/TRau$

Glacial till of Pinedale age over Ankareh Formation, upper member (upper Pleistocene/Upper Triassic) – Mapped in the upper Mill Creek cirque basin where strata of the upper member are densely vegetated and covered by colluvium and glacial till; surficial cover locally in excess of 20 feet (6 m) thick.

$Qgmp_1/TRag$

Glacial till of Pinedale age over Ankareh Formation, Gartra Grit Member (upper Pleistocene/Upper Triassic) – Mapped in the upper Mill Creek cirque basin where resistant Gartra strata are densely vegetated and covered by a veneer of glacial till; surficial cover likely less than 10 feet (3 m) thick.

$Qgmp_1/TRam$

Glacial till of Pinedale age over Ankareh Formation, Mahogany Member (upper Pleistocene/Upper Triassic) – Mapped in the upper Mill Creek cirque basin where map scale and limited exposure precludes delineating bedrock ridges from swales filled with glacial till; surficial cover locally in excess of 20 feet (6 m) thick.

$Qgmp_1/TRtu$

Glacial till of Pinedale age over Thaynes Formation, upper limestone member (upper Pleistocene/Lower Triassic) – Mapped in the upper Iron Canyon cirque basin where map scale and limited exposure precludes delineating bedrock ridges from swales filled with glacial till; surficial cover locally in excess of 20 feet (6 m) thick.

$Qgmp_2/JTRn$

Glacial till of Pinedale age over Nugget Sandstone (upper Pleistocene/Lower Jurassic to Upper Triassic) – Mapped west of Iron Mountain where older Pinedale-age glacial till may be draped over a bedrock ridge of Nugget Sandstone; surficial cover may be several tens of feet thick.

unconformity

OLIGOCENE and EOCENE

The Keetley Volcanics are late Eocene to earliest Oligocene volcanic mudflow breccias, lava flows, fine-grained tuffaceous strata, volcaniclastic conglomerate, and 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 volcaniclastic sandstone and conglomerate at least locally deposited in a lake; a middle thick unit of volcanic mudflow breccia, debris-avalanche deposits, and lesser volcaniclastic conglomerate; and an upper unit of lava flows and lesser volcanic mudflow breccia (Bryant, 1992; Leveinen, 1994). Keetley strata are andesite and rhyodacite by field classification, but most samples chemically range from basaltic trachyandesite and latite to andesite using the classification of LeBas and others (1986) (Bromfield and others, 1977; Hanson, 1995; Feher, 1997; Vogel and others, 1997; Biek, 2017). Woodfill (1972) provided petrographic descriptions of many of the Keetley units described below.

The Keetley Volcanics lie at the east end of the east-west-trending, 28-mile-long (45 km) Wasatch igneous belt. As described by John (1987, 1989a), Hanson (1995), Feher (1997), and Vogel and others (1997, 2001), 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), the Park Premier porphyry, and the Indian Hollow plug. With the exception of the more mafic Clayton Peak stock, the silica content of the plutons generally increases to the west (Hanson, 1995). The depth of emplacement of the exposed portion increases to the west, from less than 0.6 mile (less than 1 km) for the porphyritic Park Premier and Indian Hollow intrusions to about 6.5 miles (11 km) for the phaneritic Little Cottonwood stock due to uplift and rotation on the Wasatch fault (John, 1987, 1989a). The 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, Biek, 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) (see table 2, Biek, 2017). Nelson (1971, 1976) reported on early Oligocene vertebrate fossils in Keetley tuffaceous strata near Peoa, and Keetley strata locally produce petrified tree stumps and fossil wood.

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

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

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

Tksc **Volcanic mudflow breccia of Silver Creek** (lower Oligocene to upper Eocene) – Andesitic to rhyodacitic volcanic mudflow breccia; heterolithic; clasts are andesite and rhyodacite by field classification but chemically range from latite and trachyte to andesite and dacite (Bromfield and others, 1977); weathers to rounded hills, typically with a deep regolith and poor exposure, and commonly covered with a lag of volcanic boulders; 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; although their contact is not exposed, the mudflow breccia appears to conformably overlie

Tertiary alluvial deposits (Ta) in this map area; mapped only east and north of Parleys Park where it is as much as about 200 feet (60 m) thick; this unit is as much as 1000 feet (300 m) thick in the southeast part of the adjacent Park City East quadrangle (Biek, 2017).

Intrusive rocks

Dikes of intermediate composition – Medium-dark-gray to olive-gray andesitic porphyry containing 15% to 20% phenocrysts of plagioclase and hornblende as much as 5 mm in length; prospects in the larger dike, on the ridge crest west of upper Thaynes Canyon, locally reveal a light-gray quartz monzonite with minor epidote alteration; dikes are 1 to 12 feet (0.3 to 4 m) in width where they intrude the upper limestone member of the Thaynes Formation at the crest of the Wasatch Range.

Ta **Tertiary alluvial deposits** (Eocene?) – Very poorly exposed pebble to boulder conglomerate with subrounded to rounded clasts that weathers to form rounded slopes mostly blanketed by colluvium and regolith; given weathering habit, likely contains nonresistant, finer grained mudstone and sandstone interbeds, but these are not exposed; clasts are principally Pennsylvanian-Permian orthoquartzite (likely Weber Quartzite) and Nugget Sandstone as much as 6 feet (2 m) in diameter; east of Parleys Park, locally includes rare limestone clasts from Paleozoic and Twin Creek strata; host to several previously unrecognized landslides of mostly subdued morphology; lower contact is unconformable over Mesozoic strata; unit appears to partially fill paleotopographic depressions on and immediately south of thrust sheets of the Wyoming salient; upper contact with the Keetley Volcanics is not exposed but appears to be conformable and likely gradational as reported by Bryant (1990) in the Porcupine Ridge area about 20 miles (30 km) to the northeast; as mapped here, upper contact corresponds to a break in slope, with lower slopes of Tertiary alluvial deposits (Ta) covered with Weber and Nugget sandstone clasts, above which are steeper slopes and abundant resistant volcanic clasts of the Silver Creek breccia (Tksc); Bryant (1990) reported a maximum thickness of about 1000 feet (300 m) for this map unit in the Salt Lake City 30′ x 60′ quadrangle; in this map area, the unit is as much as about 200 feet (60 m) thick.

unconformity

JURASSIC

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

Twin Creek Limestone (Middle Jurassic, Callovian to middle Bajocian) – Consists of six members following usage of Sprinkel and others (2011a), who reassigned the Gypsum Springs as a separate formation. The members have similar lithologies within the hanging wall and footwall of the Mount Raymond thrust unless otherwise noted. Thicknesses in this quadrangle are estimated from the map; thicknesses reported from the nearby Center Creek quadrangle (Biek and others, 2003) were measured by Doug Sprinkel and Hellmut Doelling (UGS unpublished data, June 22, 1999), who also measured a section near Peoa and Oakley. 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).

Jtu **Twin Creek Limestone, undivided** (Middle Jurassic, Callovian to middle Bajocian) – Mapped along the Mount Raymond and subsidiary thrust faults where complex deformation and limited exposure preclude accurate member identification at map scale; also shown on cross sections. Imlay (1967) reported a total thickness (less their Gypsum Spring Member) of Twin Creek strata exposed near Peoa and Oakley of 1357 feet (414 m); in their unpublished measured section of the same area, Sprinkel and Doelling reported that Twin Creek strata are 1558 feet (475 m) thick; Imlay (1967) reported that Twin Creek strata (less their Gypsum Spring Member) are 2614 feet (797 m) thick near Devils Slide and 2700 feet (823 m) near the head of Emigration Canyon.

Jtg **Twin Creek Limestone**, **Giraffe Creek Member** (Callovian) – Light-gray, thin-bedded, calcareous sandstone, sandy limestone, and siltstone; thin- to medium-bedded with widespread ripples; regionally, the member is locally sandy, oolitic and fossiliferous with crinoid and echinoid fragments and is more resistant than enclosing Leeds Creek and Pruess strata; incompletely and poorly exposed east of Kimball Junction in the upper plate of the Mount Raymond thrust; upper contact, not exposed, corresponds to the base of reddish-brown silty sandstone of the Pruess Sandstone;

deposited in a regressive shallow-marine environment at the end of the second major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); probably about 100 to 130 feet (30–40 m) thick; Imlay (1967, 1980) reported that the unit thickens westward from 82 feet (25 m) in outcrops near Peoa and Oakley to 200 feet (60 m) in Burr Fork near the top of Emigration Canyon; Coogan and King (2016) reported 225 feet (70 m) of Giraffe Creek strata near Devils Slide.

Jtl **Twin Creek Limestone**, **Leeds Creek Member** (Callovian to Bathonian) – Light-gray, splintery, thin-bedded to laminated, slope-forming, argillaceous to silty limestone with thin beds of fossiliferous limestone and siltstone that increase in abundance toward the top of the member; thin-bedded with variably spaced cleavage at high angles to bedding that result in "pencil" fracturing; non-resistant and poorly exposed forming gentle slopes; upper contact gradational with sandstone-bearing Giraffe Creek Member; deposited in a shallow-marine environment during the second major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, incomplete sections of Leeds Creek strata are a few tens of feet thick east and southeast of Kimball Junction; poor exposure and complex deformation preclude accurate thickness measurements in the Summit Park area, but there the member is probably about 1300 feet (400 m) thick; Imlay (1967, 1980) reported that the unit thickens westward from 776 feet (237 m) in outcrops near Peoa and Oakley, 1520 feet (463 m) in Burr Fork near the top of Emigration Canyon, and 1289 feet (393 m) at Devils Slide; at the northwest side of Deer Creek Reservoir, Biek and Lowe (2009) reported an incomplete and attenuated section of about 400 feet (120 m) exposed beneath the Charleston thrust fault along the west side of the reservoir.

Jtw **Twin Creek Limestone, Watton Canyon Member** (Bathonian) – Yellowish-gray to medium-gray, slightly silty to clayey micritic limestone with oolitic and intraclast-bearing limestone; mostly medium-bedded with widely spaced tectonic stylolites at high angles to bedding that result in blocky weathering habit; moderately resistant forming blocky ledges; upper contact is gradational and placed at a change from ledge-forming dense limestone to slope-forming argillaceous limestone; deposited in a shallow-marine environment during the second major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Watton Canyon strata are about 300 to 360 feet (90–110 m) thick; Imlay (1967) reported that the unit thickens westward from 220 feet (68 m) thick in outcrops near Peoa and Oakley, 348 feet (106 m) thick in Burr Fork near the top of Emigration Canyon, and 380 feet (116 m) at Devils Slide; southwest of Heber Valley, about 10 miles (16 km) south of this map area, Watton Canyon strata are about 250 feet (75 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009).

Jtb **Twin Creek Limestone, Boundary Ridge Member** (Bathonian) – Non-resistant, reddish-brown mudstone, yellowish-brown siltstone with ripples, and lenses of light-gray, thick-bedded, oolitic and fossiliferous limestone; thin-bedded to laminated mudstone and siltstone are non-resistant and poorly exposed whereas limestone forms resistant ledges; overall weathers to form poorly exposed saddles and slopes between more resistant enclosing limestone members, but where limestone is dominant, as north of Kimball Junction, forms resistant ledges; Imlay (1967) noted that thicker, western exposures are characterized by more limestone and less siltstone and sandstone red beds; in this map area, the upper contact is difficult to pick but is placed at the top of a light-gray, thick-bedded, oolitic and fossiliferous limestone; deposited in a shallow-marine environment during the first major regression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Boundary Ridge strata are about 100 feet (30 m) thick; Imlay (1967) reported that regionally the unit thickens irregularly westward, but in the greater Wasatch back valley area it is 97 feet (30 m) thick at Devils Slide, 102 feet (31 m) thick in Burr Fork near the top of Emigration Canyon, and 107 feet (33 m) thick in outcrops near Peoa and Oakley; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Boundary Ridge strata are about 120 feet (35 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 145 feet (44 m) thick in adjacent Center Creek quadrangle (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; in lower plate of Mount Raymond thrust the upper contact is placed at a change from ledgy slopes of grayish, argillaceous limestone to reddish-brown siltstone slopes, whereas in upper plate the contact corresponds to the base of resistant oolitic limestone; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Rich strata are about 300 to 400 feet (100–120 m) thick; Imlay (1967) reported that the unit is 125 feet (38 m) thick in outcrops near Peoa and Oakley, but thickens to the northwest to 391 feet (119 m) in Burr Fork near the top of Emigration Canyon and 540 feet (165 m) at Devils Slide; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Rich strata are about 160 feet (50 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 116 feet (35 m) thick in adjacent Center Creek quadrangle.

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 comprises medium-gray weathering, medium-bedded, micritic limestone having moderately spaced tectonic stylolites; lower part typically forms resistant ridge and upper part forms moderately blocky ledges near the top; upper gradational contact typically corresponds to a break in slope between more resistant Sliderock limestone and less resistant argillaceous Rich limestone; deposited in a shallow-marine environment during the first major transgression of the Middle Jurassic seaway (Imlay, 1967, 1980); in this map area, Sliderock strata are about 100 to 150 feet (30–45 m) thick; Imlay (1967) reported that the unit is 47 feet (14 m) thick in outcrops near Peoa and Oakley, but thickens to the northwest to 150 feet (46 m) in Burr Fork near the top of Emigration Canyon and 100 feet (30 m) at Devils Slide; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Sliderock strata are about 200 feet (60 m) thick at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 209 feet (64 m) thick in adjacent Center Creek quadrangle.

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

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; weathers to a poorly exposed slope or strike valley between resistant slopes of Nugget and Sliderock strata; southward, in the greater Heber Valley area, also contains sandy, calcareous siltstone, minor jasperoid, pinkish-brown sideritic limestone, and brown to gray, dense, very fine grained limestone with a conchoidal fracture (Biek and others, 2003; Biek and Lowe, 2009), and near Peoa the basal foot is a chert pebble sandstone (Doug Sprinkel, written communication, February 7, 2017), but these lithologies were not recognized in this map area; usage follows Sprinkel and others (2011a); upper contact is sharp, corresponds to the J-2 unconformity, and marks a change from dominantly reddish-brown siltstone slopes to gray, ledgy limestone; Sprinkel and others (2011a) reported an $^{40}Ar/^{39}Ar$ sanidine age of 184.6 ± 0.2 Ma and a U-Pb zircon age of 183.2 ± 0.49 Ma for ash beds in the lower Gypsum Spring at Devils Slide, 22 miles (35 km) north of this map area, 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); Gypsum Spring strata are about 20 to 40 feet (6–12 m) thick, similar to their thickness near the Browns Canyon quarries (Biek, 2017); Imlay (1967) reported that the unit is 22 feet (7 m) thick in outcrops near Peoa and Oakley, but thickens greatly to the northwest to about 140 feet (43 m) in Burr Fork near the top of Emigration Canyon and 208 feet (63 m) at Devils Slide; in the greater Heber Valley area about 10 miles (16 km) south of this map area, Gypsum Spring strata are about 60 feet thick (18 m) at the northwest side of Deer Creek Reservoir (Biek and Lowe, 2009) and 83 feet (25 m) thick east of Heber Valley (Biek and others, 2003).

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

JURASSIC-TRIASSIC

JTRn **Nugget Sandstone** (Lower Jurassic to Upper Triassic) – Moderate-reddish-orange, moderate-orange-pink and very pale orange, cross-bedded, moderately well cemented quartz sandstone composed of well-rounded, fine- to medium-grained, frosted quartz grains; bedding consists of high-angle, large-scale cross-bedding in tabular planar, wedge planar, and trough shaped sets 10 to 45 feet or more (3–14+ m) thick; upper unconformable contact is sharp and planar and corresponds to a prominent lithologic and topographic change, with ledge-forming, massively cross-bedded sandstone below and slope-forming, dark-reddish-brown or locally yellowish-brown, fine- to medium-grained silty sandstone with minor coarse sand grains above; deposited principally by north winds in a vast coastal and inland dune field (Kocurek and Dott, 1983; Blakey, 1994; Marzolf, 1994; Peterson, 1994), part of one of the world's largest coastal and inland paleodune 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; map patterns suggest a thickness of about 1300 feet (400 m) thick north of Kimball

Junction in the upper plate of the Mount Raymond thrust fault; Bryant (1990) reported Nugget thicknesses of about 1300 feet (400 m) near Parleys Canyon and about 900 feet (280 m) near Peoa; about 900 to 1000 feet (275–300 m) thick on the saddle west of Soldier Hollow, and about 1260 feet (385 m) thick in the West Daniels Land #1 well south of Heber Valley (Biek and others, 2003).

TRIASSIC

TRa **Ankareh Formation, undivided** (Upper and Lower Triassic) – Mapped west of Kimball Junction and on Ecker Hill where thrust deformation precludes member subdivision at map scale; also used for entire formation on cross section. Regionally consists of three members, with a major regional unconformity, the TR-3 unconformity of Pipiringos and O'Sullivan (1978), separating the middle and lower members (Kummel, 1954); map patterns suggest a thickness of about 1700 to 2000 feet (520–600 m) at the crest of the Wasatch Range, but strata in the upper plate of the Mount Raymond thrust are tightly folded and thicken and thin dramatically from less than 1000 feet (300 m) to over 2000 feet (600 m); Biek (2017) estimated the formation is unusually thick, about 2150 to 2450 feet (655–750 m), on the west side of Round Valley immediately east of the map area; 1485 feet (453 m) thick southwest of Heber Valley (Baker, 1964) and of comparable thickness near Devils Slide (Coogan and King, 2016).

TRau, TRau?

Ankareh Formation, upper member (Upper Triassic) – Reddish-brown mudstone, siltstone, and very fine to fine-grained sandstone that weathers to poorly exposed slopes but that is locally well exposed on the crest of the Wasatch Range south of Red Pine Lake; locally includes several resistant, fine- to medium-grained sandstone beds, 5 to 10 feet (2–3 m) thick, in the uppermost part of the member; along the crest of the Wasatch Range, lower part contains several thin, light-gray-weathering, medium-gray, fine-grained limestone beds with irregular reddish-brown chert blebs and nodules; queried north of Red Pine Lake where it appears to be mostly covered by glacial till; deposited in fluvial, floodplain, and lacustrine environments of an interior basin drained by north- and northwest-flowing rivers (see, for example, Dubiel, 1994); upper contact typically covered, but is well exposed about 1500 feet (460 m) southwest of Red Pine Lake where thin-bedded, reddish-brown siltstone and fine-grained sandstone is abruptly overlain by ledge-forming, moderate-reddish-orange, massively cross-bedded, quartz sandstone of the Nugget Sandstone; map patterns suggest a thickness of 600 to 700 feet (180–210 m) west of Red Pine Lake, and a similar thickness at the southwest side of Round Valley in the adjacent Park City East quadrangle (Biek, 2017); Kummel (1954) reported that the upper member is 390 feet (120 m) thick at Red Butte Canyon northeast of Salt Lake City; Coogan and King (2016) reported that equivalent beds at Devils Slide are 600 to 680 feet (180–210 m) thick, and Baker (1964) reported this unit is about 450 feet (135 m) thick southwest of Heber City.

TRag **Ankareh Formation, Gartra Grit Member** (Upper Triassic) – White, light-brown, and pinkish-gray, fine- to coarse-grained, locally pebbly and gritty, feldspathic quartz sandstone; clasts are rounded quartzite and chert; resistant and so weathers to support ridge crests; upper contact corresponds to a change from ledge-forming gritty sandstone to slopes of reddish-brown mudstone and fine-grained sandstone; deposited in north- and northwest-flowing braided river channels of an interior basin (see, for example, Dubiel, 1994); about 150 to 200 feet (45–60 m) thick; map patterns suggest a thickness of about 250 feet (75 m) at Round Valley (Biek, 2017); Kummel (1954) reported that the Gartra Grit is 60 feet (18 m) thick at Red Butte Canyon northeast of Salt Lake City, and Baker (1964) reported that it is about 40 feet (12 m) thick southwest of Heber City.

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

TRam, TRam?

Ankareh Formation, Mahogany Member (Lower Triassic) – Reddish-brown, grayish-purple, and grayish-red, locally mottled, mudstone, siltstone, and fine-grained sandstone that weathers to poorly exposed slopes; upper contact is poorly exposed, but is sharp, concordant and unconformable east of Jordanelle Reservoir (Biek, 2017); queried where concealed but likely present between thrust fault splays in Summit Park; deposited in fluvial, floodplain, and lacustrine environments of an interior basin drained by north- and northwest-flowing rivers (see, for example, Dubiel, 1994); Thomson and Loveless (2014) reported on swim tracks from exposures near Thistle, Utah, and evidence for Early Triassic age; map patterns suggest a thickness of about 1000 to 1300 feet (300–400 m) along the crest of the Wasatch Range, and about 1300 to 1500 feet (400-460 m) at Round Valley immediately east of this map area (Biek, 2017); Coogan and King (2016) reported that equivalent beds at Devils Slide are 600 to 725 feet (180–220 m) thick; Kummel

(1954) reported that the lower member is 850 feet (260 m) thick at Red Butte Canyon northeast of Salt Lake City and thickens eastward into the Uinta Mountains as Thaynes strata pinch out; Baker (1964) reported lower Ankareh strata are about 1000 feet (300 m) thick southwest of Heber City whereas Smith (1969) reported a thickness of 1372 feet (420 m) in this same area.

Thaynes Formation (Lower Triassic, Spathian to Smithian) – In 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, while containing 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 (not mapped separately due to poor exposure and structural complications), whereas red siltstone and shale occupy this interval on the lower plate; a similar red-bed marker interval is mapped west of Murdock Peak in the upper plate as described below. 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). On the upper plate north of Red Butte Canyon east of Salt Lake City, Solien and others (1979) recognized seven informal lithologic units that totaled 2296 feet (700 m) thick; farther northeast, Coogan and King (2016) estimated a thickness of 1835 feet (560 m) south of Devils Slide. Map patterns suggest that Thaynes strata are 1300 to 1400 feet (400–425 m) thick in Big Cottonwood Canyon in the southwest corner of the map area; there, Boutwell (1912) reported a thickness of 1190 feet (363 m); in Round Valley, immediately east of this map area, 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).

TRt **Thaynes Formation, undivided** (Lower Triassic, Spathian to Smithian) – Undivided across most of the upper plate of the Mount Raymond thrust due to poor exposure and complex deformation; also used on cross sections; bedding attitudes are highly variable across short distances, suggesting small-scale thrust faults and folds difficult to discern at map scale; thickness uncertain, but may be as much as about 2000 feet (600 m) thick in the upper reaches of Toll Canyon.

TRtu **Thaynes Formation, upper limestone member** (Lower Triassic, Spathian) – Light- to medium-gray, thin- to thick-bedded limestone and fine-grained calcareous sandstone interbedded with light-gray, light-brown, and olive-gray, thin-bedded calcareous siltstone and shale; locally fossiliferous with pelecypods, gastropods, and ammonites; deposited in a warm, shallow sea (Kummel, 1954; Blakey and Gubitosa, 1983); age from Solien and others (1979); map patterns suggest a thickness of about 750 feet (230 m) on the north side of Big Cottonwood Canyon; Biek (2017) reported a thickness of about 1100 feet (335 m) north of Silver Creek in the adjacent Park City East quadrangle.

The upper contact on the upper plate is not exposed. However, it is well exposed on the lower plate, along the crest of the Wasatch Range near the southern quadrangle boundary, where it appears conformable and gradational. There, we chose it to correspond to the base of a resistant, yellowish-brown sandstone ledge, as did Crittenden and others (1966), about 120 feet (35 m) above the highest gray Thaynes limestone bed. As defined here, the upper limestone member thus includes a thick interval of thin- and evenly bedded siltstone, mudstone, and very fine grained silty sandstone, commonly with interference ripples, whose dark-gray, greenish-gray and reddish-brown colors are those of clastic Thaynes strata elsewhere. This fine-grained clastic interval may represent deposition in tidal-flat environments that were eventually overtaken by fluvial and coastal-plain environments of lower Ankareh strata.

TRtm **Thaynes Formation, middle shale member** (Lower Triassic, Spathian to Smithian) – Reddish-brown, micaceous siltstone and fine-grained sandstone; typically laminated or thin- to medium-bedded with planar and ripple cross stratification; bedding surfaces commonly reveal symmetrical and interference ripple marks; soft-sediment deformation, in the form of ball and pillow structures, is locally present; nonresistant and poorly exposed, typically forming a recessive interval between the upper and lower Thaynes carbonate members, but well exposed in a road cut north of the Utah Highway 224-248 junction; likely equivalent to the middle red shale of Boutwell (1912); this red-bed interval is likely a tongue of Mahogany Member of Ankareh Formation, with which the Thaynes interfingers eastward into the Uinta Mountains (Kummel, 1954); also used for a similar, possibly correlative but thinner interval west of Murdock Peak, in the upper plate of the Mount Raymond thrust; deposited in tidal-flat and distal fluvial environments of a coastal plain (Kummel, 1954; Blakey and Gubitosa, 1983); map patterns suggest a thickness of about 150 to 200 feet (45–60 m) in Big Cottonwood Canyon, and Biek (2017) estimated a thickness of about 200 feet (60 m) north of Silver Creek in the adjacent Park City East quadrangle.

TRtl **Thaynes Formation, lower limestone member** (Lower Triassic, Smithian) – Light- to medium-gray, conspicuously dark-yellowish-brown-weathering, thin- to thick-bedded limestone and fine-grained calcareous sandstone interbedded with light-gray, light-brown, and olive-gray, thin-bedded calcareous siltstone and shale; locally fossiliferous with pelecypods, gastropods, and ammonites; except along ridge crests in Big Cottonwood Canyon where it is moderately well exposed, generally weathers to poorly exposed ledgy slopes; upper contact is poorly exposed, but appears conformable and gradational and corresponds to the first appearance of reddish-brown micaceous siltstone and fine-grained sandstone; deposited in a warm, shallow sea (Kummel, 1954; Blakey and Gubitosa, 1983); map patterns suggest a thickness of about 300 feet (90 m) in Big Cottonwood Canyon, similar to that reported north of Silver Creek in the adjacent Park City East quadrangle (Biek, 2017); lower Thaynes strata are probably somewhat thicker west of Murdock Peak in the upper plate of the Mount Raymond thrust.

TRw, TRw?

Woodside Formation (Lower Triassic, Scythian) – Moderate- to dark-reddish-brown, laminated to thin-bedded or rarely medium-bedded, micaceous and feldspathic siltstone and fine-grained sandstone with planar and small-scale cross stratification; bedding surfaces commonly reveal symmetrical and interference ripple marks; non-resistant and so weathers to form strike valleys and colluvium-covered slopes; uppermost beds typically include yellowish-brown, fine- to medium-grained sandstone; lower part well exposed in road cut near Silver King mine in the southeast corner of the map area, where it is light-yellowish-brown, light-gray, and minor reddish-brown, laminated to thin-bedded, fine-grained calcareous sandstone, siltstone, and mudstone about 50 feet (15 m) thick, similar to that in the Deer Crest development in the adjacent Park City East quadrangle (Biek, 2017); queried where exposures are poor at the entrance to Threemile Canyon west of Kimball Junction; 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; map patterns suggest 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; Baker (1964) reported a thickness of 315 feet (95 m) southwest of Heber Valley, and Constenius and others (2011) noted that the Woodside Shale may be tectonically thinned or thickened from less than 200 to over 700 feet (60–215 m) in the Provo 30′ x 60′ quadrangle; Coogan and King (2016) reported that the Woodside is 500 to 600 feet (150–180 m) thick at Devils Slide.

TR-1 unconformity (Pipiringos and O'Sullivan, 1978), spans 10 to 20 million years during 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 (Middle to Lower Permian, Leonardian to Wordian) – Boutwell (1912, p. 49; see also Boutwell, 1907) named and defined the Park City Formation for its importance as the principal host for lead-silver-zinc replacement deposits in the Park City mining district. In the central Wasatch Range, Park City strata are divisible into the lower Grandeur and upper Franson Members, which are separated by the Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation (McKelvey and others, 1959); except in one area near historic Park City, they are undivided here due to structural complications and limited exposure. At the west edge of the map area in Big Cottonwood Canyon, we map a marker bed that may correspond to Meade Peak strata. In this map area, Park City strata record warm, shallow-marine deposition (Sheldon and others, 1967b) east of the Utah hingeline, a long-lived boundary between a stable continental shelf to the east and a subsiding marine basin to the west, when southwest Utah lay just north of the equator on the western margin of the supercontinent Pangea. Phosphoria strata, however, were deposited in a deep-water, oxygen- and sediment-starved part of the basin (Sheldon and others, 1967a). Gordon and Duncan (1970) and Wardlaw and Collinson (1979) reported on the age of Park City and Phosphoria strata.

Park City and Phosphoria strata are remarkably poorly exposed in this map area, only locally forming ledgy outcrops. The best, though incompletely exposed, section is Boutwell's (1912) section in Big Cottonwood Canyon, on the ridge north of Beartrap Fork; there, he 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. 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, Wordian to Leonardian) – Undivided throughout most of the map area due to structural complications and limited exposure; also used on cross sections; see members below for unit description.

Ppcf **Park City Formation, Franson Member** (Middle Permian, Wordian to Roadian) – 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; mapped separately only on the northeast flank of Crescent Ridge at the base of the Park City Mountain Resort on the edge of historic Park City; upper contact well exposed in road cut near the Silver King mine at the southwest end of Treasure Hill, where it corresponds to the top of a light-gray, medium- to thick-bedded limestone overlain by light-yellowish-brown, light-gray, and minor reddish-brown, laminated to thin-bedded, fine-grained calcareous sandstone, siltstone, and mudstone; upper contact appears conformable, 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); Franson (and Rex Chert) strata are about 240 to 300 feet (75–90 m) thick in the Ogden 30′ x 60′ quadrangle (Coogan and King, 2016).

Ppm **Phosphoria Formation, Meade Peak Phosphatic Shale Tongue** (Middle to Lower Permian, Wordian to Leonardian) – 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; mapped separately only on the northeast flank of Crescent Ridge at the base of the Park City Mountain Resort on the edge of historic Park City; Meade Peak strata are mostly concealed under the east branch of Negro Hollow, which was partly filled (Qhd) for the Treasure Hill ski run; at the west edge of the map area in Big Cottonwood Canyon, we map a marker bed that may correspond to Meade Peak strata; regionally consists of upper and lower phosphatic shale units split by a tongue of the Franson Member; incompletely exposed but likely about 100 feet (30 m) thick; about 60 feet (18 m) thick west of Heber City (Baker, 1964).

Ppcg **Park City Formation, Grandeur Member** (Lower Permian, Leonardian) – 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; 458 feet (140 m) thick west of Heber City (Baker, 1964) and about 220 to 310 feet (65–95 m) thick in the Ogden 30′ x 60′ quadrangle (Coogan and King, 2016); Cheney (1957) reported that Grandeur strata are 290 feet (88 m) thick northeast of Salt Lake City and that the member thins and becomes sandy eastward into the Uinta Mountains where it pinches out east of Duchesne.

PERMIAN-PENNSYLVANIAN

IPPw **Weber Quartzite** (Lower Permian? to Middle Pennsylvanian, Desmoinesian) – Very pale orange, grayish-orange, and yellowish-gray, typically thick- to very thick bedded, fine-grained, well-cemented quartzitic and less commonly calcareous sandstone with uncommon, thin, light-gray limestone, cherty limestone, and dolomite interbeds; commonly bleached white and locally iron-stained; typically highly fractured and indistinctly bedded and so bedding attitudes are surprisingly difficult to obtain; weathers to steep, rounded, colluvium-covered hillsides; upper contact is conformable and gradational, thus difficult to consistently pick, and corresponds to the base of the first 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); map patterns suggest a thickness of about 1100 feet (335 m) in Big Cottonwood Canyon in the southwest corner of the map area; structural complications preclude accurate thickness estimates in the greater Park City area, but Bromfield (1968) estimated that the formation is 1300 to 1500 feet (400–460 m) thick and that westward in Big Cottonwood Canyon, limestone interbeds make up about 15% to 20% of the formation; Coogan and King (2016) estimated Weber strata are 2600 feet (790 m) thick near Morgan.

IPrv **Round Valley Limestone** (Lower Pennsylvanian, Atokan and Morrowan) – 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; exposed only in Big Cottonwood Canyon in the southwest corner of the map area; age from Sadlick (1955); Round Valley strata are about 400 feet (120 m) thick north of Silver Fork in Big Cottonwood Canyon; Bryant (1990) reported Round Valley strata are as much as 900 feet (300 m) thick in the Wasatch Range; about 225 to 400 feet (70–120 m) thick west of Heber City (Baker, 1964); 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; incompletely exposed only in Big Cottonwood Canyon in the southwest corner of the map area and so unit description is modified from Bryant (1990); about 430 feet (130 m) thick in the Wasatch Range and 210 feet (65 m) thick in the Uinta Mountains; 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; upper contact not exposed but regionally 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; mapped in the southwest corner of the quadrangle where the upper contact is concealed south of Silver Fork; regionally, it 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); about 585 feet (175 m) thick in the Wasatch Range (Baker, 1964); 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).

Mdg **Deseret and Gardison Limestones, undivided** (Upper to Lower Mississippian) – Poorly exposed and thus undivided in the southwest corner of the quadrangle on the south side of Big Cottonwood Canyon, but likely consists mostly of Deseret strata, described above; **Gardison Limestone** (Lower Mississippian) is 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; upper contact not exposed but regionally 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.

ACKNOWLEDGMENTS

We appreciate the help of Andy Armstrong, Doug Evans, and Brian Davenport of the Mountain Regional Water District, who shared well data and facilitated access to several developments throughout the map area. Barrett Burghard, Park City Mountain Resort, facilitated access to much of the Wasatch Range in the map area. Emily Kleber (UGS) and Adam McKean (UGS) prepared raw Summit County lidar data for use in this project, and Gordon Douglass (UGS) made Wasatch County lidar data accessible. Dan Smith, Utah Division of Oil, Gas and Mining, Abandoned Mines Program, shared mine location and closure data obtained during reclamation of the Park City mining district. Hydrogeologist Chris DeKorver, Bowen Collins & Associates, shared early results of the new Kimball Junction water well. Consulting engineering geologist Harry Audell shared his preliminary mapping of landslides in the greater Park City area. Colleagues Grant Willis, Zach Anderson, and Stephanie Carney (UGS) reviewed the map and supporting materials, and I am grateful for their collective wisdom. Basia Matyjasik (UGS) created the ArcGIS files and Lori Steadman (UGS) drafted plate 2 figures. This geologic map was funded by the Utah Geological Survey and U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number G17AC00266, 2017–18.

REFERENCES

Álvarez-Solas, J., Montoya, M., Ritz, C., Ramstein, G., Charbit, S., Dumas, C., Nisancioglu, K., Dokken, T., and Ganopolski, A., 2011, Heinrich event 1—an example of dynamical ice-sheet reaction to oceanic changes: Climate of the Past, v. 7, p. 1297–1306, https://doi.org/10.5194/cp-7-1297-2011. Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey Special Study 105, 49 p.

Ashland, F.X., Bishop, C.E., Lowe, M., and Mayes, B.H., 2001, The geology of the Snyderville basin, western Summit County, Utah, and its relation to ground-water conditions: Utah Geological Survey Bulletin 28, 59 p., 15 plates.

Baker, A.A., 1964, Geology of the Aspen Grove quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-239, 9 p., 1 plate, scale 1:24,000.

Baker, A.A., Calkins, F.C., Crittenden, M.D., Jr., and Bromfield, C.S., 1966, Geologic map of the Brighton quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-534, 1 plate, scale 1:24,000.

Baker, A.A., and Crittenden, M.D., Jr., 1961, Geologic map of the Timpanogos Cave quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-132, 1 plate, scale 1:24,000.

Biek, R.F., 2017, Interim geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah: Utah Geological Survey Open-File Report 677, 24 p., 2 plates, scale 1:24,000.

Biek, R.F., 2018, Ancient volcanoes of the central Wasatch Range: Utah Geological Survey Survey Notes, v. 50, no. 3, page 5–6.

Biek, R.F., and Lowe, M., 2009, Geologic map of the Charleston quadrangle, Wasatch County, Utah: Utah Geological Survey Map 236, 2 plates, scale 1:24,000.

Biek, R.F., Hylland, M.D., Welsh, J.E., and Lowe, M., 2003, Geologic map of the Center Creek quadrangle, Wasatch County, Utah: Utah Geological Survey Map 192, 26 p., 2 plates, scale 1:24,000.

Bissell, H.J., 1964, Lithology and petrography of the Weber Formation, in Utah and Colorado, *in* Sabatka, E.F., editor, Guidebook to the geology and mineral resources of the Uinta Basin, Utah's hydrocarbon storehouse: Intermountain Association of Petroleum Geologist 13th annual field conference, p. 65–91.

Blakey, R.C., 1994, Paleogeographic and tectonic controls on some Lower and Middle Jurassic erg deposits, Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 273–298.

Blakey, R.C., and Gubitosa, R., 1983, Late Triassic paleogeography and depositional history of the Chinle Formation, southern Utah and northern Arizona, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of the west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Paleogeography Symposium 2, p. 57–76.

Boutwell, J.M., 1907, Stratigraphy and structure of the Park City mining district, Utah: Journal of Geology, v. 15, p. 434–458.

Boutwell, J.M., 1912, Geology and ore deposits of the Park City district, Utah: U.S. Geological Survey Professional Paper 77, 231 p.

Bradley, M.D., 2001, Interim geologic maps of the Crandall Canyon and Hidden Lake quadrangles, Summit County, Utah: Utah Geological Survey Open-File Report 382, 27 p., 6 plates, scale 1:24,000.

Bromfield, C.S., 1968, Source of Keetley volcanic field: U.S. Geological Survey Professional Paper 600-A, p. A33.

Bromfield, C.S., Baker, A.A., and Crittenden, M.D., Jr., 1970, Geologic map of the Heber quadrangle, Wasatch and Summit Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-864, 1 plate, scale 1:24,000.

Bromfield, C.S., and Crittenden, M.D., Jr., 1971, Geologic map of the Park City East quadrangle, Summit and Wasatch Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-852, 1 plate, scale 1:24,000.

Bromfield, M.D., Erickson, A.J., Jr., Haddadin, M.A., and Mehnert, H.H., 1977, Potassium-argon ages of intrusion, extrusion and associated ore deposits, Park City mining district, Utah: Economic Geology, v. 72, p. 837–848.

Bryant, B., 1990, Geologic map of the Salt Lake City 30′ x 60′ quadrangle, north-central Utah and Uinta County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1944, scale 1:100,000.

Bryant, B., 1992, Geologic and structure maps of the Salt Lake City 1° x 2° quadrangle, Utah and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1997, scale 1:125,000.

Bryant, B., Naeser, C.W., Marvin, R.F., and Mehnert, H.H., 1989, Ages of late Paleogene and Neogene tuffs and the beginning of rapid regional extension, eastern boundary of the Basin and Range Province near Salt Lake City, Utah: U.S. Geological Survey Bulletin 1787-K, 12 p.

Chadwick, O.A., Hall, R.D., and Phillips, F.M., 1997, chronology of Pleistocene glacial advances in the central Rocky Mountains [Wind River Range, Wyoming]: Geological Society of America Bulletin, v. 109, no. 11, p. 1443–1452.

Cheney, T.M., Smart, R.A., Waring, R.G., and Warner, M.A., 1953, Stratigraphic sections of the Phosphoria Formation in Utah, 1949-51: U.S. Geological Survey Circular 306, 40 p.

Cheney, T.M., 1957, Phosphate in Utah: Utah Geological and Mineralogical Survey Bulletin 59, 54 p., 3 plates.

Clark, P.U., Dyke, A.S., Shakun, J.D., Carlson, A.E., Clark, J., Wohlfarth, B., Mitrovica, J.X., Hostetler, S.W., and McCabe, A.M., 2009, The last glacial maximum: Science, v. 325, p. 710–714.

Constenius, K.N., Clark, D.L., King, J.K., and Ehler, J.B., 2011, Interim geologic map of the Provo 30' x 60' quadrangle, Salt Lake, Utah, and Wasatch Counties, Utah: Utah Geological Survey Open-File Report 586DM, 42 p., 1 plate, scale 1:62,500.

Coogan, J.C., and King, J.K., 2016, Interim geologic map of the Ogden 30' x 60' quadrangle, Box Elder, Cache, Davis, Morgan, Rich, and Summit Counties, Utah, and Uinta County, Wyoming: Utah Geological Survey Open-File Report 653DM, 112 p. plus appendices and plates, scale 1:62,500.

Crittenden, M.D., Jr., 1965a, Geologic map of the Mount Aire quadrangle, Salt Lake County, Utah: U.S. Geological Survey Quadrangle Map GQ-379, 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., 1965b, Geologic map of the Dromedary Peak quadrangle, Utah: U.S. Geological Survey Quadrangle Map GQ-535, 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., Calkins, F.C., and Sharp, B.J., 1966, Geologic map of the Park City West quadrangle, Salt Lake County, Utah: U.S. Geological Survey Quadrangle Map GQ-275, 1 plate, scale 1:24,000.

Crittenden, M.D., Jr., Stuckless, J.S., Kistler, R.W., and Stern, T.W., 1973, Radiometric dating of intrusive rocks in the Cottonwood area, Utah: U.S. Geological Survey Journal of Research, v. 1, no. 2, p. 173–178.

Dickinson, W.R., and Gehrels, G.E., 2003, U-Pb ages of detrital zircons from Permian and Jurassic eolian sandstones of the Colorado Plateau, USA—paleogeographic implications: Sedimentary Geology, v. 163, nos. 1 and 2, p. 29–66.

Dickinson, W.R., and Gehrels, G.E., 2009a, U-Pb ages of detrital zircons in Jurassic eolian and associated sandstones of the Colorado Plateau—evidence for transcontinental dispersal and intraregional recycling of sediment: Geological Society of America Bulletin, v. 121, nos. 3 and 4, p. 408–433.

Dickinson, W.R., and Gehrels, G.E., 2009b, Insights into North American paleogeography and paleotectonics from U-Pb ages of detrital zircons in Mesozoic strata of the Colorado Plateau USA: International Journal Earth Science, 19 p., https://doi.org/10.1007/s00531-009-0462-0.

Doelling, H.H., Sprinkel, D.A., and Kuehne, P.A., 2013, Temple Cap and Carmel Formations in the Henry Mountains Basin, Wayne and Garfield Counties, Utah, *in* Morris, T.H., and Ressetar, R., editors, The San Rafael Swell and Henry Mountains basin—geologic centerpiece of Utah: Utah Geological Association Publication 42, p. 279–318 with appendices.

Dubiel, R.F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the Western Interior, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region: Rocky Mountain Section, Society for Sedimentary Geology, p. 133–168.

Eardley, A.J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 55, p. 819–894, plate 1, scale 1:125,000.

Elliott, A.H., and Harty, K.M., 2010, Landslide maps of Utah: Utah Geological Survey Map 246DM, 14 p., 46 plates, scale 1:100,000.

Feher, L.A., 1997, Petrogenesis of the Keetley Volcanics in Summit and Wasatch Counties, north-central Utah: East Lansing, Michigan State University, M.S. thesis, 95 p.

Feher, L.A., Constenius, K.N., and Vogel, T.A., 1996, Relationships between the Wasatch intrusive belt and the Keetley Volcanics, north-central Utah: Geological Society of America Abstracts with Programs, v. 28, no. 7, p. 483.

Forrester, J.D., 1937, Structure of the Uinta Mountains: Geological Society of America Bulletin v. 48, no. 5, p. 631–666.

Fryberger, S.G., 1979, Eolian-fluviatile (continental) origin of ancient stratigraphic trap for petroleum, Weber Sandstone, Rangely oil field, Colorado: The Mountain Geologist, v. 16, no. 1, p. 1–36.

Godsey, H.S., Currey, D.R., and Chan, M.A., 2005, New evidence for an extended occupation of the Provo shoreline and implications for regional climate change, Pleistocene Lake Bonneville, Utah, USA: Quaternary Research, v. 63, p. 212–223.

Gordon, M., Jr., and Duncan, H.M., 1970, Biostratigraphy and correlation of the Oquirrh Group and related rocks in the Oquirrh Mountains, Utah, *in* Tooker, E.W., and Roberts, R.J., Upper Paleozoic rocks in the Oquirrh Mountains and Bingham mining district, Utah: U.S. Geological Survey Professional Paper 629-A, p. A38–A70.

Gosse, J.C., Klein, J., Evenson, E.B., Lawn, B., and Middleton, R., 1995, Beryllium-10 dating of the duration and retreat of the last Pinedale glacial sequence: Science, v. 268, p. 1329–1333.

Hansen, W.R., 1965, Geology of the Flaming Gorge area, Utah-Colorado-Wyoming: U.S. Geological Survey Professional Paper, 490, 196 p.

Hanson, S.L., 1995, Mineralogy, petrology, geochemistry and crystal size distribution of Tertiary plutons of the central Wasatch Mountains: Salt Lake City, University of Utah, Ph.D. dissertation, 371 p.

Hayden, J.M, 2011, Geologic map of the White Hills quadrangle, Washington County, Utah: Utah Geological Survey Map 250DM, 16 p., 2 plates, scale 1:24,000.

Hintze, L.F., and Kowallis, B.J., 2009, Geologic history of Utah: Provo, Utah, Brigham Young University Geology Studies Special Publication 9, 225 p.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackleton, N.J., 1984, The orbital theory of Pleistocene climate —support from a revised chronology of the marine ^{18}O record, *in* Berger, A., Imbrie, J., Hays, J., Kukla, G., and Saltzman, B., editors, Milankovitch and climate part 1: Dordrecht, Holland, Reidel, p. 269–306.

Imlay, R.W., 1967, Twin Creek Limestone (Jurassic) in the western interior of the United States: U.S. Geological Survey Professional Paper 540, 105 p.

Imlay, R.W., 1980, Jurassic paleobiogeography of the conterminous United States: U.S. Geological Survey Professional Paper 1062, 134 p.

John, D.A., 1987, Evolution of hydrothermal fluids in intrusions of the central Wasatch Mountains, Utah: Palo Alto, California, Stanford University, Ph.D. dissertation, 236 p.

John, D.A., 1989a, Geologic setting, depths of emplacement, and regional distribution of fluid inclusions in intrusions of the central Wasatch Mountains, Utah: Economic Geology, v. 84, p. 386–409.

John, D.A., 1989b, Evolution of hydrothermal fluids in the Park Premier stock, central Wasatch Mountains, Utah: Economic Geology, v. 84, p. 879–902.

Kocurek, G., and Dott, R.H., Jr., 1983, Jurassic paleogeography and paleoclimate of the central and southern Rocky Mountains region, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of the west-central United States: Denver, Rocky Mountain Section Society of Economic Paleontologists and Mineralogists, p. 101–116.

Kummel, B., 1954, Triassic stratigraphy of southeastern Idaho and adjacent areas: U.S. Geological Survey Professional Paper 254-H, p. H165–H194.

Laabs, B.J.C., and Munroe, J.S., 2016, Late Pleistocene mountain glaciation in the Lake Bonneville basin, *in* Oviatt, C.G., and Shroder, J.F., editors, Lake Bonneville—a scientific update: Developments in Earth Surface Processes, v. 20, p. 462–503.

LeBas, M.J., LeMaitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745–750.

Leveinen, J.E., 1994, Petrology of the Keetley Volcanics in Summit and Wasatch Counties, north-central Utah: Duluth, University of Minnesota, M.S. thesis, 175 p.

Lisiecki, L.E., and Raymo, M.E., 2005, A Pliocene–Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records: Paleoceanography, v. 20, PA1003, https://doi.org/10.1029/2004PA001071.

Marzolf, J.E., 1994, Reconstruction of the early Mesozoic cordilleran cratonal margin adjacent to the Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 181–216.

McKelvey, V.E., Williams, J.S., Sheldon, R.P., Cressman, E.R., Cheney, T.M., and Swanson, R.W., 1959, Geology of Permian rocks in the western phosphate field—the Phosphoria, Park City, and Shedhorn formations in the western phosphate field: U.S. Geological Survey Professional Paper 313-A, 47 p.

Milligan, M., 2012, Sizing up titans—Navajo erg vs. Sahara ergs, which was the larger sand box?: Utah Geological Survey, Survey Notes, v. 44, no. 3, p. 8–9.

Morris, H.T., and Lovering, T.S., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geological Survey Professional Paper 361, 145 p.

Nelson, M.E., 1971, Stratigraphy and paleontology of the Norwood Tuff and Fowkes Formation, northeastern Utah and southwestern Wyoming: Salt Lake City, University of Utah, Ph.D. dissertation, 169 p.

Nelson, M.E., 1976, A new Oligocene faunule from northeastern Utah: Transactions of the Kansas Academy of Science, v. 79, p. 7–13.

O'Toole, W.L., 1951, Geology of the Keetley-Kamas volcanic area: Salt Lake City, University of Utah, M.S. thesis, 38 p.

Oviatt, C.G., 2014, The Gilbert episode in the Great Salt Lake Basin, Utah: Utah Geological Survey Miscellaneous Publication 14-3, 20 p.

Oviatt, C.G., 2015, Chronology of Lake Bonneville, 30,000 to 10,000 yr B.P.: Quaternary Science Reviews, v. 110, p. 166–171.

Peterson, F., 1994, Sand dunes, sabkhas, streams, and shallow seas—Jurassic paleogeography in the southern part of the Western Interior basin, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Colorado, Rocky Mountain Section of the Society for Sedimentary Geology, p. 233–272.

Pierce, K.L., Licciardi, J.M., Good, J.M., and Jaworowski, C., 2018, Pleistocene glaciation of the Jackson Hole area, Wyoming: U.S. Geological Survey Professional Paper 1835, 55 p.

Pierce, K.L., Muhs, D.R., Fosberg, M.A., Mahan, S.A., Rosenbaum, J.G., Licciardi, J.M., and Pavich, M.J., 2011, A loess-paleosol record of climate and glacial history over the past two glacial-interglacial cycles (~150 ka), southern Jackson Hole, Wyoming: Quaternary Research, v. 76, p. 119–141.

Phillips, C.H., and Krauhlec, K., 2006, Geology and history of the Bingham mining district, Salt Lake County, Utah, *in* Bon, R.L., Gloyn, R.W., and Park, G.M., editors, Mining districts of Utah: Utah Geological Association Publication 32, p. 6–40.

Phillips, F.M., Zreda, M.G., Gosse, J.C., Klein, J., Klein, J., Evenson, E.B., Hall, R.D., Chadwick, O.A., and Sharma P., 1997, Cosmogenic ^{36}Cl and ^{10}Be ages of Quaternary glacial and fluvial deposits of the Wind River Range, Wyoming: Geological Society of America Bulletin, v. 109, no. 11, p. 1453–1463.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—a preliminary survey: U.S. Geological Survey Professional Paper 1035-A, 29 p.

Quirk, B. J., Moore, J.R., Laabs, B.J.C., Caffee, M.W., and Plummer, M.A., 2018, Termination II, Last Glacial Maximum, and Lateglacial chronologies and paleoclimate from Big Cottonwood Canyon, Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 130, no. 11/12, p. 1889–1902.

Rahl, J.M., Reiners, P.W., Campbell, I.H., Nicolescu, S., and Allen, C.M., 2003, Combined single-grain (U-Th)/He and U-Pb dating of detrital zircons from the Navajo Sandstone, Utah: Geology, v. 31, no. 9, p. 761–764.

Reiners, P.W., Campbell, I.H., Nicolescu, S., Allen, C.M., Hourigan, J.K., Garver, J.I., Mattinson, J.M., and Cowan, D.S., 2005, (U-Th)/(He-Pb) double-dating of detrital zircons: American Journal of Science, v. 305, p. 259–311.

Sadlick, W., 1955, The Mississippian-Pennsylvanian boundary in northeastern Utah: Salt Lake City, University of Utah, M.S. thesis, 77 p.

Sandberg, C.A., and Gutschick, R.C., 1984, Distribution, microfauna, and source-rock potential of Mississippian Delle Phosphatic Member of Woodman Formation and equivalents, Utah and adjacent states, *in* Woodward, Jane, Meissner, F.F., and Clayton, J.L., editors, Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists Field Conference Guidebook, p. 135–178.

Sharp, W., Ludwig, K.R. Chadwick, O.A., Amundson, R., and Glasner, L.L., 2003, Dating fluvial terraces by ^{230}Th/U on pedogenic carbonate, Wind River basin, Wyoming: Quaternary Research, v. 59, p. 139–150.

Sheldon, R.P., Cressman, E.R., Cheney, T.M., and McKelvey, V.E., 1967a, Paleotectonic investigations of the Permian System in the United States, Chapter H—Middle Rocky Mountains and northeastern Great Basin, *in* McKee, E.D. and Oriel, S.S. and others, Paleotectonic investigations of the Permian System in the United States: U.S. Geological Survey Professional Paper 515-H, p. 157–170.

Sheldon, R.P., Maughan, E.K., and Cressman, E.R., 1967b, Sedimentation of rocks of Leonard (Permian) age in Wyoming and adjacent states, *in* Hale, L.A., editor, Anatomy of the western phosphate field, a guide to the geologic occurrence, exploration methods, mining engineering, and recovery technology: Intermountain Association Geologists, Fifteenth Annual Field Conference, p. 1–13.

Smith, H.P., 1969, The Thaynes Formation of the Moenkopi Group, north-central Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 378 p. 13 plates.

Solien, M.A., Morgan, W.A., and Clark, D.L., 1979, Structure and stratigraphy of Lower Triassic conodont locality, Salt Lake City, Utah: Brigham Young University Geology Studies, v. 26, part 3, p. 165–177.

Sprinkel, D.A., Doelling, H.H., Kowallis, B.J., Waanders, G., and Kuehne, P.A., 2011a, Early results of a study of Middle Jurassic strata in the Sevier fold and thrust belt, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 151–172.

Sprinkel, D.A., Kowallis, B.J., and Jensen, P.H., 2011b, Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 131–149.

Thomas, H.D., and Krueger, M.L., 1946, Late Paleozoic and early Mesozoic stratigraphy of Uinta Mountains, Utah: American Association of Petroleum Geologists Bulletin, v. 30, no. 8, p. 1255-1293.

Thomson, T.J., and Lovelace, D.M., 2014, Swim track morphotypes and new track localities from the Moenkopi and Red Peak Formations (Lower-Middle Triassic) with preliminary interpretations of aquatic behaviors, *in* Lockley, M.G., and Lucas, S.G., editors, Fossil footprints of western North America: New Mexico Museum of Natural History Bulletin 62, p. 103–128.

Van Horn, R., and Crittenden, M.J., Jr., 1987, Map showing surficial units and bedrock geology of the Fort Douglas quadrangle and parts of the Mountain Dell and Salt Lake City North quadrangles, Davis, Salt Lake, and Morgan Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1762, 1 plate, scale 1:24,000.

Vogel, T.A., Cambray, F.W., Feher, L.A., Constenius, K.N., and the WIB Research Team, 1997, Petrochemistry and emplacement history of the Wasatch intrusive belt, Utah, *in* John, D.A., and Ballantyne, G.H., editors, Geology and ore deposits of the Oquirrh and Wasatch Mountains, Utah: Society of Economic Geologists Guidebook 29, p. 35–46.

Vogel, T.A., Cambray, F.W., and Constenius, K.N., 2001, Origin and emplacement of igneous rocks in the central Wasatch Mountains, Utah: Rocky Mountain Geology, v. 36, no. 2, p. 119–162.

Ward, P.D., 2004, Gorgon—paleontology, obsession, and the greatest catastrophe in Earth's history: New York, Viking, 257 p.

Wardlaw, B.R., and Collinson, J.W., 1979, Biostratigraphic zonation of the Park City Group, in Studies of the Permian Phosphoria Formation and related rocks, Great Basin-Rocky Mountain region: U.S. Geological Survey Professional Paper 1163-D, p. D17–D22.

Willes, S.B., 1962, The mineral alteration products of the Keetley-Kamas volcanic area, Utah: Brigham Young University Geology Studies, v. 9, part 2, p. 3–28.

Woodfill, R.D., 1972, A geologic and petrographic investigation of a northern part of the Keetley volcanic field, Summit and Wasatch Counties, Utah: West Lafayette, Indiana, Purdue University, Ph.D. dissertation, 168 p., 1 plate, scale 1:24,000.

Table 1. Selected water wells and exploration drill holes in the Park City West quadrangle.

Map #	Well Identification # (WIN)	Well Name	Easting NAD83*	Northing NAD83*	Total Depth feet)	Completed	Status	Notes	PLS Coordinates
1	1967	Gorgoza well 1	450292.0737	4510306.4676	1123	8/20/08	public water well	Nugget to TD	South 150 feet, West 250 feet, from NE corner Section 15, T. 1 S., R. 3 E.
2	1980	Gorgoza well 4R	451578.9648	4510709.7634	1665	6/16/01	public water well	Ankareh/Thaynes contact at 1035 feet?	North 1550 feet, West 1260 feet, from SE corner Section 11, T. 1 S., R. 3 E.
3	2109	Rest stop well	452795.3912	4509980.4828	920	6/30/01	public water well	unconsolidated deposits to 95 feet; Thaynes(?) to 740 feet; middle Thaynes to TD	South 750 feet, East 75 feet, from N4 corner Section 13, T. 1 S., R. 3 E.
4	23459	Grayhawk well	454802.6111	4509641.3505	1860	5/2/01	irrigation well	Tertiary alluvium to 300 feet; Twin Creek to TD	South 1600 feet, West 1000 feet, from NE corner Section 18, T. 1 S., R. 4 E.
5	17277	SCSC well No. 2R	454856.5926	4508532.0603	600	4/1/98	public water well	unconsolidated deposits to 139 feet; TD in Twin Creek	South 160 feet, West 1260 feet, from NE corner section 19, T. 1 S., R. 4 E.
6	441280	Hi-Ute well	453600.1903	4508216.0289	2515	11/8/17	public water well	TD in Twin Creek Limestone	South 1001 feet, East 577 feet, from NW corner of section 19, T. 1 S., R.4 E.
7	7557	U224 well	453937.3043	4507492.8407	600	7/4/95	public water well	unconsolidated deposits to 12(?) feet; Nugget to TD	South 3400 feet, East 1100 feet, from NW corner section 19, T. 1 S., R. 4 E.
8	20214	Nugget well	454633.8457	4507754.9716	1810	9/19/00	public water well	unconsolidated deposits to 273 feet; Twin Creek 273 to 875(?) feet; Gypsum Spring 875(?) to 947; TD in Nugget	South 2150 feet, East 3220 feet, from NW corner section 19, T. 1 S., R. 4 E.
9	100	F-7 well	455351.3107	4507989.0917	500	12/16/94	public water well	unconsolidated deposits to 180 feet; Twin Creek(?) to TD	South 1919 feet, East 422 feet, from NW corner section 20, T. 1 S., R. 4 E.
10	11484	Larsen Creekside exploration well #2	456103.1071	4507723.6315	895	11/21/05	plugged and abandoned	unconsolidated deposits to 240 feet; TD in Twin Creek?	North 3400 feet, West 1460 feet, from SE corner Section 20, T. 1 S., R. 4 E.
11	20360	Larsen Creekside exploration well #1	456387.4339	4507973.3033	970	9/16/99	plugged and abandoned	unconsolidated deposits or Tertiary alluvium to 180 feet; TD in Twin Creek?	North 2650 feet, West 2600 feet, from SE corner Section 20, T. 1 S., R. 4 E.
12	11307	SSWC well No. 3	453935.2417	4506589.9387	1048	7/15/97	water well	Nugget to TD	North 3770 feet, East 1250 feet, from SW corner section 30, T. 1 S., R. 4 E.
13		SSWC well No. 1	453946.7132	4506039.1759	500	3/29/79	water well	unconsolidated deposits to 185 feet; 185 to 210 feet Gypsum Springs(?); TD in Nugget	South 420, East 1298, from W4 Section 30, T1S, R4E
14	3899	SSWC well No. 2	453211.8318	4505447.8323	705	12/3/93	water well	unconsolidated deposits to 31 feet; Nugget to TD	North 210 feet, West 1050 feet, from SE corner section 25, T. 1 S., R. 3 E.
15	27003	SRJV 1998 well	453832.2519	4504489.9121	705	10/16/97	irrigation well	unconsolidated deposits to 235 feet; Twin Creek to TD	North 2650 feet, East 720 feet, from SW corner section 31, T. 1 S., R. 4 E.
16	23384	St. Mary White Pine well	454571.6626	4503575.4589	360	4/2/01	domestic well	TD in unconsolidated deposits	South 68 feet, East 326.5 feet, from N4 corner section 6, T. 2 S., R. 4 E.
17	1235004M00	2H2O	456092.9356	4504976.1149	800	11/30/12	test well	unconsolidated deposits to 350 feet; Twin Creek to 795 feet; Nugget(?) to TD	South 1122 feet, West 2061 feet, from NE coner section 32, T. 1 S., R. 4 E.
18	28242	Aspen test well	456021.2631	4502674.3334	985	11/19/03	observation Well	unconsolidated deposits to 295 feet; Ankareh to 460 feet; TD in Thaynes	North 2000 feet, West 2545 feet, from SE corner section 5, T. 2 S., R. 4 E.
19	21142	Bernofolo well	456032.2129	4501197.7917	175	1/3/00	domestic well	unconsolidated deposits to 135 feet; Thaynes to TD	South 305 feet, West 2510 feet, from E4 corner section 8, T. 2 S., R 4 E.
20	2455	Divide exploration well	456764.1300	4501977.9203	1010	11/12/99	plugged and abandoned	unconsolidated deposits to 75 feet; 75 to 298 upper Thaynes; 298 to 522 lower Thaynes; 982 to 1010 Woodside	South 200 feet, West 120 feet, from NE corner section 8, T. 2 S., R. 4 E.

Notes:
DRW, Utah Division of Water Rights
* = approximate location
TD = total depth
B&C= Bowen and Collins
SSWC - Silver Springs Water Company - note that SSWC now owned by Mountain Regional