INTERIM GEOLOGIC MAP OF THE OREM QUADRANGLE, UTAH COUNTY, UTAH

by

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INTRODUCTION

Location and Geographic Setting

The Orem quadrangle covers part of the Provo Bay portion of Utah Lake, northeastern Utah Valley, and the western margin of the adjoining Wasatch Range (figure 1). The quadrangle includes Orem, the sixth largest city in Utah; parts of the cities of Lindon, Pleasant Grove, and Provo; and part of the town of Vineyard. The Provo River is the primary stream in the quadrangle, flowing south from Provo Canyon in the Wasatch Range to the east side of Utah Lake in the adjacent Provo quadrangle. U.S. Interstate 15, the major transportation corridor in the region, extends from north to south in the Utah Valley part of the map area and U.S. Highway 189 lies along the eastern edge of the valley east of Orem and turns northeast into Provo Canyon.

Previous Investigations

Geologic studies of the Orem quadrangle began almost one-half century ago. Hintze (1962) compiled a 1:125,000-scale bedrock map of the southern Wasatch Range and later mapped the geology of the area surrounding Brigham Young University (the Y Mountain area) in more detail, including the southeast corner of the Orem quadrangle (Hintze, 1978). Baker (1964b) mapped the geology of the Orem quadrangle at a scale of 1:24,000. Davis (1983) and Bryant (1992) published regional compilations of geology that covered the Orem quadrangle at respective scales of 1:100,000 and 1:125,000.

Surficial geologic maps by Hunt and others (1953) and Miller (1982) were early attempts to identify the texture of Quaternary unconsolidated deposits of Utah Valley and place the deposits in a stratigraphic framework of map units. However, interpretations of Quaternary geology, and particularly of Lake Bonneville stratigraphy, continued to evolve until Machette (1992) mapped the surficial geology of eastern Utah Valley. The contacts between some lacustrine units mapped by Miller (1982), Machette (1992), and us were interpreted from the U.S. Soil Conservation Service soil maps of Utah County (Swenson and others, 1972).

Purpose and Scope

This 1:24,000-scale map is part of a larger project to map and compile the geology of the Provo 30' x 60' quadrangle. New mapping adjacent to the Orem quadrangle includes geology of the Lehi (Biek, 2005), Timpanogos Cave (Biek, 2005; Constenius, 2007), Springville (Solomon and Machette, 2008; Constenius and others, 2010b), Provo (Solomon and Machette, 2009), Lincoln Point (Solomon and Biek, 2009), Pelican Point (Solomon and others, 2009), and Aspen Grove and Bridal Veil Falls (Constenius and others, 2006) quadrangles (figure 2). Previous geologic mapping in these quadrangles includes Baker and Crittenden (1961), Baker (1964a, 1964b, 1972, 1973), Hintze (1978), and Machette (1992) (figure 2).

The bedrock map of Baker (1964b) and the Quaternary map of Machette (1992) are important contributions to our initial knowledge of the geology of the Orem quadrangle, but our map includes significant revisions. Changes from Baker's map include a reinterpretation of the structural geology, aided by subdivision of the Lower Permian to Lower Pennsylvanian Oquirrh Formation into its members (which, in descending order, include the Granger Mountain, Bear Canyon, and Bridal Veil Limestone Members) (figure 3), and recognition of large mass-movement deposits (megabreccia) along the steep western Wasatch Range front. Baker (1964b) originally mapped deposits we identify as megabreccia as thrust sheets of Permian-Pennsylvanian Oquirrh Formation carried in the hanging wall of the Cretaceous to early Tertiary Big Baldy thrust. We reinterpret these large bedrock blocks (mostly of Oquirrh Formation) as features that were emplaced downslope in the late Tertiary rather than carried in the hanging wall of the earlier thrust. We map the actual fault relationship along the mountain front of Big Baldy and Little Baldy as a normal fault, rather than a thrust fault, that places a hanging wall of the Permian Granger Mountain Member of the Oquirrh Formation over footwall rocks of the Mississippian Manning Canyon Shale (Armstrong, 1968; Constenius and others, 2006).

Machette (1992) mapped the surficial geology of eastern Utah Valley as part of a program by the U.S. Geological Survey to map the surficial geology of the active Wasatch fault zone. Machette (1992) eliminated outdated stratigraphic terminology and concepts and updated the fault mapping of Cluff and others (1973). We mapped additional detail in Quaternary deposits on the valley floor, changed the configuration of some strands of the active Wasatch fault zone along the Wasatch Range front, and mapped new details of Quaternary landslides along the range front.

Our mapping was performed between July 2007 and June 2008, using standard field mapping methods. Solomon used 1:20,000-scale black-and-white aerial photographs flown in 1965 for the U.S. Department of Agriculture, Soil Conservation Service (now Natural Resources Conservation Service), to map Quaternary geology prior to most development in the quadrangle. Because most Quaternary geology can only be accurately mapped from aerial photos, limited field checking was conducted for two weeks in the spring of 2008 to study significant Quaternary features. Constenius used 1:20,000-scale color aerial photographs flown in 1984 for the U.S. Department of Agriculture, Forest Service, to map the geology of the Wasatch Range, and mapped geology in the field intermittently throughout 2007 and 2008.

Geologic Summary

Bedrock Stratigraphy and Geologic Structure

Bedrock is exposed in the Wasatch Range east of Utah Valley. The bedrock consists of sedimentary rocks of Permian to Proterozoic age carried on thrusts of the Charleston-Nebo salient (CNS) in the Cordilleran fold and thrust belt (Baker, 1964b, 1972; Hintze, 1978; Constenius and others, 2003). These strata were deformed by Early Cretaceous to late middle Eocene (ca. 100-40 Ma) contractional folding and faulting of the Sevier orogeny (Willis, 1999; DeCelles, 2006; Schelling and others, 2007), extensional faulting during late Eocene to middle Miocene (ca. 38-18 Ma) "collapse" (Constenius, 1996; Constenius and others, 2003), and middle Miocene to recent (ca. 17-0 Ma) Basin-and-Range faulting (see, for example, Zoback and others, 1981; Smith and Bruhn, 1984). The most prominent and youngest aspect of extensional faulting in the map area is the Provo segment of the Wasatch fault zone (Machette and others, 1992), which separates Utah Valley from the Wasatch Range. Two knobs on the west flank of Mount Timpanogos, Big Baldy and Little Baldy, are remnants of a once larger, downdropped extensional fault block composed of the Granger Mountain Member of the Oquirrh Formation; the fault block may have been emplaced during late Eocene to early Miocene "collapse" and/or middle Miocene to recent normal faulting associated with the Wasatch fault zone.

The CNS is a large, highly eastward-convex salient of the frontal part of the Cordilleran fold and thrust belt in central Utah that developed during a long period of late Early Cretaceous to late middle Eocene deformation (ca. 100-40 Ma) (see, for example, Condor and others, 2003). The salient is bounded on its north side by the Charleston thrust, on its east side by curved, deeply buried, unnamed thrusts in Jurassic-Cretaceous rocks, and on its south side by the Nebo thrust (figure 4). Faults bounding the salient are collectively referred to as the Charleston-Nebo thrust.

The salient also includes several other major thrust faults, including the Uinta Basin-Mountain-Boundary thrust systems, and a deeper regional sole thrust underlying the entire salient that cut and displaced rocks ranging in age from Proterozoic to Late Cretaceous. Exposed in the Wasatch Range, including Mount Timpanogos and Cascade Peak, the overall structure of the salient is that of a "ramp anticline" or fault-bend fold: an overall east-dipping structural fabric in hanging wall strata of the Charleston-Nebo thrust produced by the sole thrust cutting up-section from Proterozoic crystalline basement or Proterozoic sedimentary rocks to the Jurassic Arapien Shale, resting on a Jurassic Arapien Shale footwall thrust-flat (Constenius and others, 2003; Schelling and others, 2007). The overall east-dip of the CNS hanging wall in the Wasatch Range was accentuated by blind thrusts that elevated, folded, and displaced the Charleston-Nebo thrust.

The Charleston-Nebo thrust is the shallowest fault of a crustal-scale antiformal duplex, and at the base of the stack is the sole fault and the Uinta Basin-Mountain-Boundary thrust, a blind thrust linked to the Uinta Mountains uplift. This structural stack of major thrusts has variously been referred to as the Santaquin or Cascade Peak culmination (Constenius and others, 2003; Schelling and others, 2007). Collectively, these thrusts produced over 10 miles (15 km) of structural uplift, resulting in structural inversion and 30 to 60 miles (50-100 km) of eastward tectonic transport of rocks of the Permian-Pennsylvanian Oquirrh basin. The CNS juxtaposes a 9-10 mile (15-16.5 km) thick Proterozoic to Lower Cretaceous miogeoclinal rock column with a 3 mile (4.6 km) thick cratonic sequence (Baker, 1959; Reiss, 1985). Similarly, Upper Mississippian-Permian strata of the Charleston-Nebo thrust sheet range from 3 to 7 miles (5-11 km) thick, whereas the same age rocks of the Cottonwood arch, outside of the Oquirrh Basin, attain a thickness of only 0.7 to 2.2 miles (1.2-3.6 km) (Baker, 1959). The CNS is truncated on its west side by the Wasatch fault zone that has exposed rocks ranging from the Proterozoic Mineral Fork Tillite to the Pennsylvanian Bear Canyon Member of the Oquirrh Formation in the core of the culmination in the Orem quadrangle.

Thermochronologic data along with the stratigraphic evidence from the Indianola Group (Jefferson, 1982; Lawton, 1985) suggest that initial motions on the Nebo thrust were probably in late Albian (early Cretaceous) time. Isotopic dating of Proterozoic rocks in the Nebo thrust sheet suggests that these rocks were rapidly exhumed in late

Albian-early Cenomanian (Cretaceous) time (ca. 100 Ma) (M.T. Heizler, written communication, 2001). Foreland basin deposits in the footwall of the CNS provide evidence of three distinct episodes of thrusting (crustal loading and tectonic-driven subsidence): 1) the main translation phase of CNS thrusting that ranged from Albian to middle Campanian (Cretaceous), 2) middle Campanian-late Paleocene (Cretaceous to Tertiary) wedgetop deposition on the CNS that was concurrent with internal imbrication of the thrust salient, and 3) accelerated rates of wedgetop deposition related to early to late middle Eocene (Tertiary) movement of the Uinta Mountains uplift and Uinta basin, and motion on the Uinta Basin-Mountain Boundary thrust system.

Fault truncation of Campanian rocks in the footwall of the Charleston thrust, defined on seismic reflection data (Constenius and others, 2003; Horton and others, 2004), indicates that the main translation phase of thrusting (the first episode of thrusting) continued through early Campanian time; the thrust was erosionally truncated and buried by Campanian strata of the Blackhawk-South Flat, Castlegate-Price River, and Currant Creek Formations, which brackets final motions on the thrust between 79 and 80 Ma. Thrusts of the CNS were subsequently folded and in some cases reactivated to accommodate slip at the base of the Santaquin/Cascade Peak culmination on the Uinta Basin-Mountain-Boundary thrust, the sole thrust of the Uinta salient (Constenius and others, 2003). Ages of synorogenic growth strata deformed by fold-thrust structures suggest that this phase of CNS shortening (including the second and third episodes of thrusting) took place from middle Campanian through late middle Eocene time (ca. 79-40 Ma). Structures representative of this shortening are superposed on the CNS in the form of thrusts with west-vergence and fault-propagation folds.

Post-Bedrock Geology

Deposits younger than bedrock in the Orem Quadrangle range in age from Pliocene (?) to Holocene. The oldest of these deposits are large bedrock blocks (megabreccias), composed largely of quartzite and limestone of the Oquirrh Formation, that have moved downslope along the steep western Wasatch Range front. Displacement of the blocks was facilitated by slope failure of the Mississippian Manning Canyon Shale, and is thought to have started in the late Tertiary (possibly Pliocene) and continued intermittently during the Pleistocene as movement along the Wasatch fault zone uplifted the range front relative to the valley.

Coalesced middle to upper Pleistocene alluvial-fan deposits underlie piedmont slopes on the margins of Utah Valley. The fans were deposited during the interlacustral episode between the last two major lake cycles in the Bonneville Basin, the Bonneville and Little Valley lake cycles (Machette, 1992). The Little Valley lake cycle occurred late in marine oxygen-isotope stage 6, which ended about 130,000 years ago (Scott and others, 1983), and is largely contemporaneous with the Bull Lake glaciation (see Chadwick and others, 1997). The highest level of the Little Valley lake cycle is below the elevation of the subsequent Lake Bonneville highstand (Scott and others, 1983) and thus is buried throughout most of the Bonneville basin. Remnants of the fans are exposed above and slightly below the highest Lake Bonneville shoreline along the base of the Wasatch Range (Machette, 1992) (table 1).

The surficial deposits in the quadrangle were mostly associated with late Pleistocene Lake Bonneville, which is largely contemporaneous with the last glacial advance, the Pinedale glaciation (marine oxygen-isotope stage 2; Oviatt and others, 1992, 1999). Lips and others (2005) estimated that the Pinedale maxima occurred from about 17 to 15 ka based on ^{10}Be exposure ages measured from moraines at Little Cottonwood Canyon in the Wasatch Range near Salt Lake City. Bull Lake and Pinedale glacial deposits are found on the flank of Mount Timpanogos in the northeast corner of the Orem quadrangle.

Other surficial deposits in the quadrangle are mostly younger than Lake Bonneville and reflect post-glacial landscape evolution. Catastrophic overflow of the lake's threshold in southern Idaho (Jarrett and Malde, 1987; O'Conner, 1993) and warming climatic conditions reduced the size of Lake Bonneville, ultimately leaving remnants such as Utah Lake stranded in Bonneville sub-basins. Utah Lake deposits, mapped below the elevation of the Utah Lake threshold of 4500 feet (1372 m) at the northern end of the lake (Jordan Narrows), are found on the margins of modern Utah Lake in the southwest corner of the Orem quadrangle. With the regression of Lake Bonneville, streams incised in response to the lowering base level, depositing alluvium in the channel and floodplain of the Provo River inset in Lake Bonneville deltaic deposits east of Orem and in smaller streams and alluvial fans in range-front drainages. Locally, steeper slopes underlain by shoreline deposits of Lake Bonneville failed, and parts of weakened megabreccia blocks reactivated and moved downslope, with some slope failures perhaps associated with earthquakes on the Wasatch fault zone; this process of landsliding continues sporadically today. Wind locally reworked Lake Bonneville sands into eolian blankets and small dunes, and eroded finer-grained desiccated Bonneville lake beds, depositing a thin but widespread mantle of calcareous loess on stable geomorphic surfaces. The loess is friable to moderately firm, homogenous, nonstratified, and porous, and forms steep to vertical faces where exposed in stream cuts; most argillic B horizons of late Pleistocene-age soils in the region are formed in this loess (Machette, 1992), which is typically 3 to 5 feet (1-1.5 m) thick.

Lake Bonneville

Deposits and shorelines of Pleistocene Lake Bonneville dominate the surficial geology of the Orem quadrangle. Lake Bonneville was a large pluvial lake that covered much of northwestern Utah and adjacent parts of Idaho and Nevada. The lake began to rise above levels comparable to those of Holocene Great Salt Lake after about 35,000 calendar years ago (CRONUS-Earth Project, 2005). Four regionally extensive shorelines of Lake Bonneville are found in the Bonneville Basin. Gilbert (1890) identified the earliest three of these shorelines (the Stansbury, Bonneville, and Provo shorelines) in the first comprehensive study of Lake Bonneville over a century ago, and Eardley and others (1957) later defined the youngest shoreline (the Gilbert shoreline). Currey (1980) published an important summary of the lake, refining many previously published interpretations of lake-level change in the Bonneville basin, and mapped at a reconnaissance scale all four major shorelines in the vicinity of Great Salt Lake. Oviatt and Thompson (2002) reviewed additions to the geologic literature of Lake Bonneville published after 1980, summarizing many recent changes in the interpretation of Lake

Bonneville radiocarbon chronology, and research has continued since. We include more recent changes in Lake Bonneville chronology in table 1, which shows references for the following discussion of the lake.

Each shoreline is actually a composite of multiple shorelines that formed as the lake level fluctuated within a short vertical interval. Only the two highest and most prominent (the Bonneville and Provo shorelines) are present in the quadrangle. The earliest of the regional shorelines is the Stansbury, which resulted from a climatically induced lake-level oscillation from about 27,000 to 24,000 years ago (dates in this section are calendar dates) during expansion (transgression) of Lake Bonneville. The Stansbury shoreline formed at elevations below the Utah Valley threshold and thus did not occupy the quadrangle. The lake continued to rise, entering the quadrangle from the north at an elevation of about 4500 feet (1370 m) about 23,000 years ago. In the Bonneville Basin, the lake reached its highest level about 18,300 years ago, controlled by a threshold near Zenda, in southern Idaho. This highstand created the Bonneville shoreline, which can be traced over most of northwest Utah. The Bonneville shoreline forms the highest bench near the base of the Wasatch Range in the Orem quadrangle (table 1).

About 17,400 years ago, catastrophic overflow and rapid downcutting through the Zenda threshold resulted in lowering of the lake by 340 feet (100 m) (Jarrett and Malde, 1987), perhaps in less than one year (O'Conner, 1993). Lake Bonneville then stabilized at a new lower threshold near Red Rock Pass, Idaho, and the Provo shoreline began to form on the piedmont slope.

The lake oscillated at or near the Provo level as intermittent landsliding and subsequent scour of alluvium in the outlet channel near Red Rock Pass caused the lake level to fluctuate (Currey and Burr, 1988). Rivers flowing into the lake at or near the Provo level formed large deltas, such as the Provo River delta in the Orem quadrangle. About 14,600 years ago, climatic factors induced further lowering of the lake level within the Bonneville Basin (Godsey and others, 2005). As Lake Bonneville fell below the elevation of the natural threshold of Utah Valley at the northern end of the valley, Utah Lake became isolated from the main body of Lake Bonneville (Machette, 1992). By about 13,500 years ago, the level of Lake Bonneville had fallen below the elevation of present Great Salt Lake (Currey and others, 1988; Godsey and others, 2005), but a subsequent minor expansion of Lake Bonneville between about 12,500 to 11,500 years ago formed the Gilbert shoreline (Oviatt and others, 2005). During the Gilbert expansion of Lake Bonneville, Utah Lake drained into Lake Bonneville through the Jordan River, thus preventing the Gilbert expansion from reaching Utah Valley (Machette, 1992). However, the level of Utah Lake also rose at this time (table 1). After formation of the Gilbert shoreline, Lake Bonneville had fallen to near the current level of Great Salt Lake, leaving Great Salt Lake and Utah Lake as its two most prominent remnants.

Isostatic rebound following overflow of Lake Bonneville, as well as displacement along the Wasatch fault zone, uplifted regionally extensive shorelines in the Bonneville basin (Crittenden, 1963; Currey, 1982; Bills and others, 2002). The amount of isostatic uplift increases toward the center (deepest part) of the basin where the volume of removed water was greatest; Crittenden (1963) originally estimated a maximum isostatic uplift of 210 feet (64 m) near the Lakeside Mountains west of Great Salt Lake, but Currey (1982) estimated maximum isostatic uplift of 240 ft (74 m) using additional topographic data and aerial photographs. Machette (1992) reported combined isostatic and fault uplift of the Bonneville and Provo shorelines as much as 110 feet (34 m) and 65 feet (20 m), respectively, along the Wasatch fault zone in eastern Utah Valley. In the Orem quadrangle, combined isostatic and fault uplift of both shorelines on the footwall of the fault approaches the maximum recorded by Machette (1992). The maximum elevation of the Bonneville shoreline in the Orem quadrangle is about 5180 feet (1580 m) compared to its threshold elevation of 5092 feet (1552 m) at Zenda, and the maximum elevation of the Provo shoreline in the quadrangle is about 4790 feet (1460 m) compared to its threshold elevation of 4737 feet (1444 m) at Red Rock Pass (table 1). Thus, the combined uplift of the Bonneville and Provo shorelines in the quadrangle is about 88 feet (28 m) and 53 feet (16 m), respectively.

Paleoseismology

Utah Valley is a structural basin formed by late Cenozoic (younger than 18 Ma) displacement along the Wasatch fault zone and associated Basin-and-Range faults. Quaternary fault scarps indicate significant seismic hazards in the quadrangles, with potential earthquakes from moment magnitude 7.0 to 7.5 (Machette and others, 1992; Wells and Coppersmith, 1994). Paleoseismic data from a trench near Rock Canyon in the Orem quadrangle (SW1/4 section 29, T. 6 S., R. 3 E., SLBLM) indicate that the most recent large earthquake produced about 10.8 feet (3.3 m) of net vertical tectonic displacement of the ground surface (Lund and Black, 1998). Based on currently available information on earthquake timing and displacement, the preferred vertical slip-rate estimate for the Provo segment is 1.2 mm/yr, but has a possible range from 0.6 to 3.0 mm/yr (Lund, 2005). Lund (2005) indicated the three most recent surface-faulting events occurred on the segment at 600 ± 350 cal yr B.P., 2850 ± 650 cal yr B.P., and 5300 ± 300 cal yr B.P., with a preferred recurrence-interval estimate of 2400 years (possibly ranging from 1200 to 3200 years). However, preliminary results from new trenching in Mapleton (NE1/4 section 23, T. 8 S., R. 3 E., SLBLM) 8 miles (13 km) southeast of Provo indicate that the interval from the middle Holocene to latest Pleistocene may include several more surface-faulting earthquakes, and an additional late Holocene earthquake at about 1600 cal yr B.P. (Olig and others, 2004, 2009). These results suggest a recurrence interval much shorter than 2400 years for major earthquakes in Utah Valley.

Slope Failures

Geologic materials susceptible to slope failure underlie much of the Wasatch Range front in the Orem quadrangle. Of particular concern are megabreccia deposits (QTmb) and landslide deposits (Qms), both of which are vulnerable to new movement. The parts of the Manning Canyon Shale and Great Blue Limestone with significant amounts of shale are also prone to failure. Rocks along the mountain front have been highly dismembered by mass movements rooted to slope failure of the Manning Canyon Shale (Bryant, 1992; Machette, 1992). The flanks of Big Baldy and Little Baldy, particularly the south flank of Little Baldy, are riddled with landslide scarps, and incipient failure of the entire Big Baldy promontory is seen in the form of large east-west oriented “cracks” (mapped as tensional ridge crests) that bisect the mountain.

Kaliser and Slosson (1988, p. 49) noted the hazard posed by megabreccia deposits when they investigated a landslide at 1500 East Street in Provo; they found it consisted of a thin cover of Quaternary unconsolidated material on a landslide block of Mississippian shale. Baker (1964b) and Machette (1992) mapped a landslide on the north bank of the Provo River in Provo Canyon (Machette's unit clsy) that appeared to be a reactivated part of an older slide block. We map similar megabreccia deposits in the Orem quadrangle north of Little Rock Canyon along the Wasatch Range front and in lower Provo Canyon.

Historic reactivations of prehistoric deposits (both units QTmb and Qms) in the Orem quadrangle include the Sherwood Hills landslide complex in Provo, east of Orem (E1/2 section 18, T. 6 S., R. 3 E., SLBLM). In 1998, a house in the Sherwood Hills subdivision was demolished after being severely damaged by landslide movement sometime during the previous three years, and subsequent movement threatened additional buildings (Ashland, 2003). Another landslide occurred in similar material in 2005 on an adjacent horse ranch (Ashland, 2006). In the adjacent Timpanogos Cave quadrangle, a landslide in comparable deposits about 0.5 mile (0.8 km) south of American Fork Canyon moved in 1983 (Machette, 1992), and renewed movement in 2005 damaged two condominiums (Ashland and McDonald, 2005).

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MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

Qai **Alluvial silt deposits** (Holocene to upper Pleistocene) – Silt and minor clay, sand, and gravel, deposited by streams and sheetwash in two lagoonal areas behind transgressive Lake Bonneville barrier beaches on the north side of the mouth of Battle Creek Canyon, above the Provo shoreline and below the Bonneville shoreline; thickness less than about 10 feet (3 m).

Qal_1 **Level-1 stream deposits** (upper Holocene) – Moderately sorted pebble and cobble gravel with a matrix of sand, silt, and minor clay; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded. Mapped along the Provo River (south of the mouth of Provo Canyon) in its channel, on its active floodplain, and on minor terraces less than 5 feet (1.5 m) above its channel; locally includes minor colluvial deposits along steep stream embankments; equivalent to the younger part of young stream deposits (Qaly), but differentiated where active channels and bar-and-swale topography can be mapped separately. Exposed thickness less than 15 feet (5 m).

Qaly **Young stream deposits, undivided** (Holocene to upper Pleistocene) – Moderately sorted pebble and cobble gravel with a matrix of sand and minor silt and clay. Deposited by the Provo River in Provo Canyon, by a small ephemeral stream in Lindon west of the mouth of Sumac Hollow, and in small channels southwest of Orem; locally includes areas of small alluvial-fan and colluvial deposits; includes middle Holocene to upper Pleistocene stream deposits incised by active stream channels and partly overlain by level-1 stream deposits (Qal_1) that are too small to show at map scale or where the specific age of Holocene deposits cannot be determined; postdates regression of Lake Bonneville from the Provo shoreline and lower levels. Thickness variable, probably less than 15 feet (5 m).

Qalp **Stream deposits, regressive (Provo) phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted pebble and cobble gravel with a matrix of sand, silt, and minor clay; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded; mapped as stream deposits where found in channels rather than on terraces. Deposited (1) in channels along the front of the Provo River delta in Lindon and Orem, incised into Lake Bonneville deltaic deposits (Qldp) and regressive Lake Bonneville sand and silt (Qlsp) and commonly truncated by minor regressive shorelines, (2) in a channel along the front of the Rock Canyon delta in Pleasant View, incised into regressive Lake Bonneville deposits of silt and clay (Qlmp) and “hanging” above Holocene alluvial-fan deposits (Qafy), and (3) above the Provo shoreline in abandoned channels incised into sand and silt of the transgressive phase of Lake Bonneville (Qlsb) at three locations between the mouths of Provo Canyon and Rock Canyon; at the two northern locations above the Provo shoreline regressive-phase stream deposits lie on terraces incised by active stream channels, at the southern location deposits are found in relatively shallow channels beheaded by the Wasatch fault zone, and deposits at both locations are truncated by young alluvial-fan deposits (Qafy); regressive-phase stream deposits probably underlie proximal alluvial-fan deposits in similar channels between the two locations, but these channels are steep-sided and v-shaped, and are continuous with drainages from the Wasatch Range across the Wasatch fault zone, suggesting continued erosion and deposition into the Holocene. Exposed thickness less than 15 feet (5 m).

Qat_{1-10} **Stream-terrace deposits** (middle Holocene to upper Pleistocene) – Poorly to moderately sorted pebble and cobble gravel with a matrix of sand, silt, and minor clay; contains thin sand lenses; subangular to rounded clasts; thin to medium bedded. Mapped on ten levels of gently sloping terraces, with subscripts denoting relative position above modern stream channels in downcutting sequence, with 1 being the lowest level; level 1 deposits (Qat_1) lie 5 to 15 feet (1.5-5 m) above the Provo River and are incised by them; levels 2 through 7 lie at increasing relative heights of 15 to 25 feet (5-8 m) (Qat_2), 40 to 50 feet (12-15 m) (Qat_3), 50 to 60 feet (15-18 m) (Qat_4), 60 to 70 feet (18-21 m) (Qat_5), 70 to 90 feet (21-27 m) (Qat_6), and 80 to 110 feet (24-34 m) (Qat_7) above modern streams; and levels 8 through 10 lie at increasing relative heights above level 7 near the mouth of Provo Canyon, though each level is only a few feet above the adjacent lower level; numbered subscripts do not indicate specific age. The most extensive deposits are adjacent to the Provo River, where the highest (oldest) terraces (Qat_8 through Qat_{10}) are incised into alluvial-fan deposits of the regressive phase of Lake Bonneville (Qafp) that grade downslope to regressive Lake Bonneville deltaic deposits (Qldp), intermediate terraces (Qat_3 through Qat_7) are graded to the steep delta front, and the lowest (youngest) terraces (Qat_1 and Qat_2) are incised into the delta, suggesting a late Pleistocene to middle Holocene age; terrace remnants near Rock Canyon (Qat_5 and Qat_6) are graded to a smaller Lake Bonneville delta emanating from that canyon. Thicknesses typically 5 to 15 feet (1.5-5 m) for each map unit.

Qaf_1 **Level-1 alluvial-fan deposits** (upper Holocene) – Poorly to moderately sorted, weakly to non-stratified, pebble to cobble gravel with a matrix of sand, silt, and minor clay; clasts commonly well-rounded, derived from Lake Bonneville gravel; medium to very thick bedded. Deposited by debris flows, debris floods, and streams at the mouth of Rock Canyon; equivalent to the younger part of young alluvial-fan deposits (Qafy) but differentiated because these small, active, discrete fans are not incised by younger channels and can be mapped separately. Exposed thickness less than 10 feet (3 m).

Qaf_2 **Level-2 alluvial-fan deposits** (middle Holocene to upper Pleistocene) – Poorly sorted pebble and cobble gravel, locally bouldery, with a matrix of sand, silt, and minor clay; clasts angular to subrounded, with sparse well-rounded clasts derived from Lake Bonneville gravel; medium to very thick bedded. A small part of a much larger fan complex in the adjacent Pelican Point quadrangle (Solomon and others, 2009) is present in the northwest corner of the Orem quadrangle; the fans were deposited by debris flows, debris floods, and stream flow from American Fork as the river lost confinement beyond the American Fork delta front in the adjacent Lehi quadrangle (Biek, 2005); equivalent to the older part of Qafy, but differentiated where deposits are graded slightly above modern stream level and can be mapped separately. Exposed thickness less than 15 feet (5 m).

Qafy **Young alluvial-fan deposits, undivided** (Holocene to upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel with boulders near bedrock sources, with a matrix of sand, silt, and clay, grading to mixtures of sand, silt, and clay on gentler slopes. Deposited by debris flows, debris floods, and streams in three physiographic settings: (1) at the mouths of streams draining the Wasatch Range front where alluvial-fan deposits have locally incised Bonneville shoreline deposits (Qlgb and Qlsb) and typically form a coalesced apron overlapping offshore deposits (Qlmb and Qlmp), (2) at the mouths of side canyons draining into Provo Canyon, and (3) at the mouths of small streams draining the steep Provo delta front near Utah Valley University. Includes level-1 and level-2 alluvial-fan deposits (Qaf_1 and Qaf_2) that postdate the regression of Lake Bonneville from the Provo shoreline and lower levels, and either cannot be differentiated because of map scale or are in areas where the specific age of Holocene deposits cannot be determined; no Lake Bonneville shorelines are found on these alluvial fans. Thickness variable, probably less than 40 feet (12 m).

Qafp **Alluvial-fan deposits, regressive (Provo) phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and minor clay; clasts typically angular but well rounded where derived from Lake Bonneville gravel; medium to very thick bedded. Deposited by debris flows, debris floods, and stream flow: (1) west of the mouth of Provo Canyon, grading downslope to regressive Lake Bonneville deltaic deposits (Qldp); (2) near the mouth of Dry Canyon, incised into and covering transgressive Lake Bonneville silt and clay (Qlmb), and graded to the Provo shoreline; and (3) at the mouth of a small drainage along the steep Provo delta front northeast of the community of Lakeview, truncated by a minor regressive Lake Bonneville shoreline. The large deposit west of the mouth of Provo Canyon was mapped by Machette (1992) as stream alluvium related to the regressive phase of Lake Bonneville, however the deposit has a fan-shaped morphology and grades downslope to deltaic deposits (Qldp), representing the subaerial part of the fan-delta complex; stream-terrace deposits (Qat_3 through Qat_{10}) incised into the alluvial fan are younger, extending to lower elevations along the delta front. The B soil horizon of paleosols developed on regressive-phase alluvial-fan deposits commonly shows an intensification of brown colors due to oxidation of iron-bearing minerals or a slight accumulation of clay, and may include a pedogenic accumulation of calcium carbonate as thin, discontinuous coatings on gravel; Machette (1992), using the terminology of Birkeland (1984), designated the soil profile of this unit and others of similar age as A/Bw/Bk(or Cox) to A/Bt(weak)/Bk(or Cox). Exposed thickness less than 30 feet (10 m).

Qafb **Alluvial-fan deposits, transgressive (Bonneville) phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, locally bouldery, with a matrix of sand, silt, and minor clay; clasts angular to subangular; medium to very thick bedded. Deposited by debris flows, debris floods, and stream flow; perched above the mouth of Provo Canyon and in a small exposure between Provo and Dry Canyons, and graded to the highest (Bonneville) shoreline of Lake Bonneville. The B soil horizon of paleosols developed on transgressive-phase alluvial-fan deposits commonly shows a slight to moderate accumulation of clay and may include a pedogenic accumulation of calcium carbonate as filaments in fine-grained soil or thin, discontinuous coatings on gravel; Machette (1992), using the terminology of Birkeland (1984), designated the soil profile of this unit as A/Bt/Bk(or Cox).

Qafo **Older alluvial-fan deposits, pre-Bonneville lake cycle, undivided** (upper to middle Pleistocene) – Poorly sorted, pebble to cobble gravel, locally bouldery, with a matrix of sand, silt, and clay. Although Machette (1992) mapped remnants of these deposits (and his correlative deposits of fan alluvium, units 4 and 5) along the entire length of the Wasatch Range front in the Orem quadrangle, we restrict this unit to exposures with gently sloping (relict) surfaces above and cut by the Bonneville shoreline near Battle Creek in the northern part of the quadrangle; we remap other deposits of Machette (1992) as either landslide deposits (unit Qms) that have a steeper and irregular surface or as megabreccia deposits (unit QTmb) that are steep, deeply incised, and contain large blocks of bedrock. The B soil horizon of paleosols developed on the alluvial-fan deposits commonly shows a moderate to significant accumulation of clay, gravel is typically coated with calcium carbonate, and calcium carbonate may occur either as significant accumulations between clasts or as cement; Machette (1992), using the terminology of Birkeland (1984), designated the soil profiles of the differentiated units as A/Bt(moderate)/Bk(stage II-III)/Cox and A/Bt(strong)/Bk(stage II-III)/K(stage II)/Cox. Thickness probably less than 60 feet (20 m).

Glacial deposits

Qg, Qg?

Glacial deposits, undivided (early Holocene to middle Pleistocene) – Includes till (moraine deposits) and outwash of various ages (Pinedale and/or Bull Lake ages) deposited east of Big Baldy at the head of Dry Canyon; till is non-stratified, poorly sorted clay, silt, sand, cobbles, and boulders; outwash is stratified and variably sorted, but better sorted and bedded than till due to alluvial reworking; all glacial deposits locally include mass-movement and colluvial deposits (Qms, Qmt, Qct) too small to show separately at map scale; thickness less than 150 feet (45 m). Queried where glacial origin uncertain due to the lack of a well-developed upslope cirque.

Qgm **Glacial moraine deposits** (early Holocene to middle Pleistocene) – Till; mapped where distinct shapes of end, recessional, and lateral moraines are visible east of Big Baldy at the head of Dry Canyon. Thickness less than 150 feet (45 m).

Fill deposits

Qf **Artificial fill** (Historical) – Earth fill used in the construction of (1) elevated sections of U.S. Interstate Highway 15, (2) the site of the former Geneva Steel plant (near the town of Vineyard), including levees bounding abandoned cooling ponds, and (3) embankments for debris basins at the mouths of Rock, Battle Creek, and Grove Creek Canyons; unmapped fill is locally present in most developed areas, but only the largest deposits are mapped. Maximum thickness about 20 feet (6 m).

Qfd **Disturbed land** (Historical) – Land disturbed by (1) borrow pits used to remove soil from Lake Bonneville deposits (Qlmp) for fill and foundation material near the former Geneva Steel plant; (2) sand, gravel, and aggregate operations in the Provo River delta (Qldp) and nearshore Lake Bonneville deposits (Qlgb); and (3) debris basins at the mouths of Rock, Battle Creek, and Grove Creek Canyons. The outlines of disturbed land are based on 1965 aerial photographs, updated using the 1998 orthophotographic quadrangles; only the larger areas of disturbed land are mapped, and many sites have since been regraded and developed and may contain unmapped deposits of artificial fill (Qf); land within the Orem quadrangle contains a complex, rapidly changing mix of cuts and fills. Thickness unknown.

Qfs **Slag deposits** (Historical) – Material produced from the steelmaking process (slag) and accumulated in mounds at the former site of the Geneva Steel plant. Maximum thickness about 70 feet (20 m).

Lacustrine deposits

Deposits younger than the Bonneville lake cycle: Only mapped below the Utah Lake highstand (“U” shoreline on map), which is at elevations from about 4495 to 4500 feet (1370-1372 m) in the Orem quadrangle (table 1).

Qlsy **Young lacustrine sand and silt** (Holocene to upper Pleistocene) – Well-sorted, fine to medium sand and silt that forms beach deposits at Utah Lake’s high stand near Powell Slough and barrier beaches below the high stand. Maximum thickness about 5 feet (1.5 m).

Qlmy **Young lacustrine silt and clay** (Holocene to upper Pleistocene) − Silt, clay, and minor fine-grained sand deposited along the margin of Utah Lake; locally organic rich and locally includes pebbly beach gravel; overlies sediments of the Bonneville lake cycle. Brimhall and others (1976) reported that Holocene gray clayey silt composed mostly of calcite forms the upper 15 to 30 feet (5-10 m) of sediment on the bottom of Utah Lake.

Deposits of the regressive (Provo) phase of the Bonneville lake cycle: Only mapped below the Provo shoreline ("P" shoreline on map), which is at elevations from about 4750 to 4790 feet (1450-1460 m) in the Orem quadrangle (table 1). Currey (1982) estimated a maximum elevation of 4738 feet (1444 m) for the Provo shoreline on a northwest-facing beach ridge in Lindon in the northwest corner of the quadrangle (NW1/4 section 34, T. 5 S., R. 2 E., SLBLM), but we believe that this ridge is a regressive beach superimposed on the steep front of the Provo River delta (Qldp) during a fluctuation slightly below the Provo high stand. We agree with Machette (1992), who placed the high stand about 0.8 mile (1.3 km) to the east, coinciding with the aligned western tips of erosional remnants of transgressive-phase lacustrine silt and clay (Qlmb) incised by regressive-phase alluvial-fan deposits (Qafp) graded to the Provo shoreline. At this location (E1/2 section 34, T. 5 S., R. 2 E., SLBLM), the Provo shoreline is at an elevation of about 4770 feet (1450 m).

The B soil horizon of paleosols developed on regressive-phase lacustrine deposits commonly shows an intensification of brown colors due to oxidation of iron-bearing minerals or a slight accumulation of clay, and may include a pedogenic accumulation of calcium carbonate as filaments in fine-grained soil or thin, discontinuous coatings on gravel; Machette (1992), using the terminology of Birkeland (1984), designated the soil profile of these units as A/Bw/Bk(or Cox) to A/Bt(weak)/Bk(or Cox).

Qldp **Deltaic deposits** (upper Pleistocene) – Moderately to well-sorted, clast-supported, pebble and cobble gravel with a matrix of sand and silt; interbedded with thin pebbly sand beds; clasts subrounded to rounded; locally weakly cemented with calcium carbonate. Deposited as bottomset beds having original dips of 1 to 5 degrees and overlying foreset beds having original dips of 30 to 35 degrees; exposed along the steep delta fronts of the larger Provo River delta in the western part of the Orem quadrangle and the smaller delta at the mouth of Rock Canyon in the southeast corner of the quadrangle, and also exposed in bluffs along stream terraces where the Provo River and the creek from Rock Canyon incised the deltas; bluff exposures near the mouth of Provo Canyon may include deposits of regressive-phase alluvial fans that are part of the fan-delta complex but cannot be differentiated because of similar texture; the fan-delta complex is commonly capped by a thin veneer of stream-terrace deposits (Qat_3 through Qat_{10}) and by regressive-phase alluvial-fan deposits (Qafp). Exposed thickness about 75 feet (25 m).

Qlgp **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, clast-supported, pebble to cobble gravel and pebbly sand with minor silt. Gastropods locally common in sandy lenses; gravel commonly cemented with calcium carbonate (tufa); thin to thick bedded. Deposited in relatively shallow water near shore as linear beaches along the Provo River delta front at one location east of the site of the former Geneva Steel Plant; commonly interbedded with or laterally gradational to lacustrine sand and silt of the regressive phase (Qlsp). Exposed thickness less than 15 feet (5 m).

Qlsp **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel. Thick to very thick bedded, commonly laminated, with some ripple marks and scour features; gastropods locally common. Deposited in relatively shallow water near shore as linear beaches close to the Provo shoreline near the mouth of Grove Creek in Pleasant Grove, and along the Provo River and Rock Canyon delta fronts; erosional remnants are incised by young alluvial-fan deposits (Qafy) near the mouths of Grove Creek and Rock Canyon; near Grove Creek, overlies and grades downslope into lacustrine silt and clay of the regressive phase (Qlmp); locally buried by loess veneer and reworked into eolian deposits (Qes) along the delta front. Exposed thickness less than 30 feet (10 m).

Qlmp **Lacustrine silt and clay** (upper Pleistocene) – Calcareous silt (marl) and clay with minor fine sand; typically laminated or thin bedded; ostracodes locally common. Deposited below the Provo shoreline in quiet water in moderately deep parts of the Bonneville basin and in sheltered bays; overlies lacustrine silt and clay of the transgressive phase (Qlmb) and commonly grades upslope into lacustrine sand and silt (Qlsp); locally buried by loess veneer; regressive lacustrine shorelines typically poorly developed. Regressive silt and clay is extensive down slope from the Provo River delta and, near Powell Slough, is incised by abandoned stream channels filled with marsh deposits (Qsm) and young alluvium (Qaly) graded to the Utah Lake high stand. Machette (1992) reported that silt and clay of the regressive phase can be differentiated from silt and clay of the transgressive phase by the presence of conchoidal fractures in blocks of transgressive deposits and their absence in regressive deposits, but Qlmp may include some undifferentiated transgressive deposits. Exposed thickness less than 15 feet (5 m), but total thickness may exceed several tens of feet.

Deposits of the transgressive (Bonneville) phase of the Bonneville lake cycle: Mapped between the Bonneville and Provo shorelines. The highest Bonneville shoreline ("B" shoreline on map) is at elevations from about 5160 to 5180 feet (1570-1580 m) in the Orem quadrangle (table 1). The B soil horizon of paleosols developed on transgressive-phase lacustrine deposits commonly shows a slight to moderate accumulation of clay and may include a pedogenic accumulation of calcium carbonate as filaments in fine-grained soil or thin, discontinuous coatings on gravel; Machette (1992), using the terminology of Birkeland (1984), designated the soil profile of these units as A/Bt/Bk(or Cox).

Qlgb **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, clast-supported pebble to cobble gravel with a matrix of sand and silt; locally interbedded with thin to thick beds of silt and pebbly sand; clasts commonly subrounded to rounded, but some deposits consist of poorly sorted, angular gravel derived from nearby bedrock outcrops; gastropods locally common in sandy lenses; gravel locally cemented with calcium carbonate (tufa); thin to thick bedded. Located near the base of the Wasatch Range from the vicinity of Provo Canyon northward and south of Rock Canyon, and in lower Provo Canyon; deposits typically form wave-cut or wave-built benches close to the Bonneville shoreline; wave-cut benches are commonly partly covered by colluvium derived from adjacent oversteepened slopes. Bedding ranges from horizontal to primary dips of 10 to 15 degrees on steeper piedmont slopes; interbedded with or laterally gradational to lacustrine sand and silt of the transgressive phase (Qlsb). Exposed thickness less than 30 feet (10 m).

Qlsb **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel. Thick to very thick bedded; commonly has ripple marks and scour features; gastropods locally common. Deposited in relatively shallow water near shore near the base of the Wasatch Range, exposed in erosionally resistant bluffs; overlies coarse-grained beach gravel (Qlgb), implying deposition in increasingly deeper water of a transgressing lake. Exposed thickness less than 15 feet (5 m).

Qlmb **Lacustrine silt and clay** (upper Pleistocene) – Calcareous silt (marl) and clay with minor fine sand; typically thick bedded or very thick bedded; ostracodes locally common. Deposited near the base of the Wasatch Range in quiet water, either in a sheltered bay between headlands or offshore in deeper water; overlies lacustrine gravel, sand, and silt of the transgressive phase (Qlgb and Qlsb). Between Dry Canyon and Grove Creek Canyon, deposits of Qlmb are extensively incised by alluvial fans (Qafy and Qafp), and the tips of several erosional remnants of the lacustrine silt and clay are aligned along the Provo shoreline; south of Rock Canyon, we reinterpret much of what was mapped as transgressive silt and clay by Machette (1992) as regressive deposits because they lie below a faint Provo shoreline (P) at an elevation of 4780 feet (1460 m). Exposed thickness less than 15 feet (5 m).

Eolian deposits

Qes **Eolian sand** (Holocene to upper 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 blankets and small dunes; wind-blown sand derived from regressive Bonneville beach sand (Qlsp) and sandy deltaic deposits (Qldp) along the Provo River delta front. Thickness from 3 to 10 feet (1-3 m).

Mass-movement deposits

Qmd **Debris-cone deposits** (Holocene to middle Pleistocene) – Mostly unsorted coarse sand to angular boulders with a lesser matrix of sand, silt, and clay; forms fan-shaped aprons at the base of steep slopes underlain by the Oquirrh Formation; debris-flow and talus deposits, with some slopewash and creep material; locally, likely includes glacial outwash. Thickness less than 60 feet (18 m).

Qmdf **Debris-flow deposits** (Holocene to middle Pleistocene) – Unsorted cobble and boulder gravel in a matrix of sand, silt, and clay; mapped separately from alluvial-fan deposits due to distinct overlapping levees and channels; mapped on mountain slopes as fan-shaped aprons where slope gradients decrease below steep slopes and channels lose confinement, and as linear deposits in drainages. Thickness less than 60 feet (20 m).

Qmdt **Talus-cone deposits** (Holocene to middle Pleistocene) – Mostly angular and coarse debris in unvegetated fan-shaped deposits at the base of steep drainages, and upslope filling the narrow drainages on steep, sparsely vegetated bedrock slopes; predominantly talus with lesser debris-flow deposits, and some slopewash and creep material. Thickness less than 30 feet (10 m).

Qms **Landslide deposits** (Historical to middle Pleistocene) – Poorly sorted clay- to boulder-sized material in slides, slumps, and flows, with grain size varying with the nature of source material; characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced bedrock; extensive deposits are mapped along the Wasatch Range front and in Provo Canyon, mostly above the Bonneville shoreline, and include large bedrock blocks derived from bedrock failures and renewed movement of megabreccia (QTmb); smaller deposits are north of Battle Creek derived from Pleistocene alluvial-fan deposits (Qafo) and south of Rock Canyon derived from failure of nearshore transgressive deposits of Lake Bonneville (Qlsb and Qlgb); includes historic slope failures; morphology becomes subdued with age and amount of water in deposits. Thickness highly variable; near Provo Canyon, Qms grades into megabreccia (QTmb) of bedrock blocks and is at least 200 feet (60 m) thick.

Qmt **Talus deposits** (Holocene to middle Pleistocene) − Very poorly sorted, angular debris (gravel to boulders) and minor amounts of finer-grained interstitial sediment typically deposited by rock fall on and at the base of steep slopes; mapped in the northeast part of the quadrangle on the southwest-facing mountain flank east of Big Baldy and Little Baldy, in Big Provo Cirque, and on the south side of Provo Canyon near its mouth. Generally less than 20 feet (6 m) thick.

Spring and marsh deposits

Qsm **Spring and marsh deposits** (Holocene to upper Pleistocene) – Fine, organic-rich sediment associated with springs, ponds, seeps, and wetlands; commonly wet, but seasonally dry; may locally contain peat deposits as thick as 3 feet (1 m); overlies lacustrine silt and clay (Qlmp and Qlmy) and grades laterally into young lacustrine silt and clay (Qlmy); present where water table is high near Powell Slough, and commonly fills abandoned stream channels above the Utah Lake highstand. Thickness commonly less than 10 feet (3 m).

Mixed-environment deposits

Qac **Alluvial and colluvial deposits, undivided** (Holocene to middle Pleistocene) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment mapped in Provo Canyon, where deposits of alluvium, slopewash, and creep grade into one another; small, unmapped deposits are likely in most small drainages. Thickness less than 10 feet (3 m).

Qct **Colluvial and talus deposits, undivided** (Holocene to middle Pleistocene) – Deposits of gravel and angular debris, with a finer grained matrix, deposited on and at the base of steep slopes underlain by the Oquirrh Formation, where deposits of slopewash, creep, and rock fall grade into one another. Thickness less than 30 feet (10 m).

Qle **Lacustrine and eolian deposits, undivided** (Holocene to upper Pleistocene) – Sand, silt, and clay in areas of mixed lacustrine and eolian deposits that are undifferentiated because the units grade into one another; characterized by sandy intervals of finer-grained lacustrine deposits (Qlmp) that are reworked by wind; mapped near the site of the former Geneva Steel plant. Thickness less than 10 feet (3 m).

Qmc **Landslide and colluvial deposits, undivided** (Holocene to middle Pleistocene) – Deposits of landslides (slides and slumps), slopewash, and soil creep that grade into one another in areas of subdued morphology, where mapping colluvium separately from landslides is not possible at map scale; composition and texture depend on local sources; mapped on the south side of Provo Canyon in northwest-trending linear zones in Manning Canyon Shale (Mmc) and Great Blue Limestone (Mgb); likely formed by incipient failure of underlying Manning Canyon Shale, similar to the formation of megabreccia (QTmb) north of Provo Canyon. Thickness less than 40 feet (12 m).

Qmg **Mass-movement and glacial deposits, undivided** (Holocene to upper Pleistocene) – Glacial deposits in displaced masses, where glacial morphology is indistinctly preserved and the relationship between the two types of deposits is uncertain; mapped southeast of Little Baldy, downslope of undivided glacial deposits (Qg). Thickness less than 30 feet (9m).

Stacked-unit deposits

Qlgb/Qafo

Lacustrine gravel and sand (transgressive phase) over older alluvial-fan deposits (upper Pleistocene/upper to middle Pleistocene) – A veneer of lacustrine gravel and sand related to the transgressive phase of Lake Bonneville reworked from underlying alluvial-fan deposits older than Lake Bonneville; mapped on the northern edge of the Orem quadrangle near the mouth of Grove Creek Canyon, between the Provo and Bonneville shorelines. Lacustrine deposits are generally less than 3 feet (1 m) thick.

QUATERNARY-TERTIARY

QTmb **Megabreccia deposits** (Pleistocene to Pliocene?) – Includes nearly intact bedrock megabreccia blocks, large bedrock blocks and rubble, and younger Quaternary landslide deposits; younger deposits (Qms) are mapped separately where they can be differentiated by the presence of distinct hummocky topography and arcuate scarps; megabreccia deposits commonly include ridges that form next to tension cracks as bedrock is pulled apart, and bedding that is discordant with regional structure; formed by displacement of the Permian to Pennsylvanian Oquirrh Formation on underlying Manning Canyon Shale (Mmc), with movement into Provo Canyon and down the Wasatch Range front north of Rock Canyon; the main member of the Oquirrh Formation involved is the Permian Granger Mountain Member (Pogm); where possible, megabreccia blocks composed of a single map unit are mapped separately, with the bedrock unit identified in parentheses within the label—for example, QTmb(Mmc). Previously shown as complex thrust faulting by Baker (1964b). Thickness highly variable.

Major unconformity

PERMIAN-PENNSYLVANIAN

The Oquirrh Group/Formation was deposited in the marine Oquirrh basin of north-central Utah and southern Idaho, with sand derived principally from the Weber shelf and Uncompahgre Uplift (Welsh and Bissell, 1979). Terminology and subdivision of the Oquirrh Group/Formation and associated Permian strata vary by author (compare, for example, Welsh and James, 1961; Tooker and Roberts, 1970; Swenson, 1975; Morris and others, 1977; Welsh and Bissell, 1979; Jordan and Douglas, 1980; Biek, 2004; Biek and Lowe, 2009; Hintze and Kowallis, 2009) because a comprehensive regional study of the basin, including thrust plate and paleogeographic location, has not been conducted. Thus, differing terminology has been applied west and east of Utah and Salt Lake Valleys (figure 3). In the Oquirrh Mountains, Lake Mountains, and West Mountain, the Pennsylvanian strata of the Oquirrh Group are divided into three formations and are overlain by the Permian Freeman Peak and Curry Peak Formations. In the Wasatch Range, including the Orem quadrangle, the Oquirrh Formation includes Pennsylvanian and Permian strata and is divided into, in ascending order: the Pennsylvanian Bridal Veil

Limestone, Bear Canyon, Shingle Mill Limestone, and Wallsburg Ridge Members, and the Permian Granger Mountain Member. Only the Bridal Veil Limestone, Bear Canyon, and Granger Mountain Members of the Oquirrh Formation are present in the Orem quadrangle.

Oquirrh Formation

PIPo **Oquirrh Formation, undivided** (Lower Permian to Lower Pennsylvanian) − Only identified in megabreccia blocks, where either the member present is not known or more than one member is in a block.

Pogm **Oquirrh Formation, Granger Mountain Member** (Lower Permian, Wolfcampian) − Gray, tan-weathering, calcareous, 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. Present in Little Baldy and Big Baldy knobs and as megabreccia blocks (QTmb); thickness in quadrangle not known, but 8200 to 10,255 feet (2500-3125 m) thick on Wallsburg Ridge (after Baker, 1976, using the contact of Constenius and others, 2006; Welsh, 1981, unpublished; respectively).

IPobc **Oquirrh Formation, Bear Canyon Member** (Middle Pennsylvanian, Desmoinesian to Atokan) − Gray to tan, limy to quartzitic sandstone with interbedded gray to black, thin- to thick-bedded, cherty to locally sandy limestone; about 4250 feet (1300 m) thick in area (after Baker, 1947, 1972); age from Baker (1976); latest Morrowan conodonts reported in lowest part of roughly equivalent strata in Bridal Veil Falls quadrangle (Shoore, 2004), but sample sites not well located and may be in underlying member (J.K. King, UGS, written communication, 2009).

IPobv **Oquirrh Formation, Bridal Veil Limestone Member** (Middle to Lower 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 in adjacent Bridal Veil Falls quadrangle 1245 feet (380 m) (Baker, 1972); contains Morrowan conodonts in Charleston quadrangle (Biek and Lowe, 2009); latest Chesterian (Late Mississippian) conodonts reported in lowest part of roughly equivalent West Canyon Limestone to west in Oquirrh Mountains (see Davis and others, 1994), but these conodonts are actually from the uppermost Manning Canyon Shale (J.K. King, UGS, written communication, 2009); Shoore and Ritter (2007) report that, to date, samples of Bridal Veil Limestone lack conodonts and foraminifera, limiting correlation with basal Oquirrh carbonates outside of the central Wasatch Range.

PENNSYLVANIAN?-MISSISSIPPIAN

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; shale is carbonaceous with a few nodules of marcasite; measured thickness in adjacent Bridal Veil Falls quadrangle 1650 feet (500 m) (Baker, 1972); age from macro-fossils (for example cephalopod *Eumorphoceras bisulcatum*) reported in Baker (1972), that are Chesterian in age (see Welsh and Bissell, 1979); Pennsylvanian age considered unlikely because definitive brachiopod, *Dictyoclostus hermosanus*, from Baker (1972) is actually Atokan, so brachiopod identification is unlikely (J.K. King, UGS, written communication, 2009).

MISSISSIPPIAN

Mgb **Great Blue Limestone** (Upper Mississippian, Chesterian? and 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; measured thickness 2800 feet (855 m) in Rock Canyon, adjacent Bridal Veil Falls quadrangle (Baker, 1947, 1972; after Chamberlain, 1981); series age after Chamberlain (1981). Black shale is prominent basal part in southwest Bridal Veil Falls quadrangle and in Orem quadrangle; described as basal unit 100 feet (30 m) thick and shown as 300 feet (90 m) thick by Crittenden (1959); Baker (1947) showed a roughly 700-foot (215-m) thick covered interval beginning 250 feet (75 m) above base at Rock Canyon; this shaly interval is in drainages north and south of Rock Canyon, Bridal Veil Falls quadrangle. In the Wasatch Range, Chamberlain (1981) showed about 75 feet (20 m) of shale near the base, overlain by about 300 feet (90 m) of limestone, with about 150 feet (45 m) of shale above that, and the remainder of the Great Blue section (~2200 feet [670 m]) mostly limestone; shaly interval(s) likely present along mountain front north of Provo Canyon, suggested by topographic benches. This shaly interval raises some questions about faulting and complexity in Great Blue Limestone and Manning Canyon Shale both north and south of Provo Canyon.

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, 1972).

Mde **Deseret Limestone** (Upper to Lower Mississippian) − Interbedded, thick-bedded limestone and dolomite with distinctive light- and dark-gray banded outcrops; fossil crinoids and coral common; black chert occurs as thin layers, blebs, and irregular masses in most beds and is locally very abundant; reportedly 375 feet (115 m) thick in Rock Canyon, Orem quadrangle (Baker, 1964b), but 575 feet (175 m) thick just to northeast in the Aspen Grove quadrangle (Baker, 1964a), although the contact between the Humbug Formation and Deseret Limestone may not have been consistently identified (J.K. King, UGS, written communication, 2010). The Delle Phosphatic Member is present at Rock Canyon, but is likely thinner than shown by Sandberg and Gutschick (1979).

Mg **Gardison Limestone** (Lower Mississippian) − Dark-gray, "stair-step"-forming, mostly thin-bedded limestone with scattered abundant light-brown to black chert; about 900 feet (275 m) thickness reported in Rock Canyon, Orem quadrangle (Baker, 1964b), but likely includes Deseret strata; about 600 feet (180 m) thick in Timpanogos Cave quadrangle (Baker, 1947; Baker and Crittenden, 1961).

MISSISSIPPIAN AND DEVONIAN

Mf **Fitchville Dolomite** (Lower Mississippian to 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; 265 feet (80 m) thick in Rock Canyon, Orem quadrangle (Baker, 1964b); Devonian age of dolomite at Rock Canyon from Sandberg and Gutschick (1979, p. 114). Basal clastic bed may unconformably underlie dolomite.

Major unconformity

CAMBRIAN

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; only 190 feet (58 m) thickness measured in Orem quadrangle (Baker, 1964b); 597 feet (180 m) thickness in Rock Canyon, Bridal Veil Falls quadrangle (Baker, 1972), indicates variation along unconformity.

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; reportedly about 250 feet (75 m) thick in Orem quadrangle. However, 510 feet (155 m) thick in American Fork Canyon with characteristic tripartite 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, 1964a).

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 or more (0.3 m+) in diameter near basal unconformity; interbedded greenish quartzite and phyllite in top 90 feet (30 m) forming gradational contact with overlying Ophir; measured thickness 1170 feet (355 m) in Slate Canyon, Springville quadrangle (Baker, 1973).

Unconformity

PROTEROZOIC

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; 200 feet (60 m) thickness at Rock Canyon (Baker, 1964b), but base not exposed; complete thickness 250 to 300 feet (75-90 m) in American Fork Canyon, Timpanogos Cave quadrangle (Baker and Crittenden, 1961) and thins southward to nothing near Slate Canyon, Springville quadrangle (Baker, 1973).

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Table 1. *Ages of major shorelines of Lake Bonneville and Utah Lake and shoreline elevations in the Orem quadrangle.*

Lake Cycle and Phase	Shoreline (map symbol)	Age		Elevation feet (meters)
		radiocarbon years B.P.	calendar years B.P.	
Lake Bonneville				
Transgressive Phase	Stansbury	22,000-20,000[1]	27,000-24,000[2]	Not present
	Bonneville (B) flood	15,000-14,500[3]	18,300[4]-17,400[5]	5160-5180 (1570-1580)
Regressive Phase	Provo (P)	14,500-12,000[6]	17,400[5]-14,400[7]	4750-4790 (1450-1460)
	Gilbert	10,500-10,000[8]	12,500-11,500[9]	Not present
Utah Lake				
	Utah Lake highstand (U)	12,000-11,500[10]	-----	4495-4500 (1370-1372)

[1] Oviatt and others (1990).
[2] Calendar calibration using Fairbanks and others (2005; http://www.radiocarbon.ldeo.columbia.edu/research/radcarbcal.htm).
[3] Oviatt and others (1992), Oviatt (1997).
[4] Oviatt (written communication, 2009), using Stuiver and Reimer (1993) for calibration.
[5] CRONUS-Earth Project (2005), using Stuiver and others (2005) for calibration.
[6] Godsey and others (2005) revised the timing of the occupation of the Provo shoreline and subsequent regression; Oviatt and others (1992) and Oviatt (1997) proposed a range from 14,500 to 14,000 ^{14}C yr B.P. Oviatt and Thompson (2002) summarized many recent changes in the interpretation of the Lake Bonneville radiocarbon chronology.
[7] Godsey and others (2005), using Stuiver and Reimer (1993) for calibration.
[8] Oviatt and others (2005).
[9] Calendar calibration of data in Oviatt and others (2005), using Stuiver and Reimer (1993) and Hughen and others (2004).
[10] Estimated from data in Godsey and others (2005); Machette (1992) estimated the age of the regression of Lake Bonneville below the Utah Valley threshold at 13,000 ^{14}C yr B.P. from earlier data.

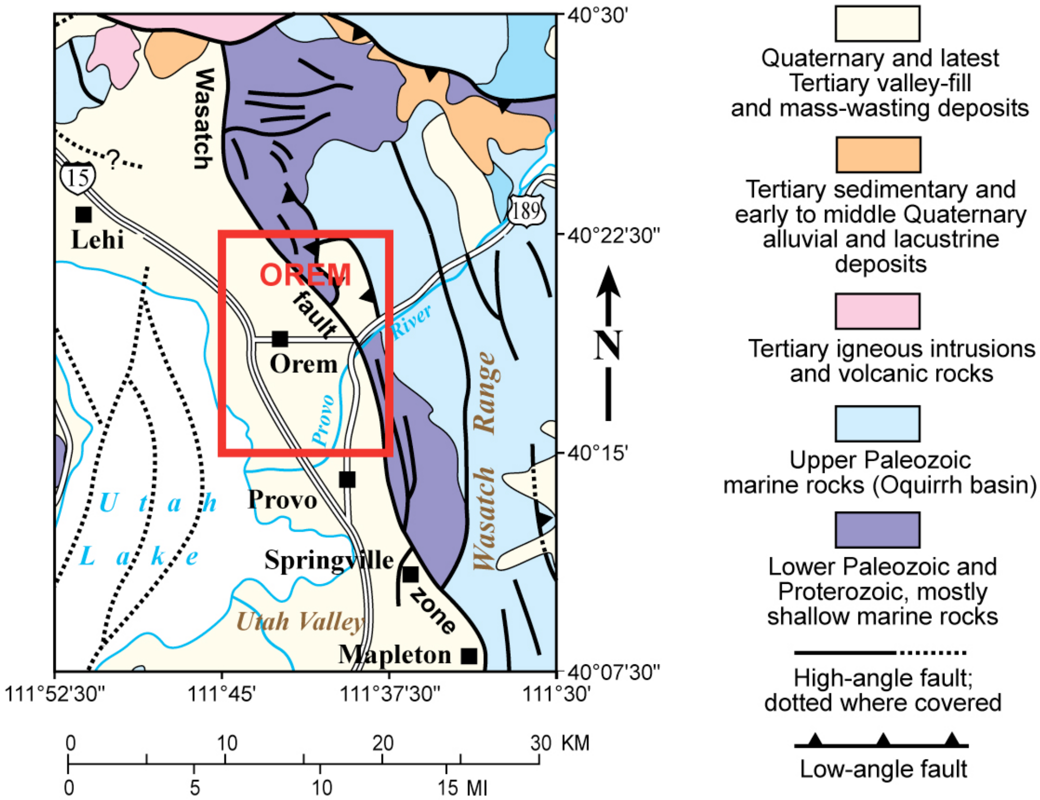


Figure 1. Index map showing the primary geographic features and generalized geology in the vicinity of the Orem quadrangle. Modified from Hintze and others (2000).

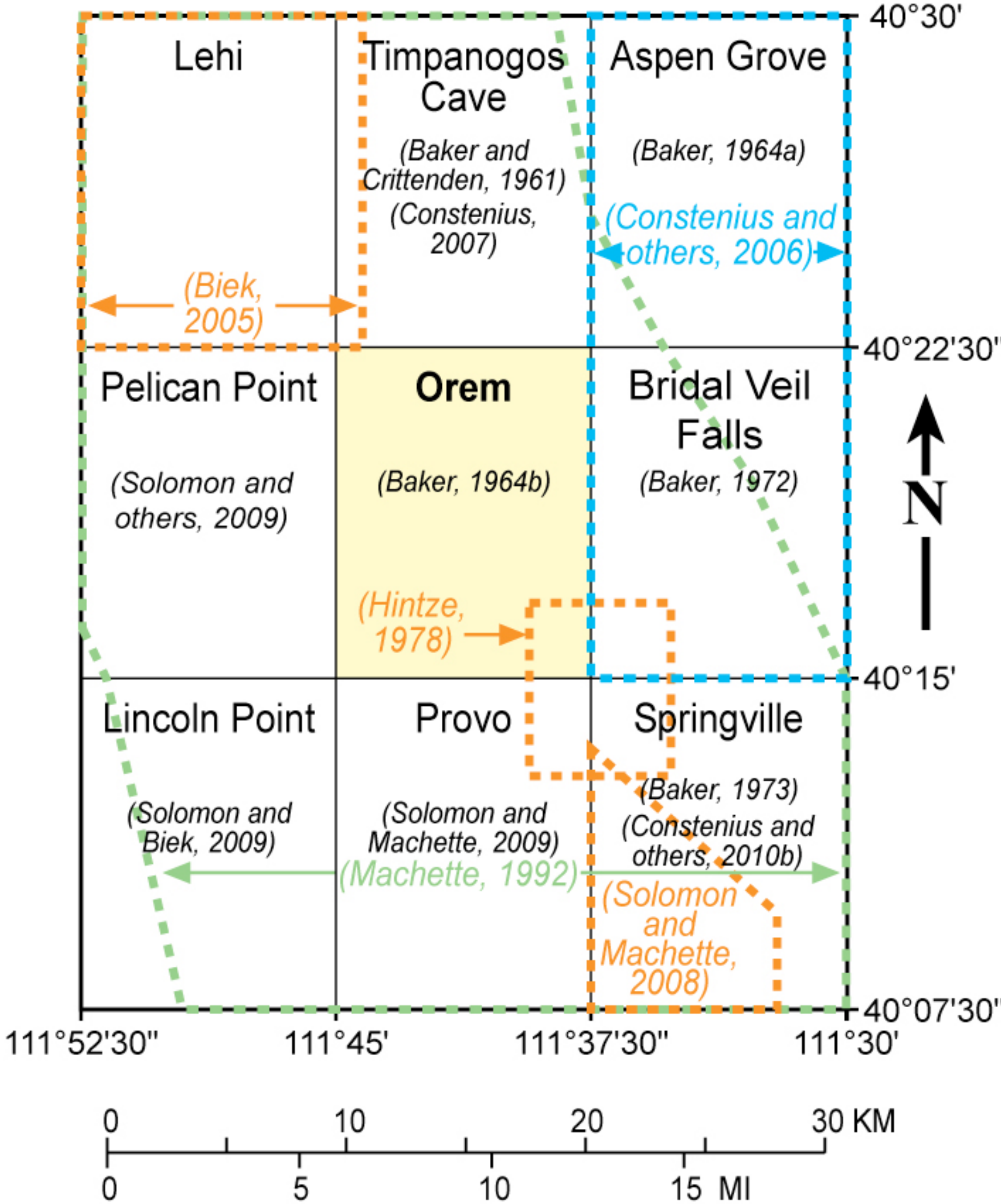


Figure 2. Index map showing selected geologic maps available for the Orem and surrounding 7.5′ quadrangles.

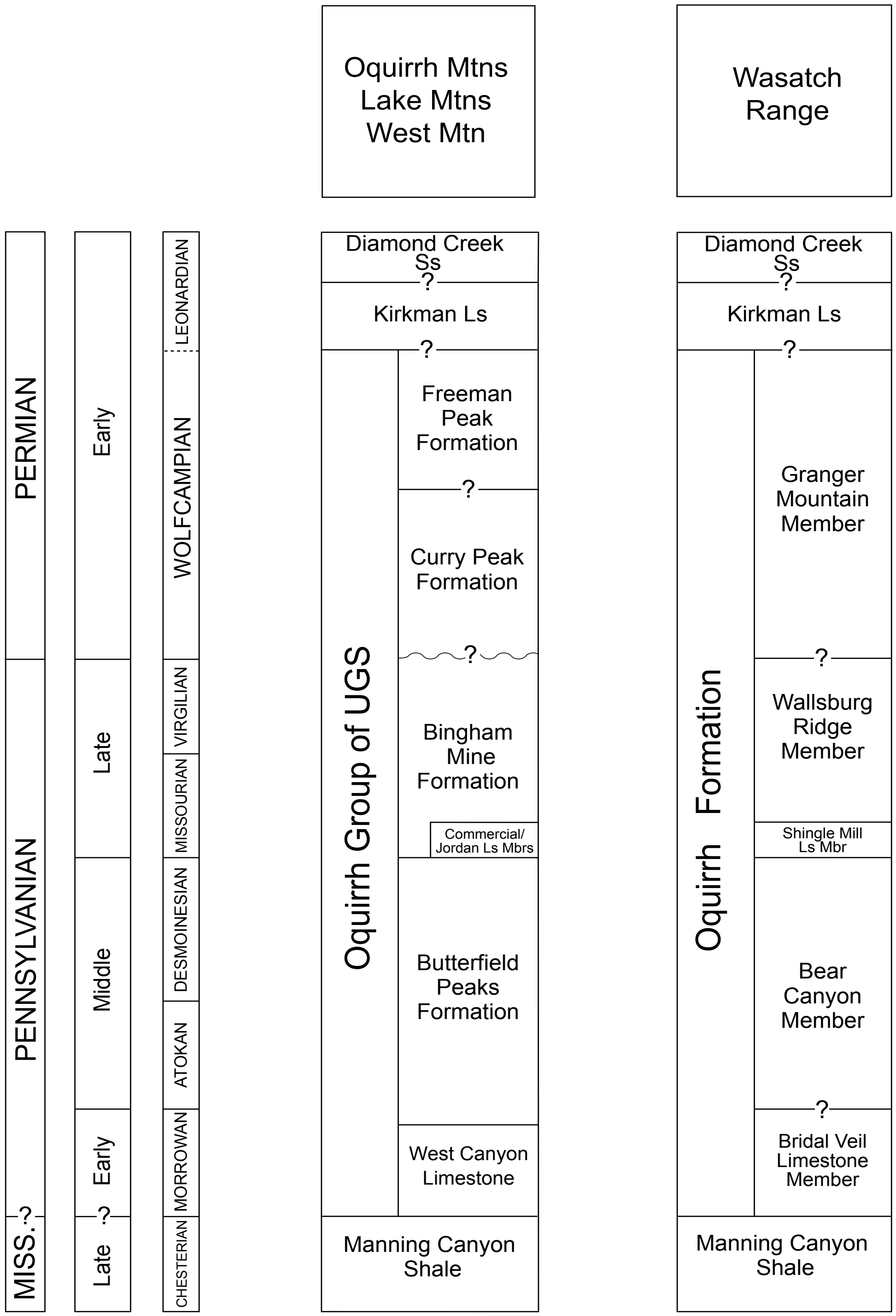


Figure 3. Comparison of stratigraphic nomenclature for the Oquirrh Formation/Group and associated strata near Salt Lake and Utah Valleys, north-central Utah. In the western part of the region, the UGS extends the Oquirrh Group to include the Curry Peak and Freeman Peak Formations (reproduced from Constenius and others, 2010a, fig. 2).

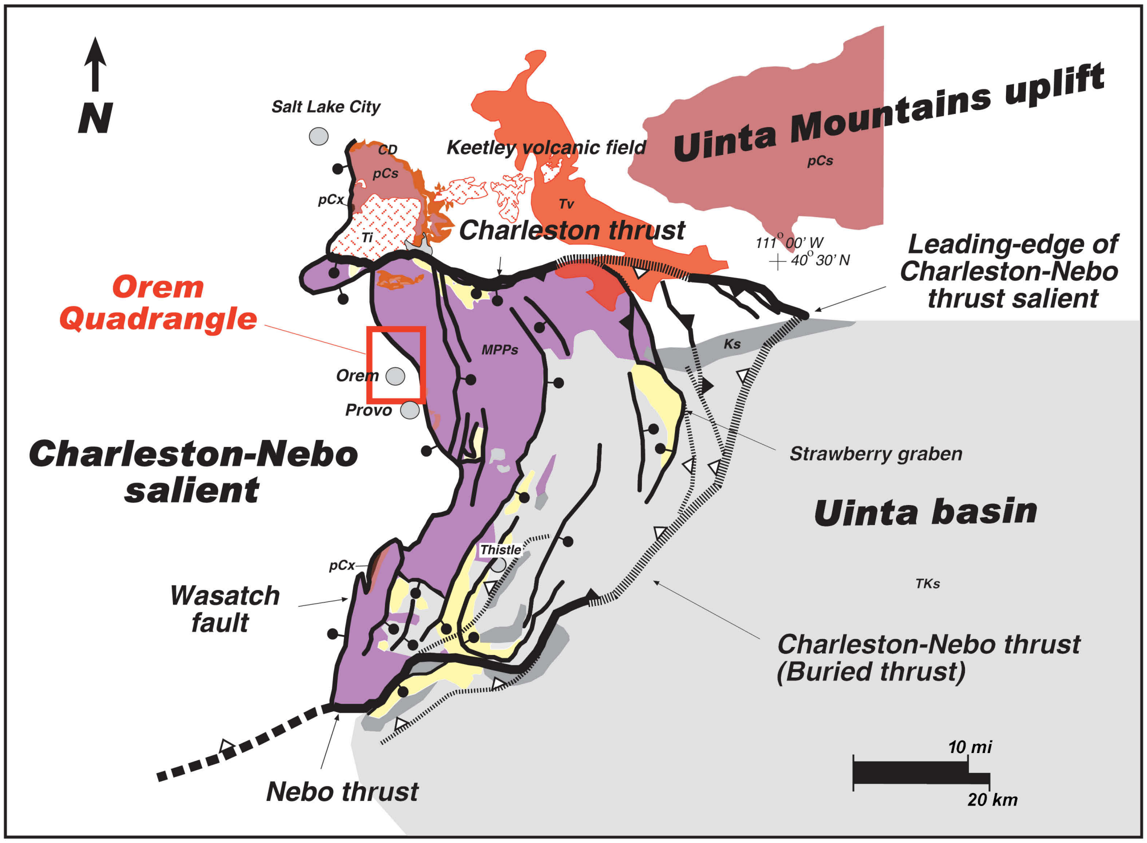


Figure 4. Geologic index map of Charleston-Nebo salient showing neighboring tectonic elements in north-central Utah, major thrusts, and location of normal faults and half grabens (yellow) that developed during extensional collapse of Charleston-Nebo salient. Description of map units: pCx (dark brown), Proterozoic crystalline rocks; pCs, Proterozoic sedimentary rocks (light brown); CD, Cambrian-Devonian sedimentary rocks (brown); MPPs, undifferentiated Paleozoic and Mesozoic rocks of Charleston-Nebo salient (purple); Ks, Cretaceous Indianola-Mesaverde Group sedimentary rocks (gray); TKs, Late Cretaceous-late middle Eocene North Horn, Flagstaff, Green River, and Uinta Formations (light gray); Ti, late Eocene-Oligocene intrusive rocks of the Wasatch igneous belt (red stipple); Tv, late Eocene-early Oligocene volcanic rocks of the Keetley volcanic field (red). Map adapted from Huddle and McCann (1947), Hintze and others (2000), and Constenius and others (2006).

GEOLOGIC SYMBOLS
Orem Quadrangle

Contact – Dashed where approximately located

Megabreccia contact with bedrock

57 Normal fault – Dashed where approximately located, dotted where concealed; bar and ball on hanging wall; arrow with number indicates fault dip direction and angle

Thrust fault, dashed where approximately located, dotted where concealed, solid teeth on hanging wall

Fold hinge-zone trace (red), dashed where approximately located

Anticline

Syncline

Lacustrine shorelines – Mapped at the wave-cut bench of erosional shorelines and the top of constructional bars and barrier beaches; may coincide with geologic contacts:

Lake Bonneville shorelines –

B Bonneville shoreline

P Provo shoreline

x Other regressive shorelines

Utah Lake shorelines –

U Pleistocene highstand shoreline of Utah Lake

Crest of lacustrine barrier beach or spit

Crest of glacial moraine

Landslide scarp – Hachures on down-dropped side

Tensional ridge crest

Tensional graben scarp - Hachures on down-dropped side

Strike and dip of bedding

20 Upright

20 Upright dip data from Baker (1964b)

Vertical

Sand and gravel pit

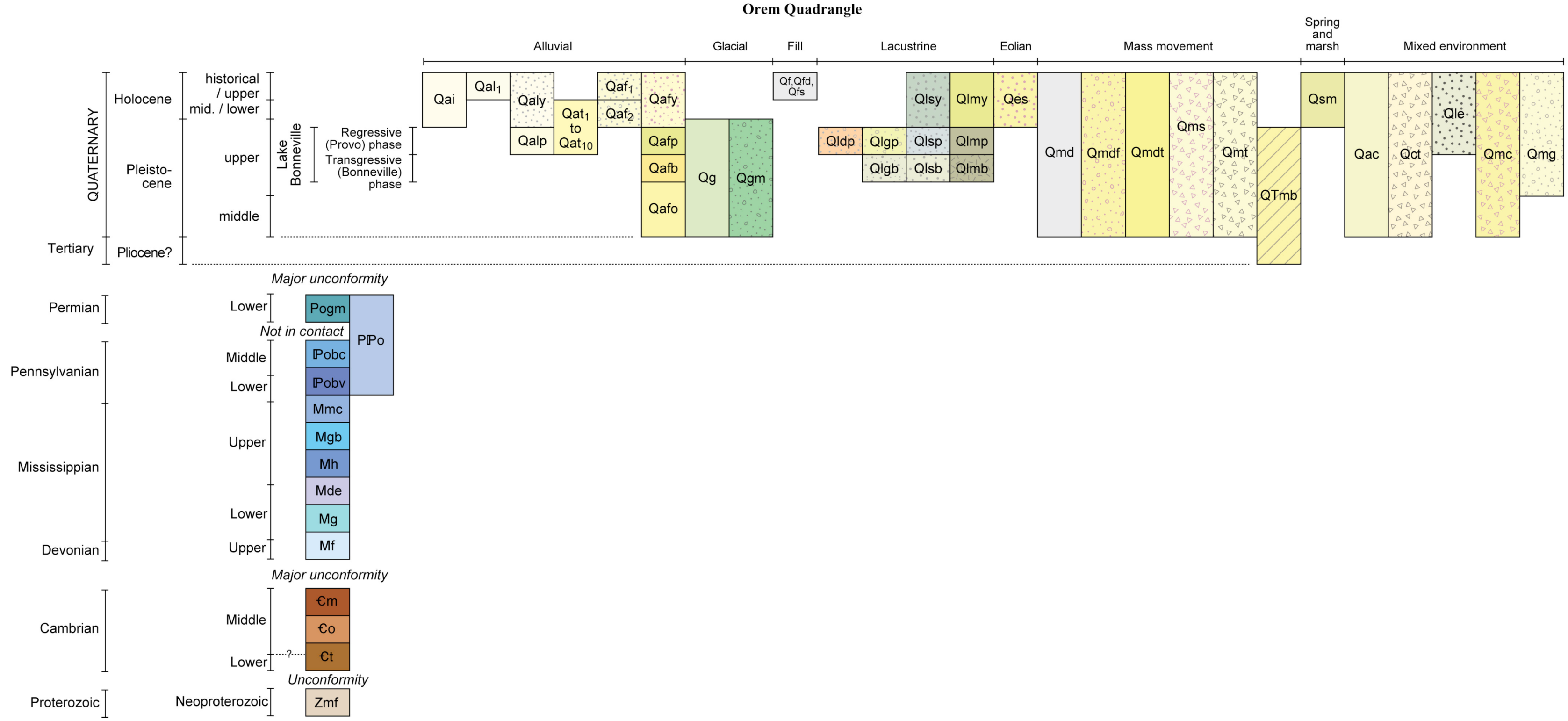
Trench site for Rock Creek paleoseismic investigation (Lund and Black, 1998)

Sample locations

KNC060707-1 Paleontology

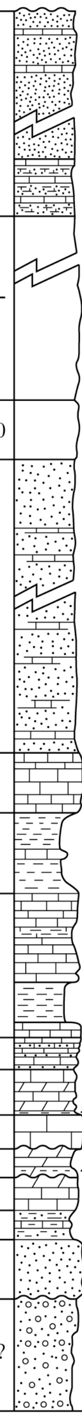
P-1 Palynology and thermal maturation

CORRELATION OF MAP UNITS
Orem Quadrangle



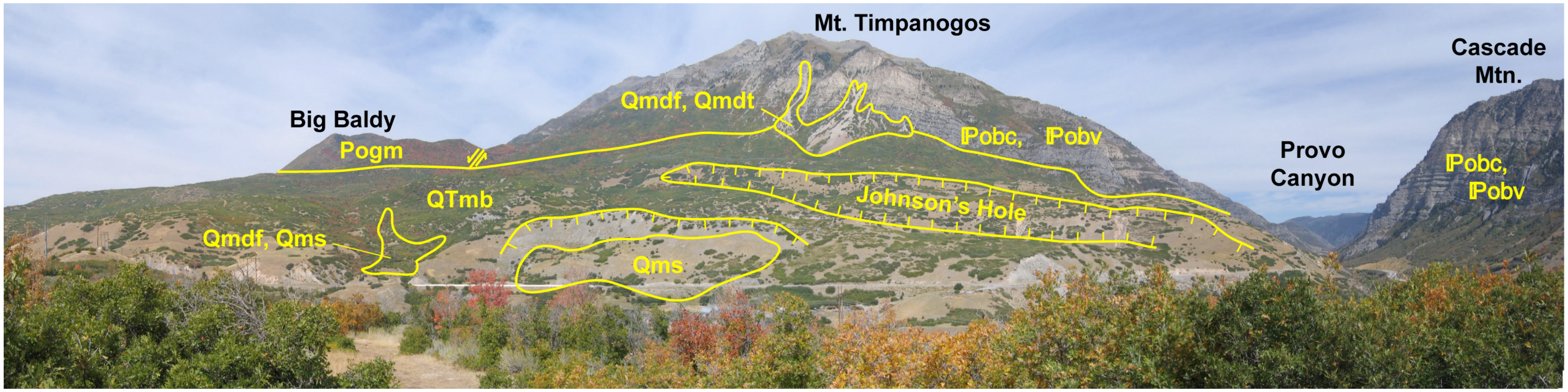
LITHOLOGIC COLUMN

ERATHEM	SYSTEM	SERIES	SYMBOL		FORMATION		THICKNESS Feet	THICKNESS Meters	LITHOLOGY
PALEOZOIC	PERMIAN	Lower	Pℙo	Pogm	Oquirrh Formation	Granger Mountain Member	8200-10,255	2500-3125	
	—?— PENNSYLVANIAN	Upper				Wallsburg Ridge Mbr.	~3700-8000	~1130-2450	Not exposed due to faulting
						Shingle Mill Ls. Mbr.	200-450	60-140	
		Middle		ℙobc		Bear Canyon Member	4250	1300	
		Lower		ℙobv		Bridal Veil Limestone Member	1245	380	
	—?— MISSISSIPPIAN	Upper	Mmc		Manning Canyon Shale		1650	500	
			Mgb		Great Blue Limestone		2800	855	
			Mh		Humbug Formation		520	160	
		Lower	Mde		Deseret Limestone		575	175	Delle Phosphate Mbr.
			Mg		Gardison Limestone		600	180	
	DEV.	Upper	Mf		Fitchville Dolomite		265	80	Devonian basal bed Regional unconformity
	CAMB.	Middle	Ꞓm		Maxfield Limestone		190	58	
			Ꞓo		Ophir Formation		250	75	
		Lower	Ꞓt		Tintic Quartzite		1170	355	
NEO-PROT.			Zmf		Mineral Fork Tillite		0-1000?	0-300?	Thins southward



Thicknesses are diagrammatic, no fixed scale.

View east on 200 South in Lindon, at the intersection with Geneva Road. Two distinct steps are visible along the front of the Provo River delta. The first step, at about 800 West, formed when a fluctuation in the level of Lake Bonneville deposited sand and silt along a regressive shoreline etched into the delta front. The second step, at about 400 West, separates the steep delta front from the gently sloping upper surface of the delta.



View north across Provo Canyon, Mount Timpanogos dominates the skyline. With Big Baldy to the left and Cascade Mountain to the right, this bedrock ridge (mostly underlain by the Oquirrh Formation [Pogm, IPobc, and IPobv]) is fringed by mass-movement deposits, including: (1) Pleistocene to Pliocene megabreccia (QTmb) underlying the foreground slopes, (2) upper Pleistocene to Holocene debris flows and talus (Qmdf and Qmdt) at the break in slope between steep bedrock and gentler megabreccia, (3) upper Pleistocene to Holocene slumps (Qms) and associated scarps from landsliding within the megabreccia, and (4) upper Pleistocene to Holocene landslide and debris-flow deposits (Qmdf and Qms) filling a drainage within megabreccia deposits. Additional landslide debris (Qms) is found in Johnson's Hole, a large closed depression rimmed by a scarp visible near the center of the photograph. Big Baldy and Mount Timpanogos are separated by a normal fault, with the direction of relative movement shown by the arrows.

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

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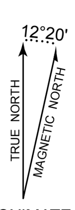

APPROXIMATE MEAN DECLINATION, 2009

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET

INTERIM GEOLOGIC MAP OF THE OREM QUADRANGLE, UTAH COUNTY, UTAH

by

Barry J. Solomon[1], Kurt K. Constenius[2], and Michael N. Machette[3]

2010

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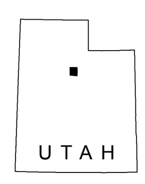

QUADRANGLE LOCATION

Base from USGS Orem 7.5' Quadrangle (1994)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1886

GIS and Cartography: James W. Parker, Kent D. Brown, J. Buck Ehler, and Jay Hill

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1	2	3
4		5
6	7	8

1. Lehi
2. Timpanogos Cave
3. Aspen Grove
4. Pelican Point
5. Bridal Veil Falls
6. Lincoln Point
7. Provo
8. Springville

ADJOINING 7.5' QUADRANGLE NAMES