Plate 1 of 2
Utah Geological Survey Open-File Report 586DM
Interim Geologic Map of the Provo 30' x 60' Quadrangle

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

INTERIM GEOLOGIC MAP OF THE PROVO 30' X 60' QUADRANGLE, UTAH, WASATCH, AND SALT LAKE COUNTIES, UTAH

by
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2011

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SCALE 1:62,500
CONTOUR INTERVAL 50 METERS
1 0.5 0 1 2 3 4 MILES
1 0.5 0 1 2 3 4 5 6 KILOMETERS

UTAH
QUADRANGLE LOCATION

TRUE NORTH
MAGNETIC NORTH
11°55'
APPROXIMATE MEAN DECLINATION, 2011

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Geologic Units

Qh	Qgo?	Tvc	Ppf
Qa	Qgmo	Tucb	Ppm
Qay	Qgao	Tuc	Ppg
Qam	Qfdp	Tu	Pdc
Qam?	Qdp	Tgu	Pk
Qao	Qfdb	Tgm	PIPo
Qal	Qdb	Tgl	Pofc
Qat	Qlg	Tc	PIPgw
Qat1	Qls	Tf	Pogm
Qat2	Qlf	Ts	Pogm?
Qat2?	Qll	Tn	Pogml
Qat3	Qly	TKnq	IPobm
Qaty	Qla	TKn	IPobm?
Qaf	Qes	TKc	IPowr
Qafy	Qst	Kpc	IPos
Qaf3	Qa/Qst	Kmv	IPobp
Qafp	Qsm	Km	IPobl
Qafb	Qrc	Kf	IPobc
Qafm	QTst	Kmm	IPobc?
Qafm?	QTa	Kd	IPowc
Qafmo	QTaf	Kcm	IPobv
Qafo	QTaf?	KJcm	IPw
Qafo?	QTmb	Jsv	IPrv
Qac	QTmb(Pogm)	Js	Mmc
Qc	QTmb(PIPo)	Jce	Mmc?
Qct	QTmb(IPobc)	Jp	Mdo
Qmc	QTmb(IPobv)	Ja	Mdot
Qmt	QTmb(Mmc)	Jtc	Mgb
Qmd	QTmb(Mgb)	Jtu	Mgbu
Qmf	Taf	Jtgl	Mgbsl
Qmdf	Taf?	Jtwl	Mh
Qms	Tsl	Jtw	Mde
Qms?(IPobc)	Tb	Jtl	Mde?
Qms?(Mmc)	Tic	Jtb	Mgf
Qmsy	Tict	Jtrsg	Mg
Qmso	Tvtw	Jn	MDfp
Qml?	Tsp	TRa	Cote
Qmg	Ti	TRau	Ccte?
Qg	Tt	TRam	Cmo
Qg?	Tt?	TRal	Cm
Qgm	Tvb	TRat	Co
Qga	Tvte	TRt	Ct
Qgr	Tm	TRtu	Zm
Qgy	Tm?	TRad	Zmf
Qgp	Tk	TRtl	Zbc
Qgmp	Tk?	TRtla	water
Qgap	Tkq	TRw	
Qgo	Tkt	Pp	

Base from USGS Provo 30' x 60' Quadrangle (1986)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1886

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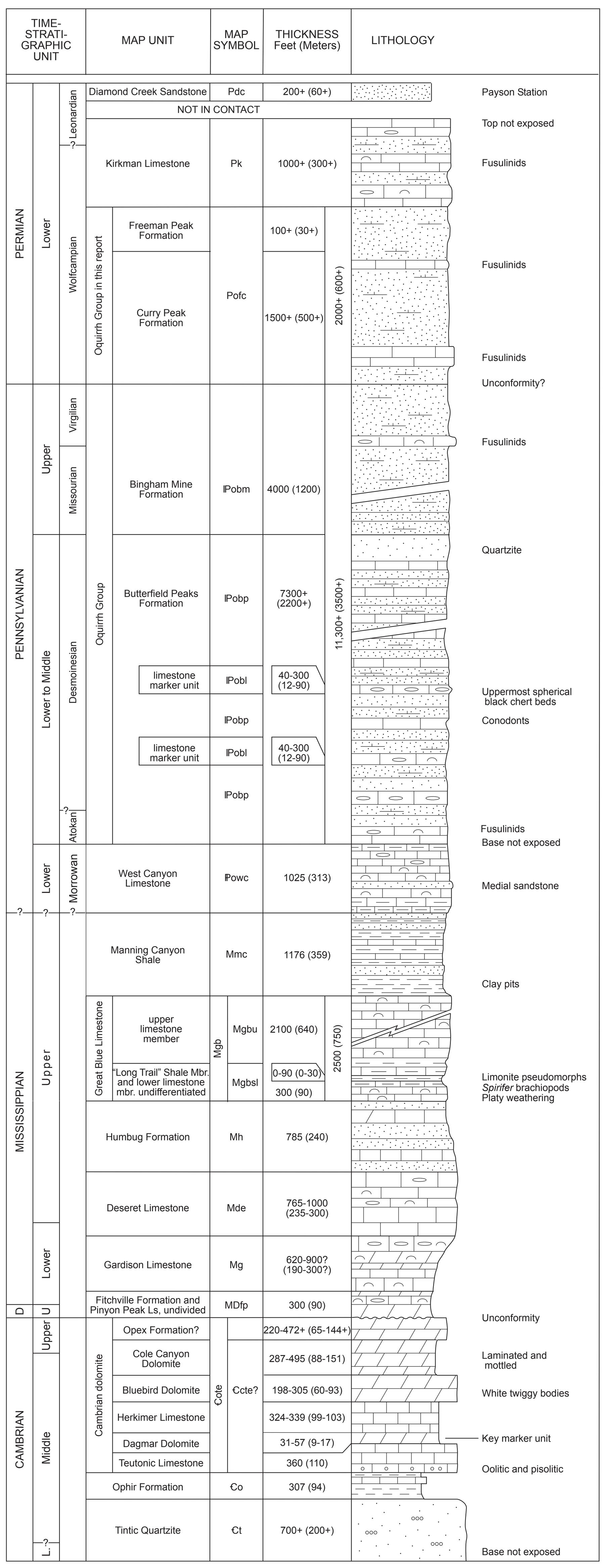
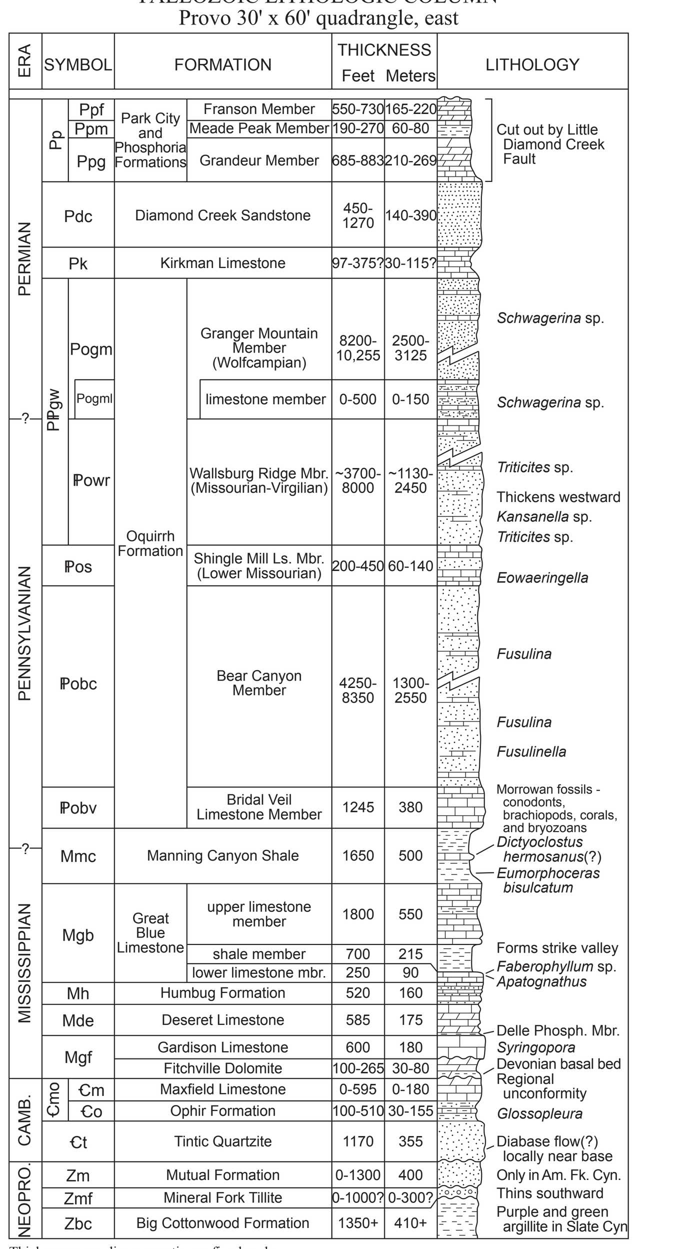
This interim geologic map is compiled from detailed new mapping of key 7.5' quadrangles, revised previously published 7.5' quadrangles, and new 1:24,000 to 1:50,000-scale reconnaissance geologic mapping, producing complete coverage at a scale of 1:62,500. This new map fills a gap in Utah's intermediate-scale geologic map coverage and is available as a paper map or GIS files. The Provo 30' x 60' quadrangle covers part of the populous Wasatch Front and Utah Valley, which have many different geologic hazard concerns, and the adjacent Wasatch Range, with competing recreational, forest, watershed, and geologic resource issues. Precambrian to Cretaceous sedimentary strata were deformed by Late Cretaceous to early Tertiary contractional folding and faulting of the Sevier orogeny, middle Tertiary regional extensional collapse or relaxation that was accompanied by igneous activity, and late Tertiary to Holocene basin-and-range extensional faulting. Much of the eastern part of the quadrangle is covered by Tertiary strata that were deposited after the Sevier orogeny and before and during middle Tertiary extension. The most prominent feature of the basin-and-range extensional faulting is the Provo segment of the Wasatch fault zone, which separates Utah Valley from the Wasatch Range. Utah Valley is filled with up to 4500 meters of basin fill that is mostly mantled by late Pleistocene Lake Bonneville deposits. Late Pleistocene glacial deposits are present at higher elevations in the Wasatch Range.

PALEOZOIC LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, west

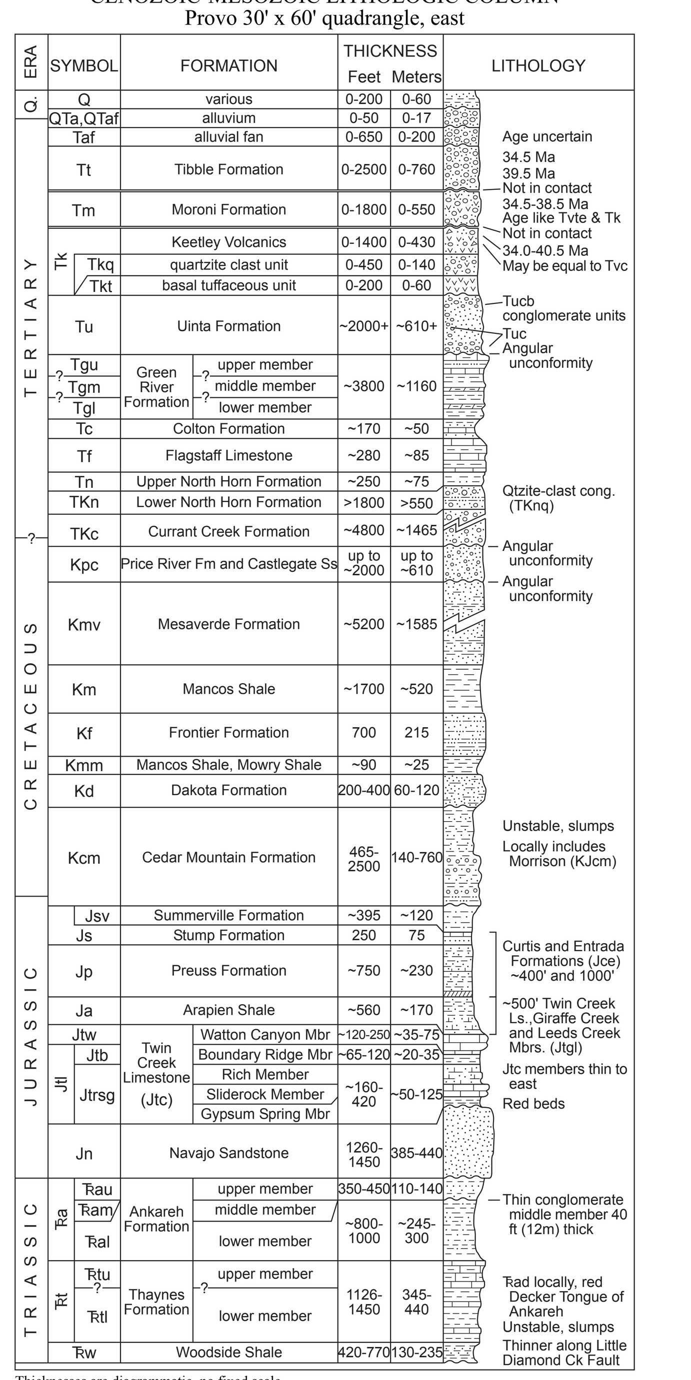


PALEOZOIC LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, east



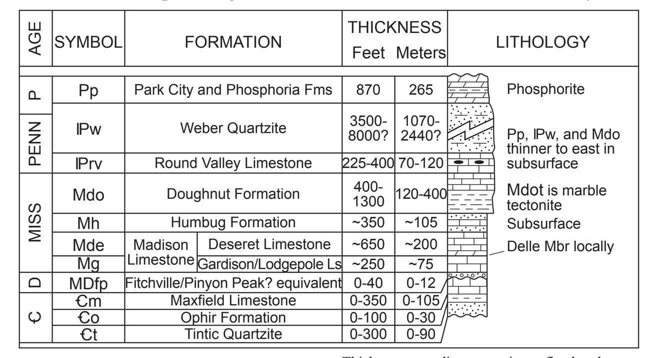
Thicknesses are diagrammatic, no fixed scale.

CENOZOIC-MESOZOIC LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, east



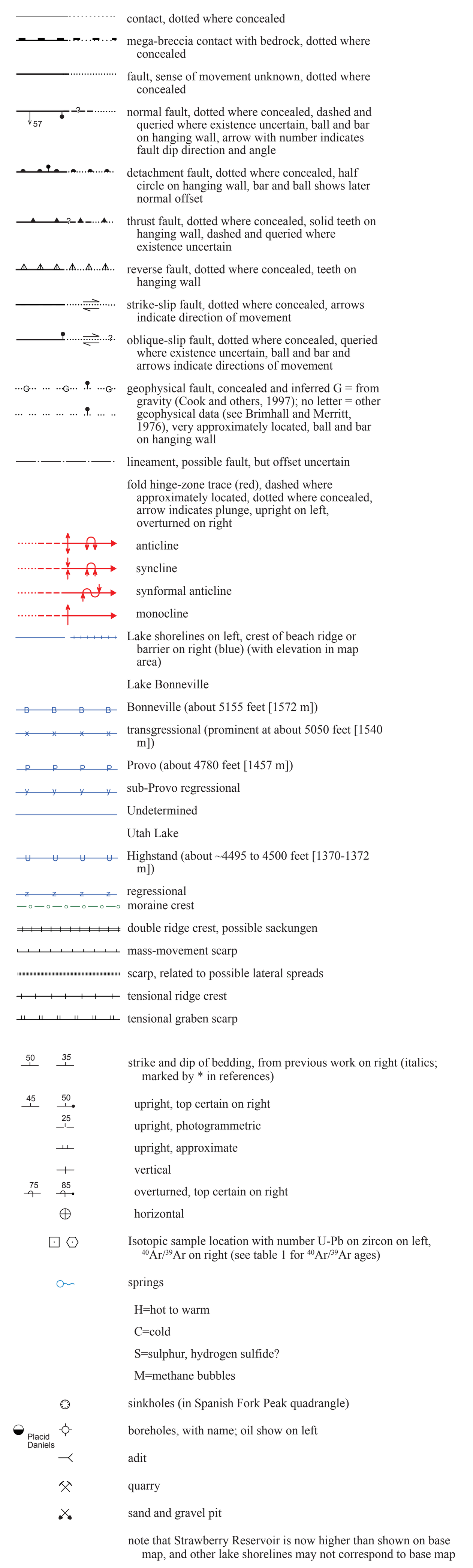
Thicknesses are diagrammatic, no fixed scale.

THIN PALEOZOIC STRATA LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, footwall of Charleston-Nebo thrust system



Thicknesses are diagrammatic, no fixed scale.

GEOLOGIC SYMBOLS



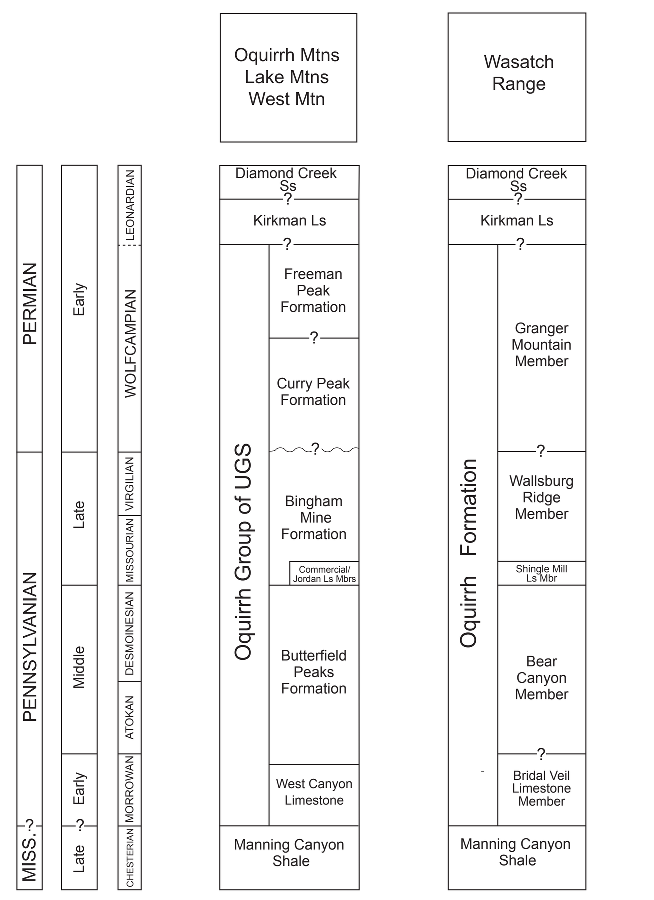
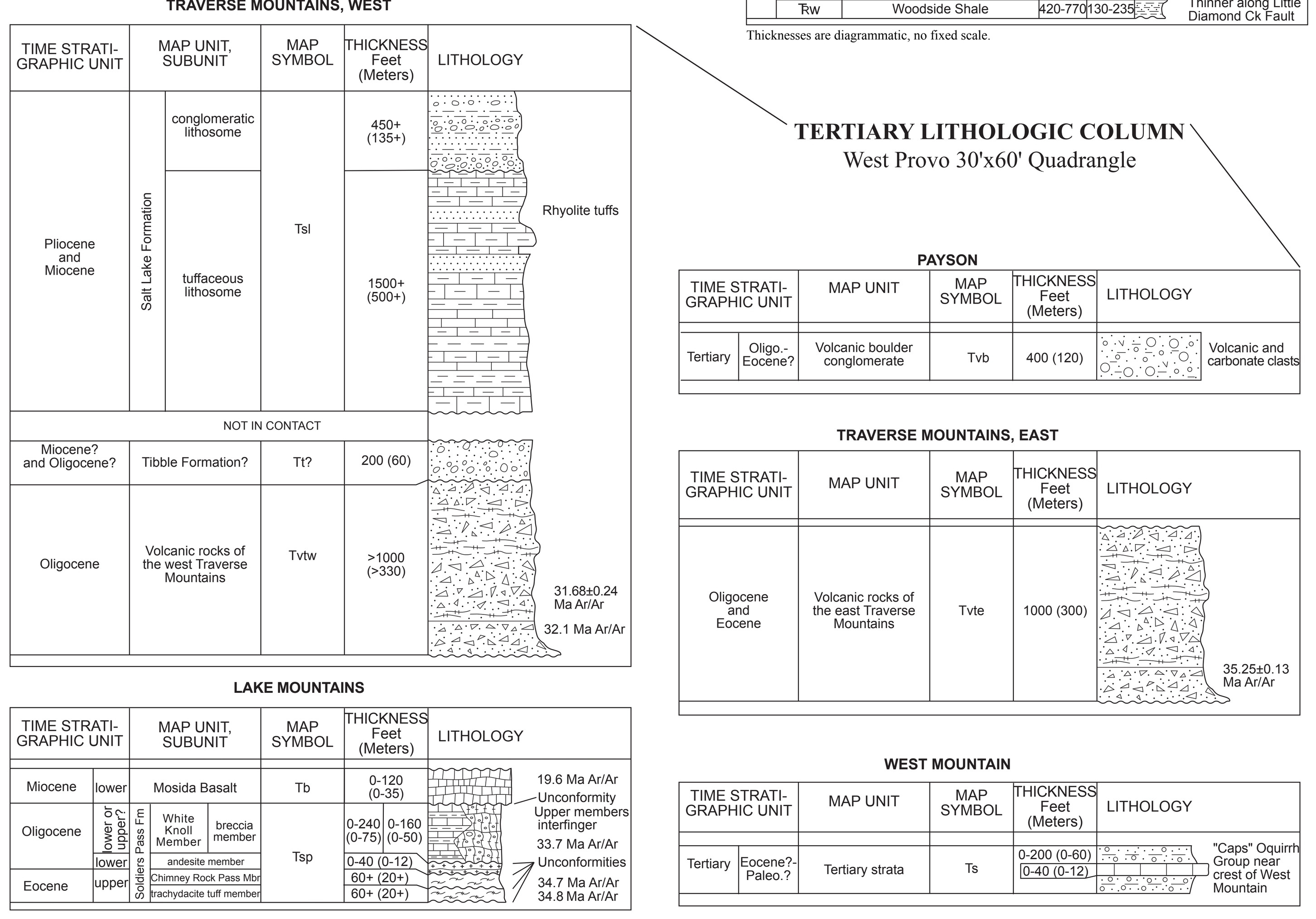
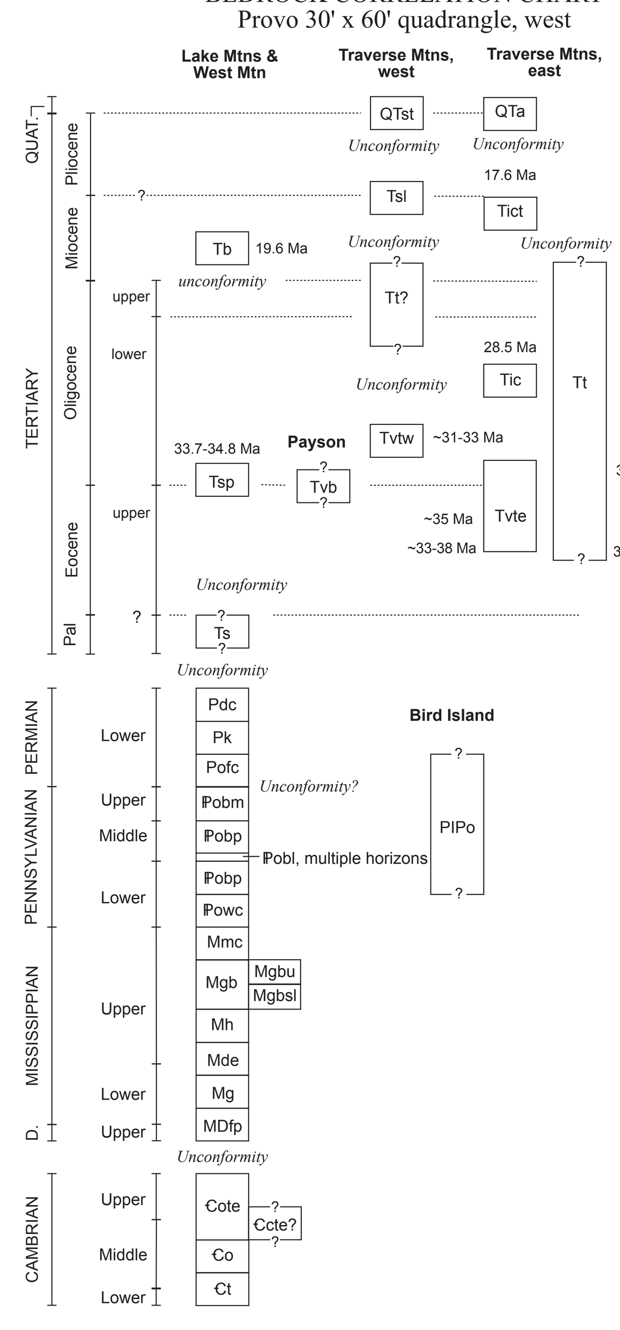


Figure 2. Comparison of stratigraphic nomenclature for the Oquirrh Formation/Group and associated strata near Salt Lake and Utah Valleys, north-central Utah. In the western part of this map the Utah Geological Survey (UGS) extends the Oquirrh Group to include the Curry Peak and Freeman Peak Formations.

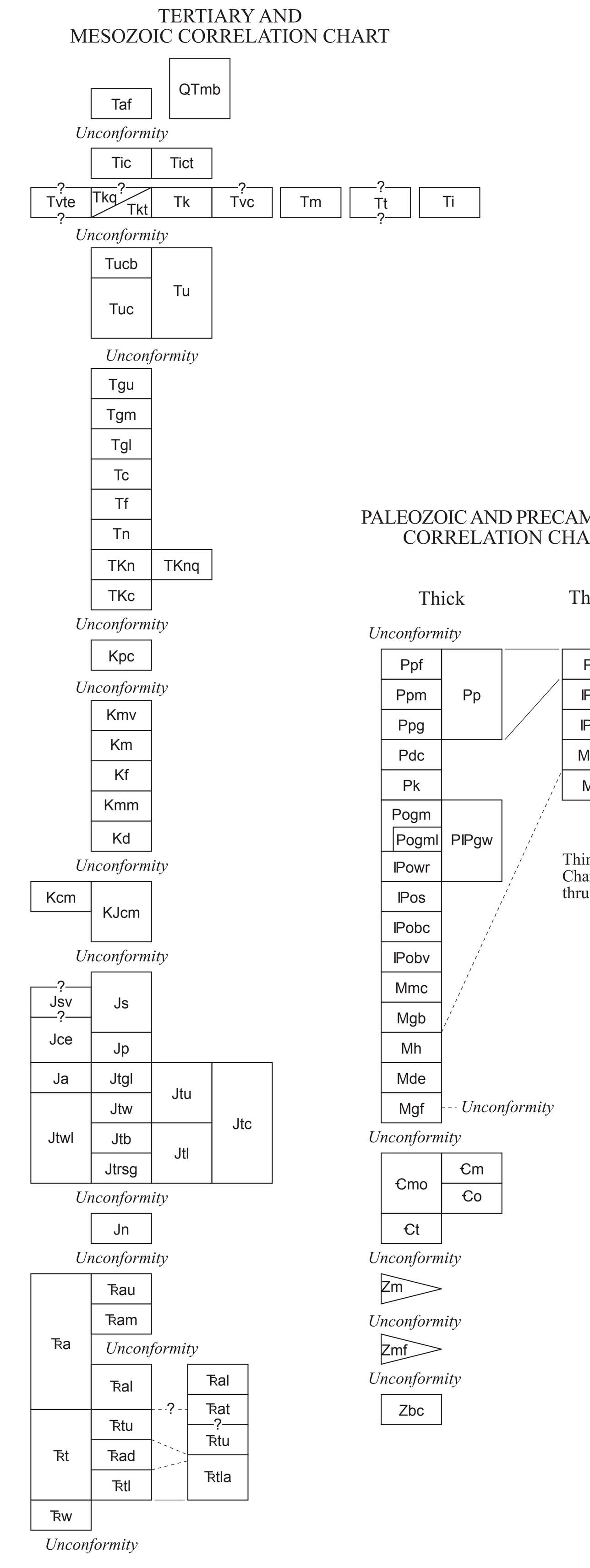
TERTIARY LITHOLOGIC COLUMN
West Provo 30'x60' Quadrangle



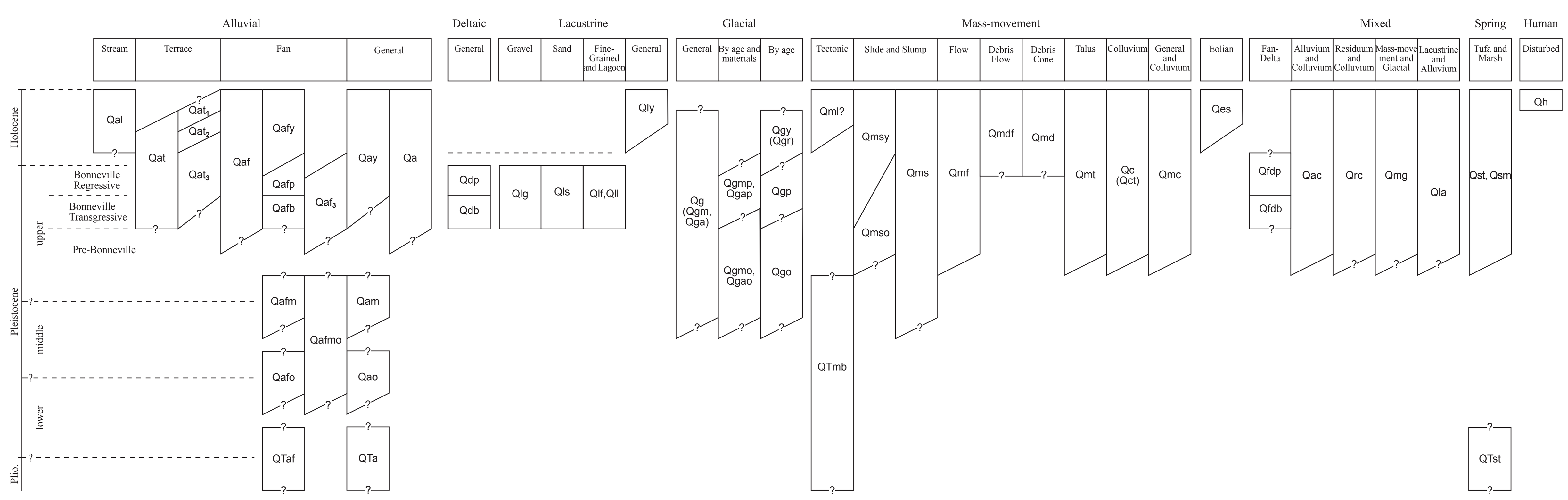
BEDROCK CORRELATION CHART
Provo 30' x 60' quadrangle, west



BEDROCK CORRELATION CHART
Provo 30' x 60' quadrangle, east



QUATERNARY CORRELATION CHART
Provo 30' x 60' quadrangle



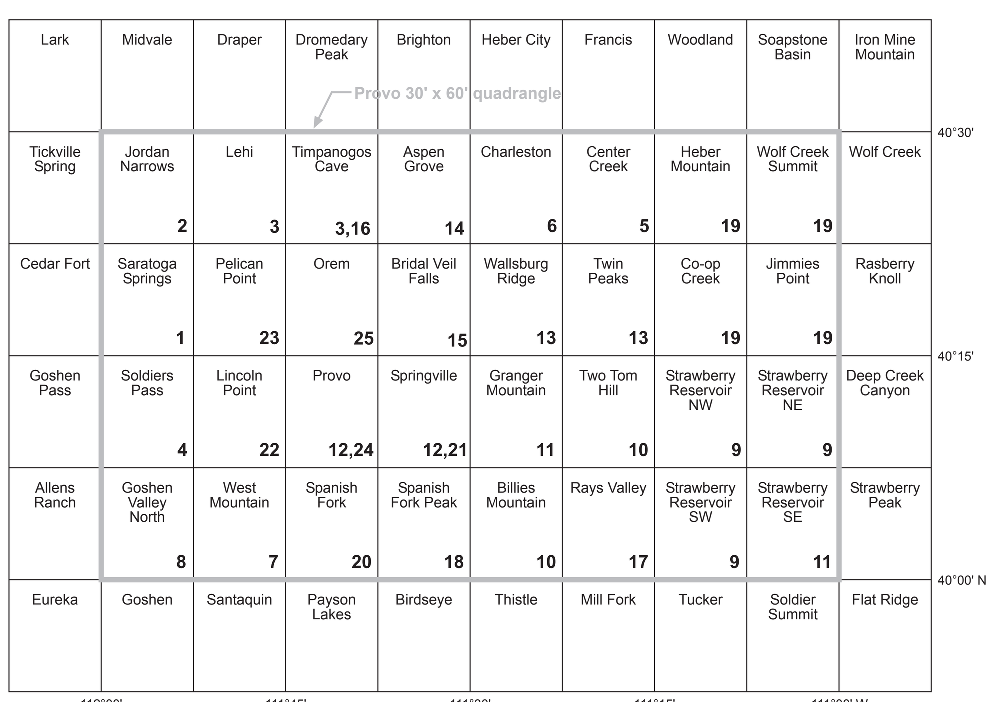


Figure 1. Provo 30' x 60' quadrangle, Utah, index to geologic mapping. Numbers refer to reference list.

TABLE 1. Summary of $^{40}Ar/^{39}Ar$-age analyses from the area of the Provo 30' x 60' quadrangle (modified from Deino and Keith, 1997; Constenius and others, 2003; Christiansen and others, 2007; and UGS and NMGRL, 2007). Latitude and longitude (in NAD27) corrected for samples in Provo 30' x 60' quadrangle and ages corrected/modified for analyses funded by STATEMAP.

Sample number	Unit	Latitude	Longitude	Age+2sd (Ma)	Mineral	Type of analysis
SP-3303	Mosida basalt	40° 10' 39.3"	111° 58' 25.0"	19.47±0.14	groundmass	furnace step-heating$
SP-4003	Mosida basalt	40° 09' 2.2"	111° 59' 22.4"	19.65±0.17	groundmass	furnace step-heating$
Tick 28*	Tvtw	40° 26' 28"	112° 05' 27"	32.12±0.14	plagioclase	single crystal Argon-ion step-heating
SP-3205	Tsp, breccia mbr	40° 09' 1.6"	111° 59' 38.3"	33.73±0.65	groundmass	furnace step-heating$
KNC7894-44*	Moroni	39° 56.867'	111° 30.983'	34.43±0.10	sanidine	single crystal CO_2 fusion
KNC101701-7*	Moroni	39° 51.377'	111° 25.807'	34.63±0.09	sanidine	single crystal CO_2 fusion
KNC71194-5	Moroni(?)	40° 07' 16.5"	111° 25' 37.4"	34.68±0.09	sanidine	single crystal CO_2 fusion$
KNC90299-1	intrusion	40° 19.056'	111° 19.657'	34.70±0.16	biotite	furnace step-heating$
SP-603A	Tsp, CRP tuff	40° 12' 12.2"	111° 58' 40.0"	34.70±0.07	sanidine	single crystal CO_2 fusion$
SP-1603B	Tsp, CRP tuff	40° 09' 18.7"	111° 58' 46.5"	34.70±0.07	sanidine	single crystal CO_2 fusion$
SP-1903	Tsp, basal tuff	40° 09' 22.7"	111° 58' 33.1"	34.79±0.10	biotite	furnace step-heating$
KNC101701-1	Moroni(?)	40° 04' 23.3"	111° 27' 21.4"	34.86±0.09	sanidine	single crystal CO_2 fusion$
L33103-9	Tvte	40° 28.010'	111° 50.419'	35.25±0.13	biotite	furnace step-heating$
KNC61093-2T	Tibble, lower	40° 28.982'	111° 38.422'	36.56±0.15	biotite	single crystal Argon-ion step-heating
KNC101701-4	Moroni(?)	40° 04' 02.3"	111° 26' 22.7"	37.18±0.38	biotite	single crystal CO_2 fusion$
KNC92799-6	Keetley, "base"	40° 22' 17.8"	111° 10' 19.8"	37.25±0.14	hornblende	furnace step-heating$
KNC92899-2	Tvc	40° 15' 44.5"	111° 12' 23.2"	37.73±0.28	biotite	furnace step-heating$
KNC6901-1*	Keetley	40° 44.483'	111° 20.857'	38.20±0.11	sanidine	single crystal CO_2 fusion
KNC92799-5	Keetley	40° 22' 21.9"	111° 10' 19.3"	40.45±0.18	hornblende	furnace step-heating$

*=sample not from Provo 30' x 60' quadrangle map.

Tvtw=Volcanic rocks of west Traverse Mountains
Tsp=Soldiers Pass Formation
Tvte=Volcanic rocks of east Traverse Mountains
CRP=Chimney Rock Pass Tuff Member
Tvc=Volcaniclastic rocks of Strawberry Valley

All analyses performed at the New Mexico Geochronology Research Laboratory, Socorro, New Mexico, except Argon-ion step heating analyses which were done at the University of California, Berkeley Geochronology Center (Tick 2) and the University of Alaska, Fairbanks (two samples). $ Indicates analysis paid for by STATEMAP funding.

TABLE 2. Summary of zircon U-Pb age analyses from the area of the Provo 30' x 60' quadrangle. Zircon mineral separates were analyzed using laser-ablation and inductively coupled plasma mass spectrometry (LA-ICPMS). Latitude and longitude in NAD27.

Sample number	Unit	Latitude	Longitude	Age+2sd (Ma)	No. of analyses	Comments
KNC62695-2*	Tic	40° 31.400'	111° 41.017'	30.5 ± 0.6	8	granite-granodiorite
KNC053107-3[$]	Tt	40° 14.665'	111° 29.311'	33.7 ± 0.6	13	tuff
KNC060407-14[$]	Tvte	40° 29.319'	111° 39.725'	35.7 ± 0.6	21	latite lava
KNC61093-2T	Tt	40° 28.982'	111° 38.422'	36.1 ± 1.7	33	tuff
KNC070109-1[$]	Tubc	40° 23.240'	111° 00.908'	38.9 ± 0.8	20	tuff
KNC070109-2[$]	Tubc	40° 23.245'	111° 01.005'	39.6 ± 0.7	29	tuff
JC 99-37[$]	TRat	40° 21.017'	111° 12.400'	249.0 ± 3.0	34	tuff

*=sample not from Provo 30' x 60' quadrangle map; result from Constenius (1998).
[$]=analysis paid for by STATEMAP funding.

Tic=Little Cottonwood stock
Tt=Tibble Formation
Tvte=Volcanic rocks of east Traverse Mountains
Tubc=Uinta Formation, boulder conglomerate
TRat=Ankareh and Thaynes Formations, transitional unit

All analyses performed at the Arizona LaserChron Center, Department of Geosciences, University of Arizona, Tucson, Arizona.

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Disclaimer

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Map Unit Descriptions

All years noted in Quaternary units (Q_) are Carbon-14 years unless otherwise noted.

Qh **Human disturbance** (Historical) - Material used in and near the Deer Creek, Strawberry, and Currant Creek dams; fill along U.S. Interstate highway 15, U.S. Highway 189 in Provo Canyon, and U.S. Highway 6 in Spanish Fork Canyon; fill at the former Geneva Steel plant (near the town of Vineyard) and slag heap south of Provo; larger sand and gravel pits; several sewage lagoons and landfills; debris basins at the mouths of numerous Canyons; Keigley Quarry waste rock and fill that obscures the underlying geology of southern West Mountain; only the largest deposits are mapped. Faults in unit shown as exposed (solid) where scarps are not entirely obscured.

Qa **Alluvium, undivided** (Quaternary) - Sand, silt, clay, and gravel in stream and alluvial-fan deposits; composition depends on source area; in Spanish Fork Canyon mapped alluvium is pre-latest Pleistocene Lake Bonneville, lip of upper surface at least 120 feet (40 m) above active stream, and 0 to 20 feet (0-6 m) thick; in Bridal Veil Falls quadrangle the alluvium is about 160 feet (50 m) above active stream, about 160 feet (50 m) thick, and is about the same age as latest Pleistocene (Pinedale age) glacial outwash (Qgap). Also on broad surfaces on top of Cretaceous bedrock, 0 to 240 feet (0-75 m) above tributaries to Currant Creek, upstream from Currant Creek Reservoir; may be partly glacial outwash; 0 to 50 feet (0-15 m) thick.

Qay **Younger alluvium** (Holocene and upper Pleistocene) - Mapped in Utah Valley as undivided post-Provo shoreline (younger) alluvial fan (Qafy) and terrace (Qat2) alluvium; likely less than 50 feet (15 m) thick. In Heber Valley, moderately sorted sand, silt, and gravel forming a broad planar surface; age constrained by local veneer of loess or alluvium, and stage II (Birkeland and others, 1991) soil carbonate development; in part deposited as glacial outwash in braided streams and therefore mostly late Pleistocene in age; borehole data indicate up to about 450 feet (140 m) thickness of fill in Heber Valley (Qay+Qao), and thicknesses about 100 feet (30 m) less than estimate from gravity data for same locations (see Peterson, 1970).

Qam **Middle alluvium** (upper Pleistocene) - Variably sorted, unconsolidated silt, sand, and gravel deposited by streams and in alluvial fans; mapped on sloping benches 120 to 240 feet (35-70 m) above active drainages in Wallsburg Ridge, Two Tom Hill, and Granger Mountain quadrangles, thinner and 160 to 300 feet (50-90 m) above active drainages in Aspen Grove quadrangle; estimated thickness 20 to 80 feet (5-25 m).

Qao **Older alluvium** (middle and lower Pleistocene) - Moderately sorted, unconsolidated sand and silt with lenses of pebbles and cobbles; clasts are subrounded to rounded Oquirrh Formation and minor intermediate volcanic rock, likely Keetley Volcanics;

mapped about 300 feet (90 m) above Provo River (now obscured by Deer Creek Reservoir) in what is likely a paleo-meander (QTa of Biek and others, 2003); 0 to about 30 feet (0-9 m) thick; Sullivan and others (1988) suggested these deposits are older than 730 ka; similar small exposure in Daniels Canyon, Center Creek quadrangle, is 300 to 400 feet (90-120 m) above drainage.

Qal **Stream and floodplain alluvium** (Holocene) - Sand, silt, clay, and gravel in channels and floodplains; composition depends on source area; 0 to 20 feet (0-6 m) thick. Locally underlain by and interbedded with spring tufa in western Heber Valley.

Qat, Qat1, Qat2, Qat3, Qaty

Stream-terrace alluvium (Holocene and upper Pleistocene) - Sand, silt, clay, and gravel in terraces above floodplains; Qat where undivided; number suffixes apply to local drainages with multiple terrace levels with lowest (youngest) terraces labeled 2; Qat2 surfaces typically 10 to 35 feet (3-11 m) above adjacent drainage while Qat3 surfaces typically 35 to 60 or more feet (11-18+ m) above adjacent drainage; 0 to 45 feet (0-14 m) thick. In the Springville and Spanish Fork Peak quadrangles, Qat1 are 5 to 15 feet (1.5-5 m) above modern streams, Qat2 are 30 to 40 feet (9-12 m) above, and Qat3 are 40 to 50 feet (12-15 m) above and postdate the regressive Lake Bonneville fan-deltas (Qfdp); Qaty used where terrace level indeterminate or where terraces of different levels are too small to show separately at map scale; however, partly glacial outwash in Center Creek quadrangle.

Qaf **Alluvial-fan deposits, undivided** (Holocene and upper[?] Pleistocene) - Mostly sand, silt, and gravel that is poorly stratified and poorly sorted; typically deposited at drainage mouths; used where age(s) of fans uncertain; generally less than 40 feet (12 m) thick.

Qafy **Younger alluvial-fan deposits** (Holocene and upper Pleistocene) - Mostly sand, silt, and gravel that is poorly stratified and poorly sorted; deposited at drainage mouths; Qafy fans are mostly Holocene and cover Lake Bonneville deposits or deflect stream channels; generally less than 40 feet (12 m) thick.

Qaf3 **Lake Bonneville-age alluvial fan deposits** (upper Pleistocene) - Deposits similar to Qafy but incised by active drainages and Qafy fans are inset into Qaf3 fans; includes fans related to Bonneville and transgressive shorelines (Qafb), as well as Provo and regressive shoreline (Qafp); generally less than 40 feet (12 m) thick.

Qafp **Regressive (Provo) Lake Bonneville-age alluvial fan deposits** (upper Pleistocene) - Deposits similar to Qafy but incised by active drainages and extend below the Provo shoreline; exposed thickness less than 30 feet (10 m) in the Springville quadrangle.

Qafb **Transgressive (Bonneville) Lake Bonneville-age alluvial fan deposits** (upper Pleistocene) - Deposits similar to Qafy but incised by active drainages and typically above and extending to the Bonneville shoreline; always above the Provo shoreline; so can be separated from deposits related to the regressive phase of the lake; exposed thickness less than 15 feet (5 m) in the Springville quadrangle.

Qafm **Intermediate-level alluvial-fan deposits** (upper and middle Pleistocene) - Fan remnants found along mountains near Utah Lake and in Round Valley; deposits similar to Qafy, but incised by active drainages and characterized by carbonate-bearing soil horizons (stage II to III of Birkeland and others, 1991); Qafm probably grades laterally in Utah Valley subsurface into lacustrine sediment of the Little Valley lake cycle; based on drainage incision and soil carbonate development, likely correlative to unit Qaf4 of Solomon and Machette (2008); 0 to about 50 feet (0-15 m) thick.

Qafmo **Intermediate and older alluvial-fan deposits, undivided** (Pleistocene) - Fan remnants like Qafm and Qafo around Utah Lake; mapped where fans are poorly exposed or lack characteristic geomorphic expression of Qafm below adjacent Qafo; also shown where fan remnants are too small to show separately at map scale; correlative with Qafo of Machette (1992). In Charleston quadrangle, Qafmo similar to Qafm and Qafo, but development of soil carbonate horizon (stage III of Birkeland and others, 1991) and amount of drainage incision intermediate between Qafm (stage II to III) and Qafo (stage III+ to IV); Qafmo=Qaf3 of Biek and Lowe (2005); 0 to about 50 feet (0-15 m) thick.

Qafo **Older alluvial-fan deposits** (middle and lower Pleistocene) - Poorly sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; present in deeply dissected fan remnants; where mapped along the Wasatch mountain front, only stage II-III soil carbonate development and mostly truncated by Bonneville shoreline of Lake Bonneville; correlative with Qaf5 of Solomon and Machette (2008); thickness probably less than 60 feet (20 m). Machette (1992) reported that his Qaf5 exposed in the Payson Lakes quadrangle contains the Lava Creek B volcanic ash bed (Izett and Wilcox, 1982, Utah locality 9) $^{40}Ar/^{39}Ar$ dated at ~ 640 ka (Lanphere and others, 2002), so is pre-Little Valley lake cycle; probably grade laterally in Utah Valley subsurface into lacustrine sediment of the Pokes Point and older lake cycles (Scott and others, 1983; Machette and Scott, 1988). Qafo in Center Creek quadrangle is 200 feet (60 m) above active drainages, and is up to 240 feet (75 m) above Diamond Fork Creek; Qafo in Charleston quadrangle is not so deeply incised but has stage III+ to IV soil carbonate development.

Qac **Alluvium and colluvium** (Quaternary) - Includes clay- to boulder-size sediment of stream and fan alluvium, colluvium, and, locally, mass-movement deposits; 0 to 20 feet (0-6 m) thick.

Qc **Colluvium** (Quaternary) - Includes slopewash and soil creep; composition depends on local bedrock; generally less than 20 feet (6 m) thick.

Qct **Colluvium and talus, undivided** (Quaternary) - Very poorly sorted angular to subangular debris at the base of and on steep, variably vegetated slopes; sediments include cobbles and boulders and finer-grained interstitial material; deposited principally by rock fall; prominent in cirques in the Wasatch Range, extending downslope to cover glacial deposits; estimate 0-30 feet (0-9 m) thick.

Qmc **Mass-movement and colluvial deposits, undivided** (Quaternary) - Includes landslides and areas of slope wash and soil creep, and locally talus; mapped in areas of subdued morphology and where mass-movement and colluvial deposits cannot be shown separately at map scale; composition depends on local sources; 0 to 40 feet (12 m) thick.

Qmt **Talus deposits** (Holocene and Pleistocene) - Angular debris on and at the base of steep, mostly unvegetated slopes; typically composed of Oquirrh Formation quartzite and form talus cones in Orem quadrangle; in Wasatch Range, locally includes protalus ramparts too small to show separately at map scale; 0 to 30 feet (0-9 m) thick.

Qmd **Debris-cone deposits** (Holocene and Pleistocene) - Mostly angular and coarse debris in cones at the base of steep drainages in Wasatch Range; seems to be mixture of talus and debris flow deposits with some slope wash and creep material; typically composed of Oquirrh Formation fragments; locally likely includes glacial outwash; 0 to 40 feet (0-12 m) thick.

Qmf **Flow deposits** (Quaternary) - Exhibit hummocky internal morphology and distinct hummocky margins; mostly large-scale earthflows in Wasatch Range (on Great Blue Limestone, Manning Canyon Shale, and Tertiary strata) and near Currant Creek (on clay-rich Mesozoic and Tertiary strata); near Provo Canyon deposits grade into mega-breccia (QTmb) of nearly intact bedrock; as much as 200 feet (60 m) thick near Currant Creek and at least that thick near Provo Canyon.

Qmdf **Debris flow deposits** (Holocene and Pleistocene) - Typically poorly sorted with angular to subangular pebbles to boulders in a muddy to sandy matrix; present in fan- to belt-shaped aprons with numerous overlapping levees and channels and originates in Oquirrh Formation; mapped separately from Qmf, Qmd, Qms, and Qaf because distinct levees and channels are visible; estimate 60 feet (18 m) thick.

Qms, Qmsy, Qmso

Landslides (Quaternary) - Poorly sorted clay- to boulder-sized material; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced bedrock; includes slump and flow deposits; morphology becomes subdued with age; divided into younger (Holocene) and older deposits where possible (suffixes y and o, respectively); bedrock units most susceptible to mass movements include the Tertiary Moroni Formation (Tm), Keetley Volcanics (Tk, Tkt), volcaniclastic rocks of Strawberry

Valley (Tvc), Uinta Formation (Tu and Tucg), Currant Creek Formation (TKc), clay-rich Mesozoic rocks (Kmv, TRa), Manning Canyon Shale (Mmc), and shaly strata in the Great Blue Limestone (Mgb); glacial deposits (various Qg units) are also highly susceptible; thicknesses highly variable. Large blocks of bedrock in landslides are mapped separately with the bedrock unit in parentheses in the label - Qms(rock unit); Qms queried where block may be in-place bedrock.

Qml? **Lateral-spread deposits?** (Holocene to upper Pleistocene) - Pebbly sand, sand, silt, and clay below (post-dating) the Provo shoreline, typically with scarps mapped; thickness probably less than 50 feet (15 m). Lateral spreads occur during earthquake ground shaking. Mapped and queried by Miller (1982) in Utah Valley, and named the Beer Creek and Springville/Spanish Fork features by Harty and Lowe (2003); both features were mapped by Machette (1992), who removed the query, although Harty and Lowe (2003) were unsure of their origin.

Qmg **Mass-movement and glacial deposits, undivided** (Holocene and upper Pleistocene) - Glacial deposits (see unit Qg description) in displaced landslide masses in northeast part of map area and in Wasatch Range; includes displaced bedrock in the lobate mass on the north side of Lake Creek drainage, Heber Mountain quadrangle; landslide masses originated in and above glacial deposits; locally includes small wet depressions in which younger sediment has accumulated; up to 300 feet (90 m) thick.

Qg, Qgm, Qga

Glacial deposits, undivided (Holocene and upper and middle Pleistocene) - Includes till (moraine deposits) and outwash of various ages, but mostly Pinedale age; till is non-stratified, poorly sorted clay, silt, sand, cobbles, and boulders and is mapped as Qgm (moraines) where distinct shapes of end, recessional, and lateral moraines are visible; outwash (Qga) is stratified and variably sorted, but better sorted and bedded than till due to alluvial reworking; Qga mapped directly downslope from other glacial deposits where thick enough to obscure older deposits and bedrock, and where it can be separated from ground moraine (mapped as Qg) and alluvium (various Qa); all glacial deposits locally include mass-movement deposits (Qms, Qmt, Qct) and rock glaciers (Qgr) too small to show at map scale; estimate 0-150 feet (0-45 m) thick. Queried where glacial origin uncertain due to low elevation, such as on west slope of Mount Timpanogos.

Qgr **Rock glacier deposits** (upper? Pleistocene) - Angular, mostly cobble- to boulder-sized debris with little matrix in unvegetated mounds with lobate crests; present in cirques in Wasatch Range; locally includes protalus ramparts; inactive (no ice matrix); may be same age as younger glacial deposits (Qgy), youngest deposits seem to be where snowfield is shown by Baker and Crittenden (1961); likely 0 to 30 feet (0-9 m) thick.

Qgy **Younger glacial deposits** (Holocene and uppermost Pleistocene) - Non-stratified, poorly sorted clay, silt, sand, cobbles, and boulders in cirque basins; clasts are angular and derived from headwall bedrock sources; generally characterized by sharp, mostly non-vegetated moraines and very poor soil development; likely includes lower and possibly middle Holocene deposits (see Madsen and Currey, 1979); includes unmapped arcuate ridge in talus that might be Little Ice Age end moraine in Cascade Cirque (formerly Big Provo Hole cirque); 0 to 50 feet (0-15 m) thick.

Qgp, Qgmp, Qgap

Glacial deposits, Pinedale age (upper Pleistocene) - Mapped as undivided deposits (Qgp), till in distinct vegetated moraines (Qgmp), and alluvially reworked outwash (Qgap); see differences under unit Qg; till has weak soil development and mapped moraines show moderate to sharp morphology; up slope includes mostly vegetated recessional deposits from glacial stillstands and/or minor advances (deglacial pauses) (see Madsen and Currey, 1979); locally include small wet depressions in which younger sediment has accumulated; 0 to 150 feet (0-46 m) thick.

Qgo, Qgmo, Qgao

Older glacial deposits (upper and middle? Pleistocene) - Mapped down drainage from and locally laterally above Pinedale deposits; shown as undivided deposits (Qgo), till in distinct vegetated moraines (Qgmo), and alluvially reworked outwash (Qgao); see differences under unit Qg; till has well-developed soil and mapped moraines have subdued morphology; age uncertain, may be older Pinedale deposits (see Madsen and Currey, 1979) or could be Bull Lake equivalent in age (~Little Valley Lake cycle) (Scott and others, 1983; Phillips and others, 1997); 0 to 150 feet (0-45 m) thick (see Biek, 2005b).

Qfdp **Lake Bonneville alluvial-fan and delta deposits, related to regression** (uppermost Pleistocene) - Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where Provo shoreline is obscure, so that line cannot be drawn between fan and delta; typically better sorted delta and lake deposits under poorly sorted regressive alluvial-fan deposits; mapped at the mouth of Dry Canyon and best developed at the mouths of Spanish Fork, Provo, and American Fork Canyons; at least 150 feet (45 m) thick.

Qdp **Deltaic deposits near and below Provo shoreline** (uppermost Pleistocene) - Moderately to well-sorted gravel in a matrix of sand and silt; interbedded with thin pebbly sand beds; clasts subrounded to rounded; includes regressional deltas more than a mile down slope from the Provo shoreline; deposited as foreset beds having original dips of 30 to 35 degrees and bottomset beds having original dips of 1 to 5 degrees; commonly capped by an unmapped thin veneer of topset alluvial deposits or by mapped fan-delta deposits (Qfdp) related to regressional (y) shorelines; best exposed in terrace scarps; shown by

Biek (2005b) as Qldp (foreset beds) and Qlap (topset beds); up to 150 feet (45 m) exposed thickness.

Qfdb **Lake Bonneville alluvial-fan and delta deposits, related to transgression** (uppermost Pleistocene) - Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where Bonneville shoreline is obscure, so that line cannot be drawn between fan and delta; typically better sorted delta and lake deposits over poorly sorted transgressive alluvial-fan deposits; mapped at the mouth of Dry Canyon and up Spanish Fork Canyon; at least 150 feet (45 m) thick.

Qdb **Deltaic deposits near Bonneville shoreline** (uppermost Pleistocene) - Mostly rounded gravel and sand deposited in delta at the mouth of American Fork Canyon at and below the Bonneville shoreline of uppermost Pleistocene Lake Bonneville; shown as Qlgb and Qldb by Biek (2005b); also mapped at the mouth of Dry Creek Canyon; up to 150 feet (45 m) exposed thickness.

Qlg **Lacustrine gravel and sand deposits** (uppermost Pleistocene) - Rounded gravel and sand deposited in beaches, typically near and above the Provo shoreline and at and below the Bonneville shoreline of Lake Bonneville; grades into unit Qls; estimate 40 feet (12 m) thick.

Qls **Lacustrine sand deposits** (upper Pleistocene) - Sand and some silt and gravel deposited in beaches, typically in two settings that correspond to transgressive and regressive phases of Lake Bonneville: (1) deposited below the Provo shoreline while the lake was at and regressing from (below) this shoreline, possibly as parts of deltas from several canyons, grading downslope into Qlf; and (2) deposited between the Provo and Bonneville shorelines of Lake Bonneville as the lake transgressed to and was at the Bonneville shoreline; estimate up to 200 feet (60 m) thick in Orem quadrangle. Locally includes Holocene eolian deposits that cannot be mapped separately because they grade imperceptibly into sandy lacustrine deposits (Qls) that are reworked by wind, in particular near the former Geneva Steel plant; thickness less than 10 feet (3 m).

Qlf **Fine-grained lacustrine deposits** (upper Pleistocene) - Silt and clay with some fine-grained sand; weathers to unstratified appearance but typically laminated; grades upslope into sandier and gravelly lacustrine and deltaic deposits; above the Provo shoreline, age is that of transgression and Bonneville shoreline; below Provo shoreline and slightly younger shorelines, age likely that of Lake Bonneville regression; likely less than 40 feet (12 m) thick.

Qll **Lagoon-fill deposits** (upper Pleistocene) - Silt and clay, with minor fine sand and pebbles; occupy level ground or closed depressions behind Lake Bonneville bars and barrier beaches; at least locally includes wind-blown and alluvial veneer; maximum thickness about 10 feet (3 m).

Qly **Young lacustrine deposits** (Holocene to upper Pleistocene?) - Silt, clay, and sand deposited along the margin of Utah Lake; mapped near and below the Utah Lake highstand elevation; forms sandy and locally pebbly beach and berm deposits at and below the Utah Lake high stand; between berms locally organic rich because unit includes small areas of spring and marsh deposits and mixed lacustrine and alluvial deposits; overlies sediments of the Bonneville lake cycle; thickness 0 to 20 feet (0-6 m). Brimhall and others (1975) reported that Holocene gray clayey silt composed mostly of calcite forms the upper 15 to 30 feet (5-10 m) of the sediments in Utah Lake. Qly includes white to light-gray, calcareous tufa that is spongy to dense and can contain mollusk shells; typically less than 1 foot (0.3 m) thick; tufa was reported on Rock (Bird) Island and below the Utah Lake highstand near Lincoln Point by Bissell (1963).

Qla **Lacustrine and alluvial deposits, undivided** (Holocene and upper Pleistocene) - Sand, silt, and clay in areas of mixed alluvial and lacustrine deposits that are undifferentiated because the units change imperceptibly into one another; likely stream and fan alluvium deposited during transgression of Lake Bonneville, overlain by thin Lake Bonneville deposits with post-Bonneville alluvium reworked from and on some lacustrine deposits; thickness typically less than 10 feet (3 m), but may be up to 40 feet (12 m) thick along the Jordan River.

Qes **Eolian sand** (Holocene and uppermost Pleistocene) - Moderately to well sorted, very fine to medium sand, with minor silt and clay; calcareous, loose to moderately firm where cemented by secondary calcium carbonate; forms thin sheets and small dunes in Utah and Goshen Valleys; typically derived from Lake Bonneville beach sand (Qls); dunes are from 3 to 10 feet (1-3 m) tall and sheets are 3 to 5 feet (1-1.5 m) thick.

Qst **Spring tufa deposits** (Holocene and Pleistocene) - Largely concealed by and interfingering with Heber Valley fill, so mapped as Qa/Qst (Qst typically exposed only at major springs); tufa is highly porous, pale yellowish gray, tan weathering calcium carbonate; present as beds in valley fill to depths greater than 150 feet (45 m) (Biek and Lowe, 2005). Also mapped along Wasatch fault zone in Timpanogos Cave quadrangle where it is calcareous tufa of uncertain origin, might be spring or Lake Bonneville tufa; thickness uncertain.

Qsm **Spring and marsh deposits** (Holocene to upper Pleistocene?) - Fine, organic-rich sediment associated with springs, ponds, seeps, and wetlands in Utah and Goshen Valleys; commonly wet, but seasonally dry; may locally contain peat deposits as thick as 3 feet (1 m); includes areas of mixed marsh and fine-grained Lake Bonneville deposits

(Qlf); overlies and grades into unit Qlf; present where water table is high; thickness commonly less than 10 feet (3 m).

Qrc **Residuum and colluvium** (Quaternary) - Poorly sorted clay- to boulder- sized, locally derived material; typically mapped on north-facing, vegetated slopes where bedrock and contacts are concealed; 0 to about 15 feet (0-5 m) thick. Only mapped in Center Creek and Twin Peaks quadrangles.

QTst **Spring deposits** (Pleistocene and Pliocene?) - White calcareous tufa and travertine in laminated, typically very thick beds; present just below Bonneville shoreline near Jordan Narrows and partly covered by lacustrine sand and gravel deposits (Qlg); as much as 30 feet (0-10 m) thick.

QTa **High-level alluvium** (lower Pleistocene and/or Pliocene?) - Clay- to boulder-size, locally derived material on gently sloping surfaces 300 to 600 feet (90-180 m) above adjacent drainages in Wallsburg Ridge, Center Creek, and Lehi quadrangles; may be younger than QTaf; estimate 0 to 50 feet (0-15 m) thick, but appears more than 200 feet (60 m) thick in Lehi quadrangle.

QTaf **High-level alluvial fans** (lower Pleistocene and Pliocene?) - Poorly sorted, clay- to boulder-size, locally derived material in gently sloping fan remnants as low as 450 feet (140 m) above and up to 800 to 1500 feet (245-460 m) above Daniels Canyon, Center Creek quadrangle (Biek and others, 2003); 0 to 50 feet (0-15 m) thick. Near Cummings Flat, mixed-clast (Oquirrh Formation & volcanic rocks) deposits reflect nearby Keetley Volcanic rocks (Tk).

QTmb **Megabreccia** (Pleistocene and Pliocene?) - Mostly formed during displacement on underlying Manning Canyon Shale near the mouth of Provo Canyon and in the upper reaches of Provo Canyon at the south end of North Fork Ridge; ranges from nearly intact brecciated bedrock masses to mega-blocks to large blocks; mapped as younger Quaternary landslide and flow deposits (Qms, Qmf) where blocks are smaller and are "floating" in rubble; shown as complex thrust faulting in previous mapping (see Baker, 1964a, 1972a).

Taf **Tertiary alluvial-fan deposits** (Pliocene?) - Poorly to moderately sorted, clay- to boulder-sized material that is poorly exposed in northwest end of Round Valley graben, Charleston quadrangle; age based on less dissection than Tibble Formation; clasts weathering out of material are subangular sandstone and limestone of adjacent Oquirrh Formation; unit may be alluvial-fan deposits (age like QTa), colluvium, and regolith that mantle the Bear Canyon Member of the Oquirrh Formation; queried on slope that may be colluvium and regolith cover; estimate 0 to 650 feet (0-200 m) thick (Biek and Lowe, 2005). Not equivalent to Taf of Biek (2005b); his Taf is here mapped as Tibble Formation.

Tsl **Salt Lake Formation** (Pliocene and Miocene?) - Includes conglomeratic and lower tuffaceous lithologies; typically poorly exposed. At Jordan Narrows upper lithosome is light-brown to reddish-brown mudstone, siltstone, and lesser fine-grained sandstone and pebble conglomerate about 450+ feet (135 m) thick; lower lithosome is white to light-gray tuffaceous marlstone and micrite, lesser limestone, minor claystone, sandstone, and rhyolitic tuff; lower lithosome includes thin volcanic ash (tuff) beds composed almost entirely of glass shards; about 1500 feet (500 m) thick. Near Payson, outcrops are conglomerate, with quartzite, limestone and volcanic clasts, and volcaniclastic sandstone.

Tb **Mosida Basalt** (Miocene) - Medium-dark-gray, porphyritic, trachybasalt lava flow; phenocrysts of olivine, plagioclase, and clinopyroxene; unexposed vent near Soldiers Pass; $^{40}Ar/^{39}Ar$ ages of 19.47 $\pm$ 0.14 and 19.65 $\pm$ 0.17 Ma (table 1); 0 to 120 feet (35 m) thick (Christiansen and others, 2007).

Tic, Tict

Little Cottonwood Stock (Oligocene) - Porphyritic quartz monzonite with potassium feldspar phenocrysts 1 to 3 inches (2.5-7.5 cm) in diameter in a holocrystalline, medium-grained groundmass of plagioclase, quartz, and orthoclase and some biotite and hornblende; intrusive age based on U-Pb zircon analysis is 30.5 $\pm$ 0.6 Ma (Vogel and others, 1997, table 2; Constenius, 1998). Tict used for tectonite of altered and fractured rock along faulted carapace of stock.

Tvtw **Volcanic rocks of west Traverse Mountains** (Oligocene) - Volcanic debris flow/lahar breccia and tuff, lesser lava flows and ash-flow tuffs, and minor fluvial volcanic-sedimentary rocks; intermediate composition; probable age range of 31 to 33 Ma (Waite and others, 1997); plagioclase $^{40}Ar/^{39}Ar$ age 32.12 $\pm$ 0.14 Ma in adjacent Tickville Spring quadrangle (Deino and Keith, 1997, TICK-28); probably from local vents including the Step Mountain andesite plug, South Mountain area, and other smaller vents; 1000+ feet (300+ m) thick.

Tsp **Soldiers Pass Formation, undivided** (lower Oligocene - upper Eocene) - Part of the Soldiers Pass volcanic field; upper part of shoshonitic brecciated lava with coeval lacustrine limestone and claystone (breccia member and White Knoll Member); intermediate lava flow (andesite member); rhyolitic ash-flow tuff with abundant pumice fragments (Chimney Rock Pass Tuff Member); lowest part is trachydacite tuff member; $^{40}Ar/^{39}Ar$ ages from 33.73 $\pm$ 0.65 to 34.79 $\pm$ 0.10 Ma (table 1); 0 to about 500 feet (150 m) thick (Christiansen and others, 2007).

Ti **Intrusive rocks** (Miocene - Oligocene) - Biotite-bearing, dark-gray, medium- to fine-grained quartz diorite (Baker, 1976) that intrudes Granger Mountain Member of Oquirrh Formation and probably the Uinta Formation (middle Eocene); $^{40}Ar/^{39}Ar$ biotite age of 34.7 ± 0.16 Ma (sample KNC90299-1, table 1) puts the intrusion in the age range of volcanic rocks in map area (table 1) and the older potassic mafic rocks (lamproites) to the north (34-35 Ma) (Mitchell and Bergman, 1991); exposure is in Second Set Canyon south wall (section 12, T. 6 S., R. 5 E., Twin Peaks quadrangle) and is several hundred feet wide and about 1500 feet (460 m) long, elongate to the northwest.

Tt **Tibble Formation** (lower Miocene?, Oligocene, and upper Eocene) - Brick-red, red-brown, and gray, cobble to boulder conglomerate; lithic clasts predominantly Pennsylvanian-Permian sandstone and quartzite, but in upper Tibble in type area include Paleozoic clasts from footwall of the Deer Creek detachment and volcanic clasts; largest boulders about 6 feet (2 m) across; intercalated with variegated brick-red and gray mudstone, bentonitic mudstone, and poorly sorted sandstone; minor white to light-gray tuffaceous sandstone and medium-gray microcrystalline limestone; rare thin beds of light-gray tuff; the Tibble is an extensional basin-fill deposit that overlies with angular unconformity, and is in fault contact with, pre-Tertiary hanging-wall rocks of the Charleston-Nebo thrust sheet; mapped in grabens in Granger Mountain, Springville, Timpanogos Cave, Aspen Grove, Lehi, and Jordan Narrows quadrangles; fossiliferous, "soft" weathering, gray shale in Pole Heaven valley, Springville quadrangle, yielded an early Miocene-Oligocene gastropod fauna (KNC052304-5); $^{40}Ar/^{39}Ar$ biotite age of 36.56 ± 0.15 Ma and U-Pb zircon age of 36.1 ± 1.7 Ma on tuff bed in Timpanogos Cave quadrangle (KNC61093-2T, tables 1 and 2); U-Pb zircon age of 33.7 ± 0.6 Ma on tuff in Granger Mountain quadrangle (KNC053107-3, table 2); thickness 0 to 2500 feet (0-760 m).

May be age-equivalent of upper Eocene-lower Oligocene and Miocene non-conglomeratic strata (Gerald Waanders, consulting palynologist, 2008, written communication) encountered below about 10,000 feet (3000 m) in Gulf Banks well in Utah Valley near Spanish Fork.

Tvb **Boulder conglomerate** (Oligocene and upper Eocene?) - Conglomerate with clasts of volcanic rocks, quartzite, and lesser dolomite and limestone in a matrix of light-gray volcanic ash and sand; age, source and correlation unknown, but clasts are similar to strata exposed in the East Tintic Mountains; present near mouth of Payson Canyon; 400+ feet (120+ m) thick (Solomon and others, 2007).

Tvte **Volcanic rocks of East Traverse Mountains** (Oligocene - upper Eocene) - Interbedded ash-flow tuff, volcanic debris flow/lahar breccia, minor lava flows, and minor fluvial volcano-sedimentary rocks; intermediate composition, poorly exposed and locally extensively altered; chemically similar to the Keetley Volcanics and some intrusions in the Wasatch igneous belt; probable age range of 33 to 39 Ma; $^{40}Ar/^{39}Ar$ age of 35.25 ±

0.13 Ma from Maple Hollow (table 1) (Biek, 2005b); about 1000 feet (300 m) thick. Includes younger pebble dikes that cut these rocks. Includes volcaniclastic rocks in Tibble graben with U-Pb zircon age of 35.7 ± 0.6 Ma on andesite porphyry in Timpanogos Cave quadrangle (KNC060407-14, table 2); thickness uncertain, confined to graben.

Tm **Moroni Formation** (Oligocene - upper Eocene) - Very light gray, gray, and white, tuffaceous and pumiceous sandstone and tuff interbedded with lesser conglomerate, pumice, welded tuff, and limestone; conglomerate clasts vary from pebbles and cobbles to small boulders (~20 inches [0.5 m]); sedimentary clasts from Permian-Pennsylvanian Oquirrh Formation, Permian Diamond Creek Sandstone and Park City Formation, and Cambrian Tintic Quartzite; volcanic clasts predominantly gray to very dark-gray, reddish brown-weathering andesite-dacite porphyry; tuffs and tuffaceous sandstones poorly exposed, conglomerate bed in lower part of unit is ledge forming and about 65 feet (20 m) thick; formation rests unconformably on Tu; top removed by erosion, 0 to an estimated 1800 feet (~550 m) thick; mapped as Tibble Formation by Young (1976) and called Wanrhodes volcanics by Neighbor (1959); like Tibble is extensional graben-fill, but contains more volcanic material than Tibble (see above); samples KNC71194-5, KNC101701-1, and KNC101701-4 from Billies Mountain quadrangle were $^{40}Ar/^{39}Ar$ dated at 34.68 ± 0.09, 34.86 ± 0.09, and 37.18 ± 0.38 Ma, respectively (table 1).

Tk **Keetley Volcanics** (Oligocene? - upper Eocene) - Volcanic breccia and conglomerate in upper part, interbedded volcanic conglomerate and minor light-gray tuffaceous sandstone in lower 300 feet (90 m); volcanic clasts are andesite to rhyodacite; conglomerate has light-orange and gray, coarse sandstone matrix and locally contains orthoquartzite, sandstone, and limestone boulders to pebbles; tuffaceous sandstone is light gray, coarse grained to pebbly, and trough cross-bedded; sample KNC92799-5 from Co-op Creek quadrangle yielded an $^{40}Ar/^{39}Ar$ age of 40.45 ± 0.18 Ma (table 1); 0 to more than 1400 feet (0-430+ m) thick. Includes mixed (Oquirrh and volcanic rock) clast unit Ta of Biek and others (2003). Keetley Volcanic units were previously K-Ar (biotite) dated by Crittenden and others (1973) at 34.0 ± 1.0 Ma for a sample (62-mc-15) from the Wolf Creek Summit quadrangle in the map area; they also reported K-Ar biotite ages of 35.1 ± 1.1 and 32.7 ± 1.0 Ma for other Keetley Volcanic units to the north of the Provo 30x60-minute quadrangle near Jordanelle and Francis, respectively.

Tkq **Keetley Volcanics, quartzite clast unit** (Oligocene? - upper Eocene) - Gray tuffaceous volcanic sandstone matrix with granules to boulders of Oquirrh Formation quartzite and some limestone; locally contains Mesozoic rock clasts from sand to gravel size that form sedimentary sandstone and sandstone matrix; only mapped separately in the Center Creek quadrangle where it is distinct because it lacks volcanic clasts; 0 to about 450 feet (0-140 m) thick, but thickness may include interbedded volcanic strata.

Tkt **Keetley Volcanics, basal tuffaceous unit** (Oligocene? - upper Eocene) - Very light gray to greenish-gray tuff and tuffaceous sandstone and pebbly sandstone; rarely exposed; sample KNC92799-6 from Co-op Creek quadrangle yielded an $^{40}Ar/^{39}Ar$ age of 37.25±0.14 Ma (table 1); another sample (KNC6901-1), from near Peoa, Utah, yielded an $^{40}Ar/^{39}Ar$ age of 38.20 ± 0.11 Ma (Constenius and others, 2003); 0 to about 200 feet (0-60 m) thick in northeast part of map area; may be as much as 800 feet (240 m) thick in Center Creek quadrangle if bedding dip in area is minimal (after Biek and others, 2003).

Tvc **Volcaniclastic rocks of Strawberry Valley** (Oligocene? - upper Eocene) - Upper part is tan to orange and gray conglomerate and coarse-grained sandstone; conglomerate contains quartzite cobbles to small boulders with sandstone, limestone, and volcanic clasts locally present. Lower part is light-gray, boulder to cobble conglomerate with quartzite and andesite to rhyodacite clasts in a coarse to pebbly sandstone matrix; interbedded with light-gray, coarse-grained, cross-bedded, tuffaceous sandstone. Correlative northward to Keetley Volcanics and possibly southward to Moroni Formation; sample KNC92899-2 from Co-op Creek quadrangle was $^{40}Ar/^{39}Ar$ dated at 37.73 ± 0.28 Ma (table 1); at least 1500 feet (460 m) thick, with top not exposed.

Tucb **Uinta Formation, boulder conglomerate** (late middle Eocene) - Red-brown and gray, thick- to very thick bedded conglomerate, commonly stained red by weathering of interbedded, thin, red-brown and brick red mudstone; extremely coarse clastic unit composed mainly of cobbles and boulders, some very large (3 to 10 feet [1-3 m] diameter); quartzite clasts derived from Permian-Pennsylvanian Oquirrh Formation predominate, with Precambrian Uinta Mountain Group, Cambrian Tintic Quartzite, Pennsylvanian Weber Formation, Permian Park City Formation, Triassic Thaynes Formation, and Jurassic Twin Creek Limestone lithic clasts locally present in the Red Ledge (eastern Co-op Creek quadrangle) and White Ledge (southeast Wolf Creek Summit quadrangle) areas; sandstone occurs as minor intercalated lenses of coarse- to very coarse grained, brick-red to red-brown sandstone; mudstone is brick red to red brown and forms thin partings between ledges of conglomerate; partings of bentonite are found at White Ledge locality between light-gray, buff weathering beds of cobble-boulder conglomerate; unit found above ~8800’ capping landscape prominences in the Twin Peaks, Co-op Creek, and Wolf Creek Summit quadrangles; overlies conglomerate member of Uinta Formation; samples KNC070109-1 and KNC070109-2 from White Ledge in Wolf Creek Summit quadrangle yielded a U-Pb zircon ages of 38.9 ± 0.8 Ma and 39.6 ± 0.7 Ma, respectively (table 2); preserved thickness ranges from about 500 to 900 feet (150-275 m).

Tuc **Uinta Formation, conglomerate** (middle Eocene) - Red-brown, tan and gray, thick- to very thick bedded pebble-cobble conglomerate interbedded with minor sandstone, commonly stained red by weathering of interbedded, thin, red-brown mudstone; quartzite clasts predominantly derived from Permian-Pennsylvanian Oquirrh Formation; sandstone is subordinate to conglomerate and occurs as intercalated lenses of coarse- to very coarse grained, brick-red to red-brown sandstone; mudstone is brick red to red brown and forms thin partings between ledges of conglomerate; interfingers with the main body of the Uinta Formation eastward and southward over short distances; up to 1500 feet (460 m) thick.

Tu **Uinta Formation, main body** (middle Eocene) - Includes: (1) light-gray, tan, and red, medium- to thick-bedded, lenticular-bedded, pebbly sandstone; (2) brick-red, reddish-brown, variegated, very thick to thin-bedded mudstone, commonly with floating sand grains; (3) red-brown, tan, and gray conglomerate with sandstone to mudstone matrix; and (4) dark-gray to yellowish- and purplish-gray marlstone of probable pedogenic origin; interfingers northward with overlying Tuc and underlying Tuc; also interfingers westward with overlying Tuc; at least 2000 feet (600 m) exposed.

Tgu **Green River Formation, upper member** (middle Eocene) - Sandstone, siltstone, mudstone, marlstone, and minor oil shale. Sandstone is light gray, light-brown-weathering, calcareous, and medium to thick bedded; some beds are trough cross-stratified and fine to medium grained, grading to siltstone; occasionally coarse-grained to conglomeratic. Marlstone is dark gray, weathering to light tan, light gray, or gray, thin to thick bedded, and microcrystalline. Mudstone is predominantly greenish gray to dark gray and poorly exposed. Oil shale is rare, grayish brown to dark brown, and fissile. Sandstone and marlstone form steep slopes and cliffs, with thin benches along oil shale and mudstone horizons. More than 400 feet (120 m) thick at Island Mountain where the base of the unit is not exposed. Unit progressively truncated and is completely removed by erosion to the west in the Billies Mountain and Two Tom Hill quadrangles along the basal Uinta Formation unconformity.

Tgm **Green River Formation, middle member** (middle Eocene) - Lower part is dominantly dark-brown, light-bluish-gray-weathering, fissile to platy, thinly laminated oil shale and marlstone; upper part is mostly greenish-gray and gray mudstone, gray siltstone, and tan, fine- to medium-grained sandstone; distinctive small steel-blue to dark-bluish-gray concretions throughout; at least 2200 feet (670 m) thick in complete sections. Unit progressively truncated and is completely removed by erosion to the west in the Billies Mountain and Two Tom Hill quadrangles along the basal Uinta Formation unconformity.

Tgl **Green River Formation, lower member** (middle Eocene) - Greenish-gray, fissile to blocky shale and mudstone as very thick beds separated by thinly laminated, gray marlstone; also contains gray-green, waxy-textured claystone and thin-bedded, brown-weathering sandstone that is locally micaceous; sandstone contains rare vertebrate fossils as lags (gar scales, turtle and crocodile plates); oil shale is common near base; at least 1200 feet (365 m) thick in complete sections. Unit progressively truncated and is completely removed by erosion to the west in the Billies Mountain and Two Tom Hill quadrangles along the basal Uinta Formation unconformity.

Tc **Colton Formation** (lower Eocene) - Medium- to coarse-grained, light-gray, light-brown-weathering, calcareous sandstone in thin to thick beds; interbedded with medium-gray, microcrystalline limestone, and red-brown, gray and gray-green mudstone; top of formation in Rays Valley quadrangle is at the top of an extremely fossiliferous sandstone bed containing *Unionidae* bivalves, gastropods, and vertebrate fossils (gar scales, crocodile teeth, crocodile and turtle plates and bones); about 170 feet (50) m thick.

Tf **Flagstaff Limestone** (lower Eocene) - Medium-gray, very thick bedded, microcrystalline limestone; weathers white and light gray; hard and brittle; forms cliffs; interbedded with less-resistant, variegated brick-red, purplish-gray, maroon, red-brown, yellow and gray marlstone and calcareous mudstone; light-gray, thin- to medium-bedded, medium- to coarse-grained sandstone increases in abundance up section; about 280 feet (85 m) thick.

Ts **Tertiary sedimentary rocks** (Eocene? and/or Paleocene?) - Red-orange mudstone, gray conglomerate, light brown limestone; conglomerate with pebbles to boulders of quartzite and limestone; locally includes oncolitic and algal limestone that is medium to irregularly bedded; caps West Mountain and exposed at mouth of Payson Canyon; up to 240 feet (75 m) thick (Clark, 2009).

Tn **North Horn Formation, upper member** (lower Eocene - upper Paleocene) - Brick-red, thick- to very thick bedded mudstone, siltstone, and sandstone; interbedded with very thick bedded, medium-gray-weathering, microcrystalline limestone; upper limestone beds contain fossil gastropods and bivalves that date the unit (see Constenius, 2008); conglomerate locally present as thick, lenticular, channel-fill deposits containing pebbles to rare boulders of Permian-Pennsylvanian Oquirrh Formation; about 200 feet (60 m) thick. At the mouth of Spanish Fork Canyon, includes brick-red and red-brown sandstone and pebble conglomerate with predominantly clasts of Oquirrh Formation sandstone/quartzite and limestone; exposed thickness 0 to about 400 feet (0-120 m), but up to 780 feet (240 m) thick in subsurface (Constenius, 2008).

TKnq **North Horn Formation, quartzite conglomerate member** (Paleocene and Upper Cretaceous, Maastrichtian) - Light-gray, thick- to very thick bedded, cobble to boulder (up to about 3 feet [1 m] across) conglomerate with dominantly well-rounded, gray and tan quartzite clasts from the Oquirrh Formation; intercalated with light-gray, yellow-tan-weathering, and minor brick-red, medium- to coarse-grained sandstone; limonitic staining common; upper contact conformable with Tn; lower contact is profound angular unconformity with Permian rocks; present in Granger Mountain area; mapped separately from TKn to emphasize clast content, location, and unconformity; 0 to 250 feet (0-75 m) thick.

TKn **North Horn Formation, lower member** (upper Paleocene - Upper Cretaceous, Maastrichtian) - Light- to medium-gray or brick-red or red-brown conglomerate, commonly discolored by red-colored slopewash from thin, interbedded, red mudstone; intercalated with light-gray, yellow-tan weathering, medium-coarse grained sandstone; clasts of Oquirrh Formation sandstone, quartzite, and limestone predominate; palynomorphs from rare lignite and carbonaceous shale indicate a late Paleocene age (see Horton and others, 2004; Constenius, 2008); lower contact is profound unconformity (see also Constenius and others, 2003); at least 1800 feet (550 m) thick.

TKc **Currant Creek Formation** (Paleocene - Upper Cretaceous, Maastrichtian) - Includes: gray- to tan-weathering, thick-bedded, boulder to cobble conglomerate, dominated by well-rounded, quartzite clasts from Oquirrh Formation; gray, yellowish-gray, and minor red, thick-bedded, coarse-grained sandstone and pebble conglomerate; and gray, very light gray and variegated siltstone; only in northeast part of map area; unconformably overlies Mesaverde Formation; about 4800 feet (1460 m) thick near Currant Creek (Bissell, 1952); see also Walton (1944), 4000 feet (1200 m) thick in same area.

Kpc **Price River Formation and Castlegate Sandstone** (Upper Cretaceous, Maastrichtian-Campanian) - Light-gray, thick- to very thick bedded, cobble to boulder conglomerate, dominated by well-rounded, gray and tan, quartzite clasts; largest boulders exceed 10 feet (3 m) across; minor intercalated sandstone; conglomerate contains light silvery-gray sandstone matrix characterized by white, smooth- to earthy-textured, clay blebs; lithic clasts >99% Permian-Pennsylvanian Oquirrh Formation quartzite, quartzite clasts derived from Proterozoic Mutual Formation and Cambrian Tintic Quartzite present in trace amounts; overlain and underlain with angular unconformity by TKn and Kcm (and older units), respectively, where exposed in Billies Mountain area; thickness ranges from 0 to 2000 feet (0 to 600 m).

Kmv **Mesaverde Formation** (Upper Cretaceous) - Light-gray, white, and tan, thick-bedded, cross-bedded, coarse-grained sandstone, gray siltstone, and dark-brownish-gray, carbonaceous shale and coal; 5165 feet (1575 m) thickness measured by Bissell (1952) in Currant Creek drainage.

Km **Mancos Shale** (Upper Cretaceous) - Dark-gray, bentonitic shale with minor gray limestone and gray, fine-grained sandstone; very poorly exposed; 1680 feet (512 m) thickness calculated by Bissell (1952) near Currant Creek Reservoir.

Kf **Frontier Formation** (Upper Cretaceous) - Light-gray, white, and tan, thick-bedded, medium-grained sandstone interbedded with dark-gray siltstone, shale, dark-brownish-gray, carbonaceous shale and minor coal in upper part; contains an oyster coquina marker bed in the lower 50 feet (15 m); extensively burrowed in the middle; about 700 feet (215 m) thick in northeast part of map area (this report; see also Bissell, 1952, his Frontier plus his lower Mancos Shale and limestone at top of his Mowry). Very poorly exposed in Center Creek quadrangle.

Kmm **Mancos Shale, Mowry Shale Tongue** (Lower Cretaceous) - Dark-gray, platy to blocky, fissile, siliceous shale in lower part, with abundant teleost fish scales. Upper part contains non-fissile, greenish-gray claystone; about 90 feet (25 m) thick in northeast part of map area (this report; see units 1-3 of Bissell, 1952).

Kd **Dakota Formation** (Lower Cretaceous) - Sandstone, white to tan, very thick bedded, cross-bedded, with extensive quartz veins; interbedded with gray and variegated siltstone; thickens northward from about 200 to 400 feet (60-120 m) in northeast part of map area (this report; see also Bissell, 1952).

Kcm **Cedar Mountain Formation** (Lower Cretaceous) - Mapped separately in Billies Mountain quadrangle. Variegated greenish-gray, red-brown, and lavender mudstone, interbedded with gray, red, and buff, coarse- to fine-grained sandstone and siltstone; minor nodular limestone and conglomerate; 465 feet (142 m) thick (Young, 1976). Likely includes Morrison Formation strata and unconformity between Cedar Mountain and Morrison.

KJcm **Cedar Mountain** (Lower Cretaceous) **and Morrison** (Upper Jurassic) **Formations, undivided** - **Cedar Mountain**, see above. **Morrison** - Interbedded greenish-gray and light-red siltstone and medium-grained, pinkish-gray sandstone and some pinkish-gray, quartz- and chert-pebble conglomerate and pebbly sandstone in thick, fining-upward, trough-cross-stratified beds; base not exposed; up to 2500 feet (760 m) thick in southeast Heber Mountain quadrangle (this report; see also “Morrison” of Bissell, 1952).

Jsv **Summerville Formation** (Middle Jurassic) - Red-orange mudstone, siltstone, and sandstone; only mapped in Billies Mountain quadrangle and conformably overlies Curtis Formation; see Imlay (1980) for correlation; 395 feet (120 m) thick (Young, 1976).

Js **Stump Formation** (Middle Jurassic) - Light-gray, medium-bedded, calcareous sandstone in lower part; gray to green-gray, thick-bedded, ridge-forming, bioclastic limestone and sandy limestone in upper part; about 250 feet (75 m) thick in Wolf Creek Summit quadrangle.

Jce **Curtis and Entrada Formations, undivided** (Middle Jurassic) - Only mapped in Billies Mountain quadrangle; lateral equivalent of lower (Curtis Member of) Stump and Preuss Formations; see Imlay (1980) for more information. **Curtis** - Greenish-gray, sandy shale, mudstone, and sandstone, with minor dark-red-brown sandstone; about 400 feet (120 m) thick. **Entrada** - Dark-red, red-brown, and purplish red-brown, with minor light-gray and light-brown, thin- to medium-bedded sandstone and siltstone; about 1000 feet (300 m) thick.

Jp **Preuss Formation** (Middle Jurassic) - Red, brownish-red, purplish red, and minor light-gray, thin- to medium-bedded sandstone and siltstone; poorly exposed; about 750 feet (230 m) thick in Wolf Creek Summit quadrangle.

Ja **Arapien Shale** (Middle Jurassic) - Light-gray-green and light-gray shale interbedded with light-gray, tan-weathering, ripple cross-laminated, calcareous siltstone and sandstone; minor interbeds of red shale, light-yellow-gray sandstone, and gray-green to brown, micritic limestone; thickness about 560 feet (170 m); only mapped in Billies Mountain quadrangle, equivalent to unit Jtgl.

Jtc **Twin Creek Limestone, undivided** (Middle Jurassic) - Used in Center Creek quadrangle; Arapien-Twin Creek interval 1200 feet (370 m) thick south of map area in Spanish Fork Canyon (Baker, 1947; Imlay, 1967) and likely about the same thickness here. See correlation chart for map-unit subdivisions.

Jtu **Twin Creek Limestone, upper members** (Middle Jurassic) - Mapped in Co-op Creek and Heber Mountain quadrangles where upper Twin Creek is structurally attenuated and top not exposed; divided into units Jtgl and Jtw elsewhere; estimated undeformed thickness about 650 feet (200 m) from regional relationships.

Jtgl **Twin Creek Limestone, Giraffe Creek and Leeds Creek Members** (Middle Jurassic) - Thinly interbedded, light-gray to light-greenish-gray, soft, shaly limestone and platy weathering, light-gray to tannish-gray, fine-grained calcareous sandstone; sandstone increases upward; a 15-foot-thick (5 m) gypsum bed lies in the middle of the unit; about 500 feet (150 m) thick in Wolf Creek Summit quadrangle and northeast parts of map area.

Jtwl **Twin Creek Limestone, Watton Canyon, Boundary Ridge, Rich, Sliderock, and Gypsum Spring Members** (Middle Jurassic) - Unit only used in Billies Mountain quadrangle where Giraffe Creek and Leeds Creek Members are indistinct and were shown by some workers as the Arapien Shale; about 600 feet (180 m) thick (Imlay, 1980).

Jtw **Twin Creek Limestone, Watton Canyon Member** (Middle Jurassic) – Dark-gray, medium- to thick-bedded, lime micrite to wackestone with oolites and pelecypod fragments; resistant ridge former; micrites display characteristic spaced, bedding-normal fracture cleavage; about 120 feet (35 m) thick in Wolf Creek Summit quadrangle and thicker to west, about 250 feet (75 m) thick in northwest Charleston quadrangle (Biek and Lowe, 2005) and about 350 feet (110 m) thick in east Billies Mountain quadrangle (after Young, 1976).

Jtl **Twin Creek Limestone, lower members** (Middle Jurassic) - Unit used in Co-op Creek and Heber Mountain quadrangles where lower Twin Creek is structurally attenuated; divided into units Jtb and Jtrsg elsewhere; estimated undeformed thickness is about 230 feet (70 m) from regional relationships.

Jtb **Twin Creek Limestone, Boundary Ridge Member** (Middle Jurassic) - Red to purplish-red shale and siltstone, and minor gray siltstone; recessive and poorly exposed; about 65 feet (20 m) thick in Wolf Creek Summit quadrangle and thicker to west, about 120 feet (35 m) thick in northwest Charleston quadrangle (Biek and Lowe, 2005) and 200 feet (60 m) measured in east Billies Mountain quadrangle (Young, 1976).

Jtrsg **Twin Creek Limestone, Rich, Sliderock and Gypsum Spring Members** (Middle Jurassic) - Light-gray, soft, shaly limestone in upper part; dark-gray, thick-bedded, bioclastic limestone in middle, and thin (5-foot [1.5-m] thick) purple shale at base; about 160 feet (50 m) thick in Wolf Creek Summit quadrangle and thicker to west, about 420 feet (125 m) thick in northwest Charleston quadrangle (Biek and Lowe, 2005) and 455 feet (140 m) thick measured in east Billies Mountain quadrangle (Young, 1976).

Jn **Nugget Sandstone** (Lower Jurassic) - Reddish-orange, orange, and pink, massive-weathering, cross-bedded, moderately cemented to friable, noncalcareous, fine- to medium-grained sandstone, with well-rounded commonly frosted grains; Navajo of some previous workers; about 1260 to 1450 feet (385-440 m) thick (this report; Baker, 1947).

TRa **Ankareh Formation** (Upper and Lower[?] Triassic) - Dull-red, reddish-brown and purple, thin-bedded mudstone, siltstone, and medium- to thin-bedded, fine-grained sandstone; siltstone is locally micaceous; green reduction spots common; in Co-op Creek quadrangle, part of the lower Ankareh is included in unit TRat (see below); to the west, Baker (1947) reported a total thickness of 1485 to 1530 feet (453-466 m) in the Wasatch Range; Bissell (1952) measured 1535 feet (468 m) in the Wolf Creek Summit quadrangle.

TRau **Ankareh Formation, upper member** (Upper Triassic) - Red, purplish-red, and reddish-gray, thin-bedded mudstone, siltstone, and fine-grained sandstone; about 350 (110 m) feet thick in Wolf Creek Summit quadrangle and 450 feet (135 m) thick in Aspen Grove quadrangle (Baker, 1964a).

TRam **Ankareh Formation, middle member** (Upper Triassic) - Gray to white, very thick bedded, cross-bedded, coarse-grained sandstone and pebble conglomerate; about 40 feet

(12 m) thick (this report; Baker, 1964a); possibly equivalent to the Gartra Grit Member and called Shinarump by some previous workers (for example Bissell, 1952).

TRal **Ankareh Formation, lower member** (Lower Triassic) - Red and purple siltstone and shale, and purplish-gray, calcareous siltstone; thin bedded throughout; poorly exposed; about 800 feet (245 m) thick in Wolf Creek Summit quadrangle; in Aspen Grove quadrangle, 1000 foot (300 m) thickness reported by Baker (1964a), while Smith (1969) reported 1372 foot (420 m) thickness.

TRat **Lower Ankareh Formation and upper Thaynes Formation, undivided** (Lower Triassic) - Only used in structurally complicated Co-op Creek quadrangle; greenish-gray and very light gray, calcareous sandstone with green clay intraclasts in upper part; white, thinly laminated, well-indurated, calcareous sandstone and micaceous sandstone in lower part; unit contains rocks that are transitional between typical lower Ankareh and upper Thaynes lithologies; U-Pb zircon age of 249 ± 3.0 Ma on tuff from Co-op Creek quadrangle (JC 99-37, table 2) implies tuff is more likely Thaynes Formation age; north of the map area Kummel (1954, figure 21) portrayed the formations as intertonguing; about 350 feet (110 m) thick.

TRt **Thaynes Formation, undivided** (Lower Triassic) - Greenish-gray to brownish-gray, thin-bedded, silty limestone and fine-grained, calcareous sandstone; only used in northeast corner of map area, where top not exposed, and in Billies Mountain quadrangle; subdivided elsewhere. Neighbor (1959) reported a dip-corrected, subsurface thickness of 1450 feet (440 m) in Billies Mountain quadrangle and Baker reported 1340 feet (410 m) thickness measured nearby; in Aspen Grove quadrangle, reportedly only 950 feet (290 m) thick (Baker, 1964a) and 1126 feet (345 m) thick (Smith, 1969). Smith's (1969) members are similar to those used elsewhere in map area; Bissell (1952, only units 1-4) reported 1210 feet (370 m) total thickness.

TRtu **Thaynes Formation, upper member of Smith (1969)** (Lower Triassic) - Gray siltstone with some grayish-green shale and gray limestone; 446 feet (136 m) thick in Aspen Grove quadrangle (Smith, 1969). About 775 feet (235 m) penetrated (not dip corrected) in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished), but high dip. Includes some or all of unit TRat.

TRad **Ankareh Formation, Decker tongue of Smith (1969)** (Lower Triassic) - Poorly exposed dark-red to brownish-red siltstone and silty shale with minor fine-grained sandstone at type area in Aspen Grove quadrangle; 222.5 feet (68 m) thick but may be faulted (Smith, 1969). About 220 and 320 feet (65 and 100 m) penetrated (not dip corrected) in Sun Oil Diamond Fork #2 well and Amoco Cottonwood Canyon well, respectively (after Welsh, 1981, unpublished), but high dip in Amoco well. Smith's

(1969) Decker tongue at Willow Creek, Co-op Creek quadrangle is unit 3 of Bissell (1952).

TRtl **Thaynes Formation, lower member of Smith (1969)** (Lower Triassic) - Gray siltstone and limestone; 457 feet (140 m) thick in Aspen Grove quadrangle (Smith, 1969). About 600 feet (180 m) and 1040 feet (320 m) penetrated (not dip corrected) in Sun Oil Diamond Fork #2 well and Amoco Cottonwood Canyon well, respectively (after Welsh, 1981, unpublished), but moderate dip in Amoco well.

TRtu **Thaynes Formation, upper member** (Lower Triassic) - Dark-gray, bioclastic, lime grainstone; weathers medium blue gray; forms two prominent ridges separated by thin-bedded, dark-gray, silty limestone; about 300 feet (90 m) thick in Co-op Creek area (this report; see also Bissell, 1952, unit 4).

TRtla **Thaynes Formation, lower member, and Ankareh Formation** (Lower Triassic) - Mainly dark-brownish-red, thin- to medium-bedded, calcareous siltstone with rare zones of dark-gray, blue-gray weathering, bioclastic grainstone resembling unit TRtu in lower part; about 1000 feet (300 m) thick in Co-op Creek area, and structurally thickened in Heber Mountain quadrangle (this report; see also Bissell, 1952, units 1-3). Mixed lithologies imply intertongued Thaynes and Ankareh, including unit TRad.

TRw **Woodside Shale** (Lower Triassic) - Dark-red to red-brown shale and siltstone; poorly exposed; forms strike valleys; 420 to 600 to 735 feet (130 to 180 to 233 m) thick in northeast part of map area (this report; Bissell, 1952; Neighbor, 1959; after Smith, 1969). About 870 feet (265 m) and 780 feet (240 m) penetrated (not dip corrected) in Sun Oil Diamond Fork #2 well and Amoco Cottonwood Canyon well, respectively (after Welsh, 1981, unpublished); about 770 feet (235 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (< 8 degrees dip); queried in Wallsburg Ridge quadrangle because, as mapped, unit is less than 200 feet (<60 m) thick. Structurally thinned along Little Diamond Creek fault system, and appears far thinner, less than 200 feet (<60 m) thick, than regional minimum in Wallsburg Ridge quadrangle (hence query); about 500 feet (150 m) thick in Aspen Grove quadrangle (Smith, 1969 after Baker, 1964a).

Thin Paleozoic Strata in Footwall of Charleston-Nebo Thrust System

These strata include thinner exposed versions of Permian and Pennsylvanian rocks (see following), the Pennsylvanian Round Valley Limestone, and the Mississippian Doughnut, Humbug, Deseret, and Gardison Formations (after Huddle and McCann, 1947a,b; Baker and others, 1949; Bissell, 1952), as well as lower Paleozoic strata (Fitchville Formation and/or Devonian rocks and Cambrian Maxfield, Ophir, and Tintic Formations (after Huddle and others, 1951). The Permian and Pennsylvanian strata are likely as thin in subsurface east of Charleston-Nebo thrust faults in the east part of map area (see lithologic column).

Pp **Park City and Phosphoria Formations, undivided** (Permian) - Consists of upper [Franson Member of Park City Formation], middle [Meade Peak Member of Phosphoria Formation] and lower [Grandeur Member of Park City Formation] units that are 352, 60, and 458 feet (107, 18, and 140 m) thick, respectively, just north of the Aspen Grove quadrangle (Baker, 1964a); in Center Creek quadrangle below the Charleston-Nebo thrust in the Placid-Daniels well, same units are about 165, 55, and 405 feet (50, 17, and 123 m) thick; in Wolf Creek quadrangle total thickness reportedly about 450 feet (140 m) (Bissell, 1952) and greater than 600 feet (180 m) thick (Smith and others, 1952); though about one-half the exposed thicknesses, units are lithologically like their counterparts (Ppf, Ppm, Ppg) of thick upper Paleozoic strata in map area.

IPw **Weber Quartzite** (Lower? Pennsylvanian) - Mainly gray to buff, quartz-cemented sandstone with some interbedded gray cherty limestone (Baker, 1964a); excessively thick in the Aspen Grove quadrangle compared to areas to north (8000 feet [2440 m] versus 1000 to 3500 feet [300-1070 m]) (after Baker, 1964a), suggesting a transition northward out of the Oquirrh basin onto continental shelf or structural thickening in the Aspen Grove area; east of map area, about 1600 feet (490 m) thickness exposed along Duchesne River (Bissell, 1952).

IPrv **Round Valley Limestone** (Lower Pennsylvanian) - Light- to medium-gray limestone with black, white, and orange-red chert and some thin beds of buff to gray sandstone; 225 to 400 feet (70-120 m) thick just north of Aspen Grove quadrangle (Baker, 1964a).

Mdo, Mdot

Doughnut Formation (Upper Mississippian, Chesterian?) - Gray to dark-gray, thin-bedded limestone overlying black shale with some interbedded thin, fine-grained, gray, quartzose sandstone beds (after Baker, 1964a); thickness uncertain, 1300 feet (400 m) thick just north of Aspen Grove quadrangle, but only 400 feet (120 m) thick farther north away from Charleston-Nebo thrust (Crittenden, 1959; Baker, 1964a); again, this suggests a transition northward out of the Oquirrh basin onto continental shelf or structural thickening, here with upper carbonate part likely structurally thickened while lower shale part is structurally attenuated. Mdot used along Deer Creek fault where unit is marble (see Biek, 2005b); may be related to faulting (tectonite) and/or Cottonwood stock (tactite); see also unit Tict.

Mh **Humbug Formation** (Upper Mississippian) - Incomplete dip-slope exposure, so see Mh under Thick Upper Paleozoic Strata.

Thick Upper Paleozoic Strata in Hanging wall of Charleston-Nebo Thrust System

Pp **Park City and Phosphoria Formations, undivided** (Permian) - Variably faulted out in the Spanish Fork Peak and Billies Mountain quadrangles by the Little Diamond Creek fault system; for descriptions see following subdivisions.

Ppf **Park City Formation, Franson Member** - Dolomite; light tannish gray; weathers very light tannish gray to white; very thick bedded; silty to sandy; with small, quartz-filled vugs and light-gray, white, and tan chert as nodules and stringers; commonly highly fractured to brecciated; estimate about 650 feet (200 m) thick at Willow Creek, Co-op Creek quadrangle; Bissell (1952, units 3-5) measured 585 feet (178 m), whereas Cheney and others (1953) measured 547 feet (167 m), and Welsh (1981, unpublished) measured about 730 feet (225 m); 820 to 930 feet (250-284 m) thick in Diamond Fork anticline and 680 feet (210 m) penetrated (not dip corrected) in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 660 feet (200 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (< 8 degree dip) (Constenius, 2008); and Baker and others (1949) reported more than 830 feet (>250 m) in Wasatch Range.

Ppm **Phosphoria Formation, Meade Peak Phosphatic Member** - Dark-gray to black, fissile, siliceous, locally oolitic shale and thin-bedded, medium-gray siltstone with brown and gray laminations; poorly exposed, forms benches and swales with siliceous shale and siltstone chips as float; about 190 to 225 feet (70 m) thick at Willow Creek, Co-op Creek quadrangle (Bissell, 1952, unit 2; Cheney and others, 1953;Welsh, 1981, unpublished); 240 to 320 feet (73-98 m) thick in Diamond Fork anticline and 300 feet (90 m) penetrated in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 267 feet (81 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008); farther west about 210 feet (65 m) thick where not faulted out (Smith and others, 1952).

Ppg **Park City Formation, Grandeur Member** - Dominantly dolomite in upper two-thirds that is medium to dark gray, weathers very light gray, is very thick bedded, and is fine to medium crystalline, with dispersed, white, chert nodules; lower part is medium-gray, gray-weathering, shelly, dolomitic lime wackestone; both parts thick bedded, with dark-gray, 0.4- to 0.8-inch-thick (1-2 cm) chert layers; about 685 feet (210 m) thick at Willow Creek, Co-op Creek quadrangle (Bissell, 1952, unit 1; Cheney and others, 1953; Welsh, 1981, unpublished); only 270 feet (82 m) thick in Diamond Fork anticline and 790 feet (240 m) penetrated in Amoco Cottonwood Canyon well (Welsh, 1981, unpublished); 835 feet (255 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008). Baker (1947) reported an 883-foot (269 m) thickness in the Wasatch Range.

Pdc **Diamond Creek Sandstone** (Lower Permian) - Very light gray, yellowish-brown and salmon-red-brown, very thick bedded and trough cross-bedded, fine-grained, friable sandstone, with thin-bedded, light-gray, calcareous sandstone interbeds; poorly exposed, forms swale between Grandeur and Kirkman carbonate ribs; 450 feet (137 m) thick at Willow Creek, Co-op Creek quadrangle (Welsh, 1981, unpublished). In Little Diamond Creek area, it is ledge-forming, buff- and salmon-colored, cross-bedded, medium- to coarse-grained sandstone with lesser thin-bedded, sandy limestone and dolomite; 480 feet (146 m) thick in Diamond Fork anticline and about 1320 feet (400 m) penetrated in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 1265 feet (386 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008). Baker (1947) reported a 835-foot (255-m) thickness in Wasatch Range; incompletely exposed in Utah Valley northwest of Payson (Clark, 2009).

Pk **Kirkman Limestone** (Lower Permian, Leonardian and Wolfcampian) - Very light gray, gray and very dark gray, thick- to medium-bedded, nonlaminated to thinly laminated, dolomitic limestone; intraformational breccia makes up upper two-thirds of Kirkman in Wasatch Range (contains saline beds in subsurface) and consists of dark-gray to black, gray-weathering beds of rotated, thinly laminated, limestone clasts, and lighter gray beds of nonlaminated, dolomitic limestone; contains rare, thin beds of red-weathering, gray, slabby-weathering, sandy limestone; strong fetid odor when broken; some interbedded medium-gray and very pale orange calcareous sandstone and minor dark-gray shale in West Mountain; age from Clark (2009); thickness varies from 97 to 375 feet (30-115 m) on east side of the Strawberry River valley (this report; Welsh, 1981, unpublished, lower value; Bissell, 1952, upper value); 190 to 300 feet (60-90 m) thick in Diamond Fork anticline depending on contact with underlying Granger Mountain(?) Formation (after Welsh, 1981, unpublished); about 250 feet (75 m) thick in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 334 feet (102 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008). Baker (1947) showed about 1600 feet (490 m) in the Wasatch Range; 1000+ feet (300+ m) thick in West Mountain, top faulted out (Clark, 2009). Saline strata are an interval of detachment/decollement in region, such that rocks above may be complexly folded and faulted while rocks below are little deformed.

Oquirrh Group (Lower Permian and Pennsylvanian) - Figure 2 (plate 2) shows the stratigraphic nomenclature and ages for the Oquirrh Group in the western part of this map and the Oquirrh Formation in the eastern part of this map. The columns are on different thrust sheets. Starting with this map, the Utah Geological Survey includes the Permian Curry Peak and Freeman Peak Formations in the Oquirrh Group (west/left column) to conform with the Permian Granger Mountain being part of the Oquirrh Formation (east/right column).

PIPo **Oquirrh Group, undivided** (Lower Permian and Pennsylvanian) - Quartzite exposed on Rock [Bird] Island (see Cottam in Bissell, 1963, p. 122); projecting West Mountain horst units along strike, rock most likely Pennsylvanian Butterfield Peaks Formation or Bingham Mine Formation, but Permian Freeman Peak and Curry Peak Formations are also exposed in the horst.

Pofc **Oquirrh Group, Freeman Peak and Curry Peak Formations, undivided** (Lower Permian, middle-lower Wolfcampian) - Gray and pale-orange, calcareous sandstone, lesser quartzite and medium-gray limestone, and minor dark-gray, sandy shale; sandstone is fine grained, and locally cross-bedded and well indurated; limestone interbeds are thin and locally fossiliferous, with calcite stringers and sandy intervals; conodont and fusulinid fossils used for age control (Clark, 2009); unit forms ledges and slopes; ~2000 feet (600 m) exposed thickness on West Mountain (Clark, 2009). Included in Oquirrh Group because lithologically and age correlative with Granger Mountain Member of Oquirrh Formation.

PIPgw **Oquirrh Formation, Granger Mountain and Wallsburg Ridge Members, undivided** - Used in Spanish Fork and adjacent Spanish Fork Peak quadrangles where difficult to tell members apart and fossil evidence not available to separate Permian Granger Mountain from Pennsylvanian Wallsburg Ridge.

Pogm **Oquirrh Formation, Granger Mountain Member** (Permian, Wolfcampian) - Gray, tan-weathering, limy, silty sandstone; minor beds with abundant track and trail markings; interbedded with minor gray, red, and buff quartzite, light-gray sandstone, and thick beds of gray limestone in lower part of unit; 8200 to 10,255 feet (2500-3126 m) thick on Wallsburg Ridge (after Baker, 1976, using our contact; Welsh, 1981, unpublished; respectively); queried in Springville quadrangle along the mountain front (compare to Baker, 1973). Present in Little and Big Baldy fault blocks.

Pogml **Oquirrh Formation, Granger Mountain Member, limestone unit** (Permian?, Wolfcampian? - Pennsylvanian, Virgilian) - Unit locally present at bottom of Granger Mountain Member; in Daniels Canyon area, consists of upper and lower ledge- and cliff-forming limestone intervals separated by slope-forming, yellowish-brown, calcareous siltstone interval with a few limestone interbeds; limestone is gray, medium to thick bedded, fossiliferous, and locally cherty; 0 to about 500 feet (0-150 m) thick (Biek and others, 2003).

Queried in Springville and Spanish Fork Peak quadrangles where Wolfcampian fusulinids present above basal limestone marker; 50 foot (15 m) thick marker in Springville quadrangle (see Baker, 1973) and could be several hundred feet thick in Spanish Fork Peak quadrangle (after Rawson, 1957, cross section and units 57 & 58, p. 27).

IPobm **Oquirrh Group, Bingham Mine Formation** (Upper Pennsylvanian, Virgilian-Missourian) - Calcareous sandstone, minor limestone, quartz sandstone, and shale; medium-gray to light-brown, calcareous sandstone typically weathers to light gray and grayish orange with pale red patches; contains medium-gray limestone interval with early Virgilian fusulinids; unit forms ledges and ledgy slopes; Missourian based on fusulinids (Welsh and James, 1961); queried on South Mountain because extensive fracturing makes identification uncertain; 5300 to 7311 feet (1600-2229 m) thick in Oquirrh Mountains (Welsh and James, 1961; Tooker and Roberts, 1970; Swenson, 1975), incomplete 4000 foot (1200 m) thickness in West Mountain (Clark, 2009), and correlative Wallsburg Ridge Member of Oquirrh is about 6400 feet (1950 m) thick to east in Wasatch Range.

IPowr **Oquirrh Formation, Wallsburg Ridge Member** (Pennsylvanian, Virgilian-Missourian) - Light-gray to yellowish-brown, thick-bedded, fine- to medium-grained quartzite and sandstone; feldspathic (orthoquartzite) to siliceous; quartzites commonly have conchoidal fracture; locally thinly laminated to cross-bedded; includes rare, silty and sandy, gray limestone interbeds; age from Baker (1976); about 3700 feet (1130 m) thick in Center Creek quadrangle (Biek and others, 2003), about 6400 feet (1950 m) thick to south in Wallsburg Ridge quadrangle (after Baker, 1976, using our contacts), 5280 feet thickness shown by Welsh (1981, unpublished), and possibly over 8000 feet (2450 m) thick to west in Wasatch Range (after Baker, 1947; 1973).

IPos **Oquirrh Formation, Shingle Mill Limestone Member** (Pennsylvanian, Missourian-Desmoinesian) - Dark-gray to black, thin-bedded limestone containing abundant black chert and locally abundant fossils; 200 to 450 feet (60-140 m) thick (Baker, 1972a); our map unit is the upper limestone of Welsh (1981, unpublished) that he showed as about 400 feet (120 m) thick; Biek and Lowe (2005) reported that conodont fauna in their Shingle Mill map unit indicate a Missourian age, rather than the Desmoinesian age reported by Baker (1976). Probable equivalent to Commercial and/or Jordan Limestone Members of the Bingham Mine Formation of Oquirrh Mountains/Bingham district (Welsh, 1981), but these limestones are not present on West Mountain (Clark, 2009).

IPobp, IPobl

Oquirrh Group, Butterfield Peaks Formation (Pennsylvanian, Desmoinesian-Atokan-Morrowan) - Interbedded, brown-weathering, fine-grained calcareous sandstone, medium-gray, fine-grained sandy limestone, minor orthoquartzite, and several limestone intervals (some mapped as IPobl); typically cyclically interbedded with several tens of feet of calcareous sandstone capped by gray limestone several feet thick; minor siltstone and shale interbeds form some poorly exposed slopes; unit typically forms ledgey to cliffy slopes; limestone intervals are locally fossiliferous with *Chaetetes* (coral) present in lower part of unit; fusulinid and conodont fossils provide some age control (Clark, 2009); queried on southwest end of South Mountain because extensive fracturing makes identification uncertain, though a single sample contained Atokan fusulinids; more than 4500 feet (1370 m) thick, top not exposed, in Lake Mountains (Biek, 2004) and more than 7300 feet (2200 m) thick, base not exposed, in West Mountain (Clark, 2009); complete thickness 9070 feet (2765 m) in Oquirrh Mountains (Tooker and Roberts, 1970); lithologically and near-age correlative with Bear Canyon Member of Oquirrh Formation. Limestone units (IPobl), locally mapped to show structural geology, commonly contain spherical or irregularly shaped, black chert; about 40 to 300 feet (12-90 m) thick in Lake Mountains and West Mountain (see Biek, 2004; Biek and others, 2009; Clark, 2009).

IPobc **Oquirrh Formation, Bear Canyon Member** (Pennsylvanian, Desmoinesian-Atokan) - Gray to tan, limy to quartzitic sandstone with interbedded gray to black, thin- to thick-bedded, cherty to locally sandy limestone; about 4250 to 8350 feet (1300-2550 m) thick in map area (after Baker, 1947, 1972a, 1976), thickening northward and eastward; Welsh (1981, unpublished) has 8650 feet (2635 m) below the upper limestone in his type section in the Aspen Grove and Wallsburg Ridge quadrangles, but the section is faulted and he reported only about 4500 feet (1400 m) in a reference section in the Charleston quadrangle; age from Baker (1976); latest Morrowan conodonts reported in lowest part of roughly equivalent strata in Bridal Veil Falls quadrangle (Shoore, 2005), but sample location uncertain. Strata at top of Mount Timpanogos may include some Shingle Mill Limestone and Wallsburg Ridge Members of Oquirrh (see Konopka, 1999).

IPowc **Oquirrh Group, West Canyon Limestone** (Pennsylvanian, Morrowan) - Gray, sandy to fossiliferous limestone; fossils include crinoid columnals, brachipods, bryozoans, and rugose corals; lower part forms ledges and upper part contains prominent cliff-forming limestone beds with irregular chert nodules and beds; medial calcareous sandstone; Webster (1984) reported Early Pennsylvanian conodonts from the Lake and Oquirrh Mountains; latest Chesterian (Late Mississippian) conodonts reported in Oquirrh Mountains (see Davis and others, 1994), but these conodonts are actually from the uppermost Manning Canyon Shale; Biek (2004) measured 1025 feet (313 m) of West Canyon in the Lake Mountains; lithologically and near-age correlative with Bridal Veil Limestone Member of Oquirrh Formation.

IPobv **Oquirrh Formation, Bridal Veil Limestone Member** (Pennsylvanian, Atokan? and Morrowan) - Medium-gray to black, thin- to thick-bedded limestone with local beds of quartzite; limestone contains much brown to black chert and some abundantly fossiliferous beds; measured thickness 1245 feet (380 m) (Baker, 1972a); contains Morrowan conodonts in Charleston quadrangle (Biek and Lowe, 2005); see roughly equivalent West Canyon Limestone description above for comment on Mississippian age.

Mmc **Manning Canyon Shale** (lower Pennsylvanian? and upper Mississippian, Chesterian) - Black to brown shale with numerous thin beds of light-brown-weathering, gray, fine-grained, shaly sandstone, some lenses or beds of rusty-weathering grit, and one or more thick beds of gray to black, cherty limestone; at least in west contains some beds of light-brown quartzite; shale is carbonaceous with occasional nodules of marcasite; measured thickness in Bridal Veil Falls quadrangle is 1650 feet (500 m) (Baker, 1972a); 1176 feet (359 m) measured thickness in Lake Mountains (Biek and others, 2009); age from macro-fossils (for example, cephalopod *Eumorphoceras bisulcatum*) reported in Baker (1972a) that are Chesterian in age (see Welsh and Bissell, 1979); Pennsylvanian age considered unlikely since definitive brachiopod, *Dictyoclostus hermosanus*, from Baker (1972a) is Atokan (Welsh and Bissell, 1979), so likely misidentified. The Manning Canyon is a zone of detachment/decollement, such that the unit is attenuated and faulted out along regional scale thrust faults (see for example Biek and others, 2003).

Mgb **Great Blue Limestone, undivided** (Upper Mississippian, Chesterian?-Meramecian) - Dark-gray to nearly black, light- to medium-gray-weathering, thin- and regularly bedded limestone and shaly limestone with interbedded black and brown shale beds up to 50 feet (15 m) thick, and, near base, scattered thin beds of olive-brown-weathering, dark-gray, fine-grained quartzite; series age after Chamberlain (1981); measured thickness about 2800 feet (850 m) in Rock Canyon, Bridal Veil Falls quadrangle (Baker, 1947, 1972a; after Chamberlain, 1981); attenuated by faulting south of Slide Canyon. Black shale is prominent basal part in Wasatch Range and is described and shown as 100 to 700 feet (30-215 m) thick by Baker (1947), Crittenden (1959), and Chamberlain (1981); this black shale can be attenuated or faulted out, possibly resulting in the thickness variation. In west part of map area divided where possible into upper and lower parts:

Mgbu **Great Blue Limestone, upper limestone member** - Bluish gray, medium- to very thick bedded limestone, locally cherty and fossiliferous, with interbedded shales in lower part; 2100 feet (640 m) thick in Lake Mountains (Biek, 2004; Biek and others, 2009).

Mgbsl **Great Blue Limestone, Long Trail Shale and lower limestone members** - Long Trail is dark shale and thin-bedded limestone that erodes to saddles; lower member is medium gray, fossiliferous limestone that is thinner bedded and argillaceous with some shale in upper part; 390 feet (120 m) thick in Lake Mountains (Biek, 2004; Biek and others, 2009).

Mh **Humbug Formation** (Upper Mississippian) - Light- to dark-gray, cherty limestone and some dolomite interbedded with light-gray to buff, brown-weathering, limy to quartzitic sandstone, which causes characteristic brown and gray bands in outcrops; measured thickness 520 feet (160 m) in Rock Canyon, Bridal Veil Falls quadrangle (Baker, 1972a); Welsh (in Clark, 2009) measured 785 feet (240 m) on West Mountain.

Mde **Deseret Limestone** (Upper and Lower Mississippian) - Interbedded, thick-bedded limestone and dolomite with distinctive light- and dark-gray banded outcrops; fossil crinoids and corals common; black chert occurs as thin layers, blebs, and irregular masses in most beds and is locally very abundant; about 585 feet (175 m) thick in Wasatch Range (Baker, 1964b); Welsh (in Clark, 2009) measured 765 feet (235 m) on West Mountain, and from 700 to 1000 feet (210-300 m) in Lake Mountains area (Biek and others, 2009). The Delle Phosphatic Member is present at Rock Canyon, but is likely thinner than shown by Sandberg and Gutschick (1979); Delle also present in Lake Mountains (Biek, 2004; Biek and others, 2009).

Mgf **Gardison and Fitchville Formations, undivided** - Used in east part of map area.

Mg **Gardison Limestone** (Lower Mississippian) - Dark-gray, "stair-step"-forming, mostly thin-bedded limestone with scattered abundant light-brown to black chert; about 600 feet (180 m) thick in Timpanogos Cave quadrangle (Baker, 1947; Baker and Crittenden, 1961); 900 feet (275 m) thickness in Rock Canyon (Baker, 1964b) likely includes Deseret strata; similar thickness in Spanish Fork quadrangle (Solomon and others, 2007), but Delle at upper contact not recognized; Welsh (in Clark, 2009) measured 620 feet (190 m) on West Mountain. Mapped separately west of Utah Lake where Pinyon Peak is present and is mapped with Fitchville (MDfp). Fitchville and Pinyon Peak Formations absent at unconformity in Spanish Fork quadrangle (Solomon and others, 2007).

Fitchville Dolomite (Lower Mississippian and Upper Devonian) - Medium- to light-gray, cliff-forming dolomite with numerous small vugs; lacks chert, which is atypical for Mississippian units; interbedded limestone in upper part; buff to gray, locally conglomeratic, coarse-grained sandstone or grit comprise basal bed 1 to 20 feet (0.3-6 m) thick; 100 to 265 feet (30-80 m) thick (Baker, 1973); Devonian age of dolomite at Rock Canyon from Sandberg and Gutschick (1979, p. 114). Basal clastic bed may unconformably underlie dolomite.

MDfp **Fitchville and Pinyon Peak Formations, undivided** (Lower Mississippian and Upper Devonian) - **Fitchville** is light-blue-gray limestone and light-gray dolomite with crinoids, brachiopods and corals. Devonian **Pinyon Peak Limestone** is medium- to dark-gray dolomite with crinoid, gastropod, and silicified coral fossils; may not be present in Wasatch Range or Devonian strata may be mapped with Fitchville; unconformably overlies Cambrian strata. Total thickness 300 feet (90 m) in West Mountain (Welsh, in Clark, 2009) and more than 300 feet (90 m), base not exposed, in Lake Mountains (Biek, 2004).

Cote **Opex through Teutonic Formations** (Upper and Middle Cambrian) - Mapped in southern West Mountain and includes the Opex Formation?, Cole Canyon Dolomite, Bluebird Dolomite, Herkimer Limestone, Dagmar Dolomite, and Teutonic Limestone; gray to mottled dolomite and limestone, locally with twiggy bodies and pisolites; limestone commonly has discontinuous, tan siltstone bands and partings; average aggregate thickness of 1725 feet (525 m) (see Clark, 2009 for details).

Ccte? **Cole Canyon through Teutonic Formations?** (Upper and Middle Cambrian) - Gray to mottled dolomite, locally with twiggy bodies and pisolites; located along Picayune Canyon fault zone in Spanish Fork quadrangle and commonly brecciated, fractured, and dolomitized (Ajax/Opex missing?); includes all or some of the Cole Canyon Dolomite, Bluebird Dolomite, Herkimer Limestone, Dagmar Dolomite, and Teutonic Limestone; 1400 feet (400 m) thick (Cu of Solomon and others, 2007).

Cmo **Maxfield and Ophir Formations, undivided** - Used where geology is complex along west flank of Wasatch Range.

Cm **Maxfield Limestone** (Middle Cambrian) - Mainly light- to dark-gray, thin-bedded limestone with yellow-brown to grayish-yellow mottling, and with interbedded gray to white dolomite and oolitic or pisolitic limestone; unconformably overlain by Fitchville and absent in northern Timpanogos Cave quadrangle (Baker and Crittenden, 1961); 0 to less than 850 feet (0 to <260 m) thick (Baker, 1973); 595 feet (180 m) thick in Bridal Veil Falls quadrangle (Baker, 1972a).

Co **Ophir Formation** (Middle Cambrian) - Olive-green, slope-forming, micaceous shale with thin beds of greenish sandstone and a zone of thin beds of yellow to brown-mottled shaly limestone in upper part; contact with Maxfield is gradational and may not have been picked consistently; about 100 to 290 feet (30-90 m) thick in Springville and Bridal Veil Falls quadrangles (Baker, 1972a, 1973). Reportedly 510 feet (155 m) thick in American Fork Canyon with characteristic three units: upper shale/micaceous sandstone [phyllite] (170 feet [50 m] thick), middle limestone (100 feet [30 m] thick), and lower shale and sandstone (250 feet [75 m] thick) (Baker and Crittenden, 1961; Baker, 1964b). Measured thickness 307 feet (94 m) in southern West Mountain (Elison, 1952; Schindler, 1952; Swanson, 1952).

Ct **Tintic Quartzite** (Middle and Lower? Cambrian) - Light-brown weathering, cliff- and ledge-forming, off-white to tan quartzite with quartz-pebble conglomeratic beds in lower 200 feet (60 m) and boulders of quartz 1 foot (0.3 m) or more in diameter near basal unconformity; interbedded greenish quartzite and phyllite in top 90 feet (30 m), forming gradational contact with overlying Ophir; near Provo, thin (0-80 feet [0-24 m]) diabase flow(?) locally near base (Abbott, 1951); measured thickness 1170 feet (355 m) in Slate Canyon, Springville quadrangle (Baker, 1973); more than 700 feet (200 m) thick in West Mountain, base not exposed (Clark, 2009).

Zm **Mutual Formation** (Neoproterozoic) - Rusty to red-purple quartzite, grit, and pebble to boulder conglomerate with minor grayish-red or greenish shale; clasts are schist, gneiss, limestone, and tillite; characteristic grit contains same lithologies, as well as black shale, quartz, and feldspar; 0 to 1300 feet (400 m) thick and thinning to east; unconformably overlies Mineral Fork Tillite (Baker and Crittenden, 1961); only exposed in Timpanogos Cave quadrangle.

Zmf **Mineral Fork Tillite** (Neoproterozoic) - Gray to brown and olive drab, dark-brown- to black-weathering, unstratified and poorly sorted, micaceous siltstone with scattered boulders of dolomite, quartzite, sandstone, and altered (green) igneous rock up to 1 foot (0.3 m) in diameter; unconformity at base; complete thickness 250 to 300 feet (75-90 m) in American Fork Canyon and may be much thicker (1000 feet [300 m]) to north in map area (Baker and Crittenden, 1961), thinning southward to nothing near Slate Canyon (Baker, 1973).

Zbc **Big Cottonwood Formation** (Neoproterozoic and Mesoproterozoic?) - Purple to maroon, brown, and pinkish-gray, fine-grained to conglomeratic quartzite with interbedded gray, green, brown, and purple micaceous quartzite and phyllite, and purple, red, and maroon slate (argillite); exposed partial thickness about 400 feet (120 m) near Deer Creek Reservoir (Biek and Lowe, 2005) and 1350 feet (410 m) east of Provo (Baker, 1973); age from data in Dehler and others (2010).

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(Numbers refer to figure 1, plate 2 - Index to sources of geologic mapping;
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