# INTERIM GEOLOGIC MAP OF THE PROVO 7.5' QUADRANGLE, UTAH COUNTY, UTAH

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# INTRODUCTION

## Location and Geographic Setting

The Provo 7.5' quadrangle covers east-central Utah Valley and includes Provo, the third largest city in Utah (figure 1). Hobble Creek, the Provo River, and Spanish Fork are the primary streams in the quadrangle, flowing westward from the Wasatch Range to the Provo Bay portion of Utah Lake. U.S. Interstate Highway 15 extends from north to south through the map area.

## Geologic Summary

### Bedrock Stratigraphy and Geologic Structure

The bedrock of the Provo quadrangle consists of highly faulted sedimentary rocks of Mississippian to Precambrian age (Baker, 1973; Hintze, 1978). These sedimentary strata are exposed in the Wasatch Range in the northeast corner of the quadrangle. Strata in the region were deformed by Late Cretaceous to early Tertiary contractional folding and faulting of the Sevier orogeny (see, for example, DeCelles, 2006), early to middle Tertiary regional extensional collapse or relaxation (Constenius and others, 2003), and late Tertiary to recent basin-and-range extensional faulting (see, for example, Zoback and others, 1981). The most prominent feature of the 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.

### Quaternary Geology

The oldest Quaternary deposits in the Provo quadrangle are middle to upper Pleistocene deposits of coalesced alluvial fans that underlie piedmont slopes on the margins of Utah Valley. Exposed fan remnants in the quadrangle were deposited during the interlacustral episode between the last two lake cycles in the Bonneville Basin, the Bonneville and Little Valley lake cycles (Machette, 1992). The Little Valley lake cycle ended as late as about 130,000 years ago, and its highest level is below the altitude of the subsequent Lake Bonneville highstand (Scott and others, 1983). 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 sediments in the Provo quadrangle were mostly deposited by latest Pleistocene Lake Bonneville (Currey and Oviatt, 1985; Oviatt and others, 1992), in part contemporaneously with the last glacial advance, the Pinedale glaciation. Lips and others (2005) date the Pinedale maxima from about 17 to 15 ka based on $^{10}Be$ exposure ages measured from moraines at Little Cottonwood Canyon in the Wasatch Range.

Other surficial deposits in the quadrangle are mostly younger than Lake Bonneville and reflect post-glacial landscape evolution. Incision of the lake's threshold in southern Idaho and warming climatic conditions reduced the size of Lake Bonneville, leaving remnants such as Utah Lake stranded in Bonneville sub-basins (Jarrett and Malde, 1987; O'Conner, 1993). Utah Lake deposits, mapped below the elevation of its threshold of 4500 feet (1372 m) at the northern end of the lake, are found on the margins of Provo Bay. Streams incised in response to the lowering lake level, depositing large alluvial fans on the broad plain surrounding the bay and smaller alluvial fans at the mouths of range-front drainages. Locally, steeper slopes underlain by shoreline deposits of Lake Bonneville failed, with some slope failures perhaps associated with earthquakes on the Wasatch fault zone; this process of landsliding continues sporadically today. On gentler slopes, a possible earthquake-induced lateral spread formed southwest of Springville, followed by headward erosion of scarps due to spring sapping and minor landsliding on locally steeper slopes of small alcoves surrounding springs. Wind eroded the desiccated Bonneville lake beds and deposited 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 derived from this loess (Machette, 1992). The loess is from 3 to 5 feet (1-1.5 m) thick.

**Lake Bonneville**

Deposits and shorelines of Pleistocene Lake Bonneville dominate the surficial geology of the Provo quadrangle. Lake Bonneville was a large pluvial lake that covered much of northwestern Utah between about 32,500 and 11,600 calendar years ago (references and radiocarbon ages for this discussion of the chronology of Lake Bonneville are shown in table 1; Oviatt and Thompson [2002] summarized many recent changes in the interpretation of Lake Bonneville radiocarbon chronology). Four regionally extensive shorelines of Lake Bonneville are found in the Bonneville Basin (Gilbert, 1890), but only the two most prominent (the Bonneville and Provo shorelines) are mapped in the quadrangle. The earliest of the regional shorelines is the Stansbury, which resulted from a climatically induced lake-level oscillation from about 24,400 to 23,200 years ago during expansion of Lake Bonneville. The Stansbury shoreline formed at elevations below those in the quadrangle. The lake continued to rise, entering the Provo 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 of about 5092 feet (1552 m) about 18,000 years ago; this level was controlled by an overflow threshold near Zenda, in southern Idaho. This highstand created the Bonneville regional shoreline. In the Provo quadrangle, the Bonneville shoreline forms the highest bench near the base of the Wasatch Range.

About 16,800 years ago, overflow and rapid erosion at the Zenda threshold resulted in catastrophic lowering of the lake by 340 feet (100 m) (Jarrett and Malde, 1987) 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 regional shoreline was formed on the piedmont slope in the quadrangle.

The lake oscillated at or near the Provo level until about 13,500 years ago (Godsey and others, 2005), when climatic factors induced further lowering of the lake level within the Bonneville Basin. As Lake Bonneville fell below the altitude of the natural threshold of Utah Valley at the northern end of Utah Lake, Utah Lake became isolated from the main body of Lake Bonneville (Machette, 1992). By about 13,000 years ago, the level of Lake Bonneville had fallen below the elevation of present Great

Salt Lake, but a subsequent expansion of Lake Bonneville from about 12,800 to 11,600 years ago formed the Gilbert shoreline. During the Gilbert expansion of Lake Bonneville, threshold control of the level of Utah Lake prevented the lake level from similarly rising (Machette, 1992). By Holocene time (about 10,000 years ago) 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). The amount of isostatic uplift increases toward the center of the basin where the volume of removed water was greatest; Crittenden (1963) estimated a maximum isostatic uplift of 210 feet (64 m) near the Lakeside Mountains west of Great Salt Lake. 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 Provo 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 Provo quadrangle is about 5195 feet (1585 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 103 feet (33 m) and 53 feet (16 m), respectively.

**Paleoseismology**

Utah Valley is a Neogene structural basin formed by late Cenozoic displacement along the Wasatch fault zone. Quaternary displacement indicates significant seismic hazards in the quadrangle, with potential earthquakes from moment magnitude 7.0 to 7.5 (Machette and others, 1992; Wells and Coppersmith, 1994). Data from paleoseismic trench exposures at Rock Canyon in the adjacent Orem quadrangle indicate that the most recent earthquake was about this magnitude and produced 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 (with 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 the Spanish Fork Peak quadrangle in Mapleton (NE1/4 section 23, T. 8 S., R. 3 E., Salt Lake Baseline and Meridian [SLBLM]) 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). These results suggest a much shorter recurrence interval for major earthquakes in Utah Valley.

**Liquefaction-Induced Landsliding**

Saturated sandy sediments that are prone to liquefaction during moderate and large earthquakes generated by the Wasatch fault zone underlie much of Utah Valley. Large earthquake-induced slope failures initiated by liquefaction can pose a hazard to life as well as property. Thirteen features thought to be liquefaction-induced landslides have been identified along the Wasatch Front (from Brigham City to Nephi) by previous researchers. Harty and Lowe (2003) conducted geologic investigations of these features, one of which is partly within our map area.

Referred to as the Springville/Spanish Fork feature by Harty and Lowe (2003), the feature was first mapped as a lateral spread by Miller (1982), remapped with revised boundaries by Machette (1992), and mapped by Harty and Lowe (2003) using the boundaries of Machette (1992) but with additional detail. The feature is in the southeast corner of the Provo quadrangle, and extends eastward to the southwest corner of the Springville quadrangle (Solomon and Machette, 2008) and southward into the adjacent Spanish Fork quadrangle (Solomon and others, 2007); in total, it covers about 1.4 square miles (3.6 $km^2$). Although genetic interpretations other than lateral spreading are possible, the feature is mapped here as a possible lateral-spread deposit because it is in an area having high liquefaction potential (Anderson and others, 1986). Until definitive evidence eliminates earthquake-induced liquefaction as its cause, for purposes of assessing geologic hazards it is prudent to consider the feature to be a lateral-spread deposit. The presence of shallow ground water and granular soils near the margin of Utah Valley, with high levels of seismicity on the Wasatch fault zone, suggests that large-scale liquefaction may have occurred repeatedly in the region.

The Springville/Spanish Fork feature extends for about 2.5 miles (4 km) parallel to the toe of the Lake Bonneville delta at the mouth of Spanish Fork Canyon. Rather than a continuous main scarp, the feature includes several small, discontinuous, arcuate scarps as much as 3 feet (1 m) high on their upslope edges, each no more than 0.5 mile (0.8 km) long. The feature is characterized by a few isolated hummocks and small depressions with relief of less than about 3 feet (1 m) and larger, flat-topped erosional remnants of transgressive lacustrine silt and clay. Harty and Lowe (2003) mapped two discontinuous lineaments within the feature that they interpreted to be regressive shorelines of Lake Bonneville; we agree with this interpretation and map a third lineament farther to the east that lies within 200 feet (60 m) of State Route 156. This third lineament coincides with discontinuous linear scarps of unknown origin mapped by Harty and Lowe (2003) on the upslope edge of the feature, and which we interpret as another regressive shoreline.

Harty and Lowe (2003) excavated three trenches across their two lineaments. Two of the trenches (SP-1 and SP-2, SW1/4 and SE1/4 section 8, T. 8 S., R.3 E., SLBLM) showed no evidence of liquefaction or soil deformation, and the third trench (SP-3, NW1/4 section 8, T. 8 S., R.3 E., SLBLM) showed no direct evidence of liquefaction but exhibited faults with minor displacements of a few centimeters. Despite the lack of deformation in two trenches and only minor brittle deformation in the third, Harty and Lowe (2003) mapped the entire feature as possible deposits of liquefaction-induced landsliding. We restrict possible landslide deposits to the small, isolated hummocks within swampy areas and larger outcrops that lie across the discontinuities of the lineaments and show no evidence of shorelines. We exclude the flat-topped erosional remnants because they exhibit greater relief than potential lateral-spread deposits, reflecting an erosional resistance similar to transgressive silt and clay mapped elsewhere, and their downslope margins coincide with lacustrine shorelines. Harty and Lowe (2003) suggested that one mechanism for preservation of the lineaments was headward erosion due to spring sapping, which ceased when relatively resistant gravels were encountered along a lacustrine shoreline; we believe that this mechanism is responsible for the lineaments in the Springville/Spanish Fork feature and for preservation of upslope lake deposits.

### Previous Investigations

Numerous geologic studies of the Provo quadrangle date back one-half century. Hintze (1962) compiled a small-scale bedrock map of the southern Wasatch Range and later mapped the geology of the area surrounding Brigham Young University in more detail (Hintze, 1978). Baker (1973) mapped the geology of the eastern edge of the Provo quadrangle and the adjoining Springville quadrangle at a scale of 1:24,000. Bissell (1963) conducted the first geologic mapping of surficial Quaternary deposits in the region, and Miller (1982) remapped the deposits. 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, and Harty and Lowe (2003) conducted geologic evaluations of liquefaction-induced landslides along the Wasatch Front, including an evaluation of the Springville/Spanish Fork feature in the southeast corner of the Provo quadrangle.

This mapping effort is part of a larger project to map the Provo 30' x 60' quadrangle (Constenius and others, 2006), during which geology of the adjacent Spanish Fork (Solomon and others, 2007), West Mountain (Clark, 2006), Lincoln Point (Solomon and Biek, 2008), and southwest (Utah Valley) part of the Springville (Solomon and Machette, 2008) quadrangles were mapped. Other quadrangles mapped during the project include Goshen Valley North (Clark and others, 2006), Saratoga Springs (Biek, 2004), and Soldiers Pass (Biek and others, 2006). Solomon also mapped the Quaternary geology of part of the Spanish Fork Peak quadrangle in 2006 (unpublished), and mapping of the Quaternary geology of the Pelican Point, Orem, and Bridal Veil Falls quadrangles is ongoing (figure 2).

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## MAP UNIT DESCRIPTIONS

### QUATERNARY

#### Alluvial deposits

$Qal_1$ **Level-1 stream deposits** (upper Holocene) – Moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded. Deposited by perennial streams such as Hobble Creek, Provo River, and Spanish Fork, and by smaller streams draining areas of shallow ground water and marshes southwest of Springville and along the margin of Utah Lake and Provo Bay; includes deposits on active flood plains and minor terraces less than 5 feet (1.5 m) above stream level; locally includes minor colluvial deposits along steep stream embankments; equivalent to the younger part of young stream deposits (Qaly), but differentiated where modern deposits with active channels and bar-and-swale topography can be mapped separately. Exposed thickness less than 15 feet (5 m).

$Qal_2$ **Level-2 stream deposits** (middle Holocene to upper Pleistocene) – Moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay; contains thin discontinuous sand lenses; subangular to rounded clasts; thin to medium bedded. Deposited in small, abandoned channels and associated flood plains adjacent to the active channel of the Provo River; equivalent to the older part of Qaly, but differentiated where deposits characterized by subdued 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 in a matrix of sand and minor silt and clay. Deposited in braided streams south of Hobble Creek on the surface of low-gradient alluvial-fans (Qafy) at the east edge of the Provo quadrangle, and deposited by small, ephemeral streams on the valley floor; locally includes small alluvial-fan and colluvial deposits; includes level-2 stream deposits ($Qal_2$) incised by active stream channels and partly overlain by level-1 stream deposits ($Qal_1$) that cannot be differentiated because of map scale or in areas 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).

$Qat_{1\text{-}5}$ **Stream-terrace deposits** (middle Holocene to upper Pleistocene) – Poorly to moderately sorted pebble and cobble gravel in a matrix of sand, silt, and minor clay; contains thin sand lenses; subangular to rounded clasts; thin to medium bedded. Deposited on as many as five levels of gently sloping terraces, with subscripts denoting relative position above modern stream channels in downcutting sequence, 1 being the lowest level; level 1 deposits ($Qat_1$) lie 5 to 15 feet (1.5-5 m) above modern streams and are incised by them; levels 2 through 5 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) ($Qat_4$), and 60 to 75 feet (18-23 m) ($Qat_5$) above modern streams; numbered subscripts do not indicate specific age. Low-level terrace remnants ($Qat_1$ and $Qat_2$) lie adjacent to Spanish Fork and Hobble Creek, but the most extensive deposits are adjacent to the Provo River, where the highest terraces ($Qat_3$ through $Qat_5$) are related to regressive Lake Bonneville deltaic deposits (Qldp) of late Pleistocene age, whereas the lowest terraces ($Qat_1$ and $Qat_2$) are incised into the delta, suggesting a late Pleistocene to middle Holocene age. 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 in 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 mouths of small channels that drain Lake Bonneville deltaic deposits (Qldp) and areas of shallow ground water in the southeast corner of the Provo quadrangle; equivalent to the younger part of young alluvial-fan deposits (Qafy) but differentiated where modern deposits of small, active, discrete fans not incised by younger channels 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, in 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. Deposited by debris flows, debris floods, and stream flow from the Provo River; 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, in 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 at the mouths of large and small mountain canyons and streams locally incising Lake Bonneville deposits, where alluvial-fan deposits typically form a coalesced apron at the base of the Wasatch Range; also deposited by debris floods and streams on broad areas of the valley floor where Hobble Creek, the Provo River, and Spanish Fork lost confinement near Utah Lake, and may include undifferentiated deltaic sediment deposited by streams flowing into the lake. 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 that 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 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) from the Provo River in Provo, where deposits are incised by level-2 alluvial fans ($Qaf_2$), and (2) near the Provo shoreline from the mouth of Slate Canyon northward, where deposits are incised into transgressive Lake Bonneville gravel and sand (Qlgb) and older alluvial-fan deposits (Qafo) and grade laterally to regressive sand and silt (Qlsp). Equivalent to the younger part of level-3 alluvial-fan deposits mapped north of Orem and southeast of Spanish Fork City by Machette (1992), but differentiated where deposits related to the regressive phase of Lake Bonneville, typically below the Bonneville shoreline, can be separated from deposits related to the transgressive phase of the lake, typically above the Bonneville shoreline; level-3 alluvial-fan deposits are not mapped in the Provo quadrangle because all mapped alluvial-fan deposits in the quadrangle related to Lake Bonneville are associated with the regressive lake phase and none are suspected to have a relationship with the transgressive phase. 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).

$Qaf_4$ **Level-4 alluvial-fan deposits, pre-Bonneville lake cycle to Little Valley lake cycle** (upper to middle Pleistocene) – Poorly sorted, clast-supported pebble to cobble gravel, with matrix-supported interbeds in the upper part; locally bouldery in a matrix of sand, silt, and clay; clasts angular to subrounded; medium to very thick bedded. Deposits are found near the mouth of Slate Canyon east of Provo, below the Bonneville shoreline, commonly covered by a thin veneer of transgressive gravel and sand (Qlgb) reworked from the underlying alluvial fan. Machette (1992) stated that correlative deposits likely underlie Lake Bonneville deposits, forming the piedmont slopes within Utah Valley, and probably grade laterally to lacustrine sediment of the Little Valley lake cycle below an elevation of about 4900 feet (1490 m) (Scott and others, 1983). Equivalent to the younger part of older alluvial-fan deposits (Qafo) but differentiated where pre-Bonneville deposits can be divided into $Qaf_4$ and $Qaf_5$ (mapped in adjacent quadrangles by Machette, 1992; Solomon and others, 2007; Solomon and Machette, 2008) based on fan morphology, degree of dissection, and incision of younger into older deposits. The B soil horizon of paleosols developed on level-4 alluvial-fan deposits commonly shows a moderate accumulation of clay, gravel is typically coated with calcium carbonate, and calcium carbonate may occur in significant accumulations between clasts; Machette (1992), using the terminology of Birkeland (1984), designated the soil profile of this unit and others of similar age as A/Bt(moderate)/Bk(stage II-III)/Cox. Exposed thickness less than 15 feet (5 m).

Qafo **Older alluvial-fan deposits, pre-Bonneville lake cycle, undivided** (upper to middle Pleistocene) – Poorly sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and clay. Mapped along the Wasatch Range front east of Provo, where pre-Bonneville lake cycle alluvial-fan deposits ($Qaf_4$ and fan alluvium, unit 5 of Machette, 1992) are undifferentiated because they are poorly exposed or lack distinct geomorphic expression. The B soil horizon of paleosols developed on these 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).

**Fill deposits**

Qf **Artificial fill** (Historical) – Engineered fill used in the construction of transportation routes, levees, building foundations, and airports; unmapped fill is locally present in all developed areas but only the largest deposits are mapped. Maximum thickness about 20 feet (6 m).

Qfd **Disturbed land** (Historical) – Land disturbed by sand, gravel, and aggregate operations; only the larger operations are mapped and their outlines are based on aerial photographs taken in 1965 and 2002; many sites have since been regraded and developed, and may contain unmapped deposits of artificial fill (Qf). Land within these areas contains a complex, rapidly changing mix of cuts and fill deposits; most operations extracted material from transgressive lacustrine gravel and sand (Qlgb) and alluvial-fan deposits older than Lake Bonneville ($Qaf_4$). Thickness unknown.

**Lacustrine deposits**

**Deposits younger than the Bonneville lake cycle:** Only mapped below the Utah Lake highstand elevation of about 4495 to 4500 feet (1370-1372 m) (table 1).

Qlsy **Young lacustrine sand and silt** (Holocene to upper Pleistocene) – Well-sorted, fine to medium sand and silt that forms bars and barrier beaches near the shore of Utah Lake. 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 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 the lake sediment in Utah Lake.

Qlly **Young lagoon-fill deposits** (Holocene to upper Pleistocene) – Silt and clay, with minor fine-grained sand and pebbles. Mapped in shallow depressions on the south side of the mouth of Provo Bay, sheltered on the north and east by beaches of young lacustrine sand and silt (Qlsy). Maximum thickness about 5 feet (1.5 m).

**Deposits of the regressive (Provo) phase of the Bonneville lake cycle:** Only mapped below the Provo shoreline, which is at elevations from about 4760 to 4790 feet (1450-1460 m) in the quadrangle (table 1). Currey (1982) estimated an elevation of 4770 feet (1454 m) for the Provo shoreline on a southeast-facing beach ridge on Lincoln Point (SE1/4 section 10, T. 8 S., R.1 E., SLBLM) in the adjacent Lincoln Point quadrangle (Solomon and Biek, 2008). 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 in 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; present near the north edge of the quadrangle in a delta below the Provo shoreline at the mouth of the Provo River; commonly capped by a thin veneer of stream-terrace deposits ($Qat_3$ through $Qat_5$) and exposed along the steep delta front and where incised by the Provo River. 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; thin to thick bedded. Near the base of the Wasatch Range, deposits typically form wave-cut or wave-built benches at and below the Provo 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; commonly interbedded with or laterally gradational to lacustrine sand and silt of the regressive phase (Qlsp). Exposed thickness less than 30 feet (10 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; overlies and grades downslope into lacustrine silt and clay of the regressive phase (Qlmp), grades laterally to sandy deltaic deposits (Qldp) in the northeast corner of the Provo quadrangle; locally buried by loess veneer. 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 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 grades upslope into lacustrine sand and silt (Qlsp); locally buried by loess veneer; regressive lacustrine shorelines typically poorly developed. Forms irregular erosional remnants surrounded by distal alluvial-fan deposits (Qafy) near Provo Bay; larger, continuous deposits in the southwest corner of the Provo quadrangle, and linear deposits parallel to steeper slopes along the Wasatch Range front. 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 Bonneville shoreline is at elevations from about 5180 to 5195 feet (1580-1585 m) in the 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 in 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. Near the base of the Wasatch Range, deposits typically form wave-cut or wave-built benches between the Provo and Bonneville shorelines; 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); commonly covered by a thin veneer of colluvium. 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; overlies coarse-grained beach gravel (Qlgb), implying deposition in increasingly deeper water of a transgressing lake. Mapped in the northeast corner of the Provo quadrangle. 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 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). A small outcrop mapped near the northeast corner of the Provo quadrangle is the southern tip of a larger outcrop extending northward along the Wasatch Range front (Machette, 1992). Exposed thickness less than 15 feet (5 m).

**Mass-movement deposits**

Qml? **Lateral-spread deposits?** (middle Holocene to upper Pleistocene) – Pebbly sand, sand, silt, and clay below (post-dating) the Provo shoreline, incised by spring-fed drainages from the southeast that converge in swampy swales. Referred to as the Springville/Spanish Fork feature by Harty and Lowe (2003). The feature lies mostly in the southeast corner of the Provo quadrangle and the southwest corner of the Springville quadrangle (Solomon and Machette, 2008), extends southward into the adjacent Spanish Fork quadrangle (Solomon and others, 2007), and covers about 1.4 square miles (3.6 $km^2$). Although interpretations other than lateral spreading are possible, the feature is mapped here as possible lateral-spread deposits because it is in an area having high liquefaction potential (Anderson and others, 1986) (see the discussion of liquefaction-induced landsliding in the introduction of this report for more details). Thickness of the deposits is unknown but probably less than 50 feet (15 m).

Qms **Landslide deposits** (Historical to upper Pleistocene) – Poorly sorted, fine to medium sand, sandy silt, and pebble and cobble gravel in two slumps mapped along the Wasatch Range front (SW1/4 section 32, T. 6 S., R.3 E. and NW1/4 section 17, T. 7 S., R.3 E., SLBLM); derived from nearshore regressive deposits of Lake Bonneville (Qlsp and Qlgp) and underlying pre-Bonneville alluvial-fan deposits ($Qaf_4$); composition reflects local sources of material. Maximum thickness about 20 feet (6 m).

$Qmd_1$ **Level-1 debris-flow deposits** (upper Holocene) – Unsorted cobble and boulder gravel in a matrix of sand, silt, and clay; contains thin discontinuous sand or gravel lenses with as much as 3 percent organic matter (Machette, 1992); commonly covered with coarse, angular rubble and distinct levees and channels. Mapped on the surface of young alluvial fans (Qafy) near the mouth of Slide Canyon and a smaller, unnamed drainage to the north. Thickness less than 15 feet (5 m).

**Spring and marsh deposits**

Qsm **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 and grades into fine-grained lacustrine deposits (Qlmp and Qlmy); present where water table is high on the eastern and northern margins of Provo Bay and in the area of the Springville/Spanish Fork feature. Thickness commonly less than 10 feet (3 m).

**Mixed-environment deposits**

Qla **Lacustrine and alluvial deposits, undivided** (Holocene to upper Pleistocene) – Sand, silt, and clay in areas of mixed alluvial and lacustrine deposits that are undifferentiated because the units grade imperceptibly into one another; mapped west of Spanish Fork and on the east side of Provo Bay, where it includes mudflats exposed by fluctuations in the level of Utah Lake. Thickness less than 10 feet (3 m).

**Stacked-unit deposits**

Qlgp/$Qaf_4$

**Lacustrine gravel and sand (regressive phase) over pre-Bonneville alluvial-fan deposits** (upper Pleistocene/upper to middle Pleistocene) – A veneer of lacustrine gravel and sand related to the regressive phase of Lake Bonneville reworked from underlying alluvial-fan deposits older than Lake Bonneville but not older than the Little Valley lake cycle; mapped below the Provo shoreline at the mouth of Slate Canyon. Lacustrine deposits are generally less than 3 feet (1 m) thick.

*Major unconformity*

Bedrock mapping and unit descriptions are modified from Baker (1973) and Hintze (1978). Thicknesses of bedrock units are described from adjacent quadrangles where more complete sections are exposed, but thicknesses of the units in the Provo quadrangle are much less due to attenuation by faulting along the Wasatch Range front.

**MISSISSIPPIAN**

Mgb **Great Blue Limestone, undivided** (Upper Mississippian) – 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 as much as 50 feet (15 m) thick; near base, contains scattered thin beds of olive-brown-weathering, dark-gray, fine-grained quartzite; thickness attenuated by faulting south of Slide Canyon; measured thickness 2800 feet (850 m) in Rock Canyon in the Bridal Veil Falls quadrangle to the northeast (Baker, 1947, 1972a). Black shale is prominent in basal part of unit in southwest Bridal Veil Falls quadrangle; this part described as 100 feet (30 m) thick but shown as 300 feet (90 m) thick by Crittenden (1959); Baker (1947) showed a 750-foot- (230-m-) thick covered interval above the base of the Great Blue Limestone at Rock Canyon; see also Chamberlain (1981).

Humbug Formation (Upper Mississippian) – Not exposed in this quadrangle; in nearby exposures, light- to dark-gray, cherty limestone and some dolomite interbedded with light-gray to buff, brown-weathering, limy to quartzitic sandstone. Measured thickness 520 feet (160 m) in Rock Canyon, Bridal Veil Falls quadrangle (Baker, 1972a).

Deseret Limestone (Upper and Lower Mississippian) – Not exposed in this quadrangle; in nearby exposures, interbedded, thick-bedded limestone and dolomite; black chert occurs in most beds and is locally very abundant. About 585 feet (175 m) thick in the Aspen Grove quadrangle (Baker, 1964a).

Mg **Gardison Limestone** (Lower Mississippian) – Dark-gray, mostly thin-bedded limestone with scattered abundant light-brown to black chert; forms characteristic "stair-step" ledges; about 600 feet (180 m) thick in Timpanogos Cave quadrangle (Baker, 1947; Baker and Crittenden, 1961).

*Unconformity*

Fitchville Dolomite (Lower Mississippian and Upper Devonian) – Not exposed in this quadrangle; in nearby exposures, medium- to light-gray 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 in the adjacent Springville quadrangle (Baker, 1973); Devonian age of dolomite at Rock Canyon in the Bridal Veil Falls quadrangle from Sandberg and Gutschick (1979, p. 114). Basal clastic bed may unconformably underlie dolomite.

*Unconformity or fault*

## CAMBRIAN

Ꞓm **Maxfield Limestone** (Middle Cambrian) – Mainly light- to dark-gray, thin-bedded limestone with yellow-brown to gray-yellow mottling, and with interbedded gray to white dolomite and oolitic or pisolitic limestone; unconformably overlain by the Fitchville Dolomite (or Formation) in the adjacent Springville quadrangle (Baker, 1973, Hintze, 1978); at least 350 feet (105 m) thick in the Provo and adjacent Springville quadrangles (Baker, 1973); 595 feet (180 m) thick in Bridal Veil Falls quadrangle (Baker, 1947, 1972a).

Ꞓo **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 the overlying Maxfield Limestone is gradational; about 100 to 290 feet (30-90 m) thick in the adjacent Springville and Bridal Veil Falls quadrangles (Baker, 1972a, 1973).

Ꞓt **Tintic Quartzite** (Middle to 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 quartzite one 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 Formation; measured thickness 1170 feet (355 m) in Slate Canyon, Springville quadrangle (Baker, 1947, 1973).

*Unconformity*

**PROTEROZOIC**

Zmf **Mineral Fork Tillite** (Upper Proterozoic) – Gray to brown, dark-brown- to black-weathering, unstratified and poorly sorted, micaceous siltstone with scattered boulders of dolomite, quartzite, sandstone, and altered (green) igneous rock as much as 1 foot (0.3 m) in diameter; at least 200 feet (60 m) thick in the adjacent Bridal Veil Falls quadrangle, thinning southward to nothing near Slate Canyon in the adjacent Springville quadrangle (Baker, 1947, 1972a, 1973).

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

| Lake Cycle and Phase | Shoreline (map symbol) | Age | | Elevation feet (meters) |
|---|---|---|---|---|
| | | radiocarbon years B.P. | calendar years B.P.[1] | |
| Lake Bonneville | | | | |
| Transgressive Phase | Stansbury | 22,000-20,000[2] | 24,400-23,200 | Not present |
| | Bonneville (B) | 15,500-14,500[3] | 18,000-16,800 | 5180-5195 (1580-1585) |
| | flood | | | |
| Regressive Phase | Provo (P) | 14,500-12,000[4] | 16,800-13,500[5] | 4760-4790 (1450-1460) |
| | Gilbert | 11,000-10,000[6] | 12,800-11,600 | Not present |
| Utah Lake | | | | |
| | Utah Lake highstand (U) | 12,000-11,500[7] | ----- | 4495-4500 (1370-1372) |

[1]Calendar-calibrated ages of most shorelines have not been published. Calendar-calibrated ages shown here, except for the age of the end of the Provo shoreline, are from D.R. Currey, University of Utah (written communication to Utah Geological Survey, 1996; cal yr B.P. = 1.16 $^{14}C$ yr B.P.).

[2]Oviatt and others (1990). Currey (written communication to Utah Geological Survey, 1996) assumed a maximum age for the Stansbury shoreline of 21,000 $^{14}C$ yr B.P., which is used in the conversion to calendar years.

[3]Oviatt and others (1992), Oviatt (1997).

[4]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.

[5]Calendar-calibrated age of the end of the Provo shoreline estimated by interpolation from data in Godsey and others (2005), table 1, who used Stuiver and Reimer (1993) for calibration.

[6]Murchison (1989), figure 20.

[7]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.

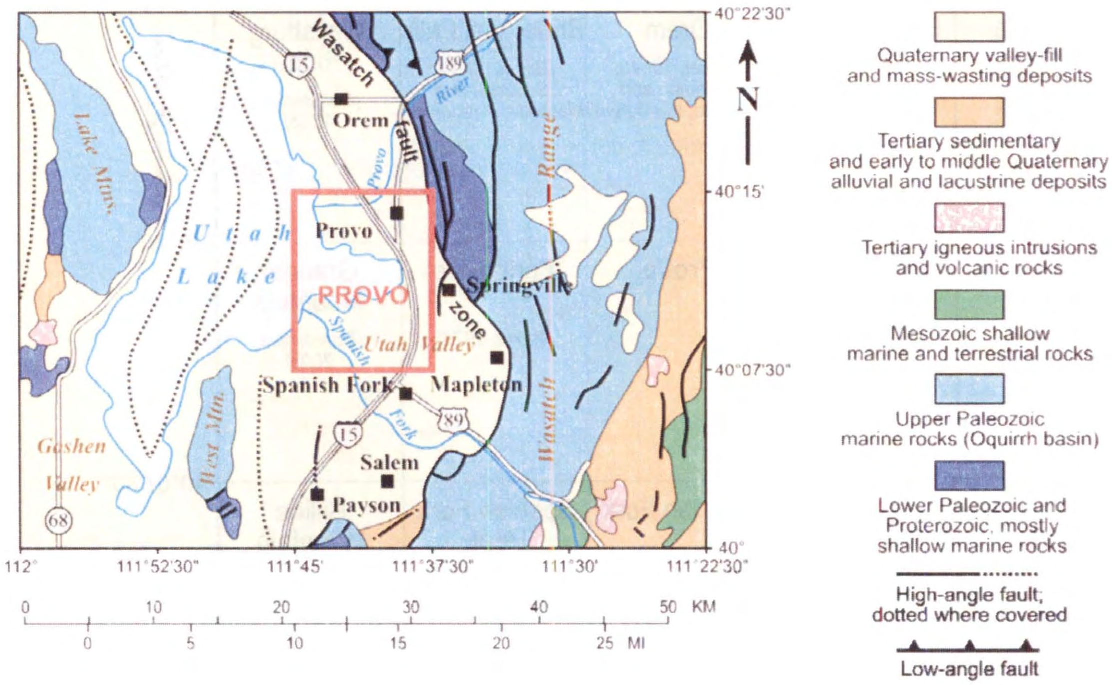



Figure 1. Index map showing the primary geographic features and generalized geology in the vicinity of the Provo quadrangle.

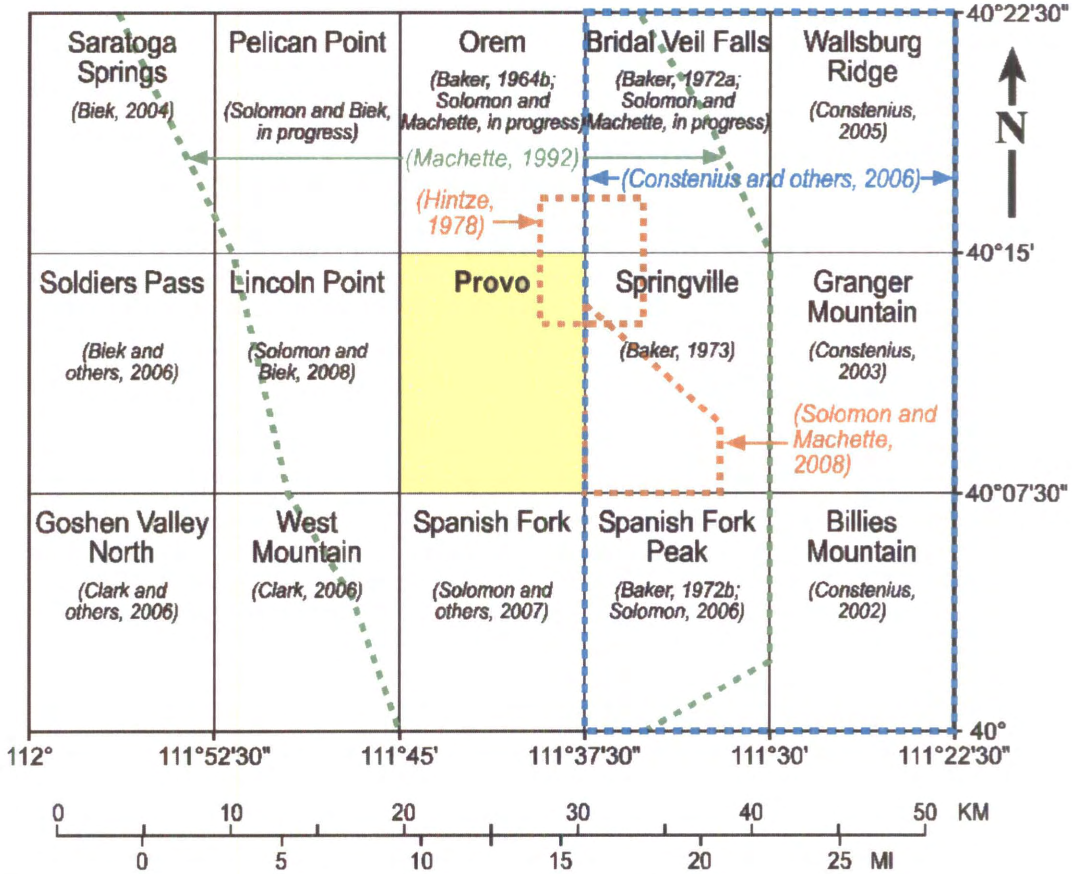


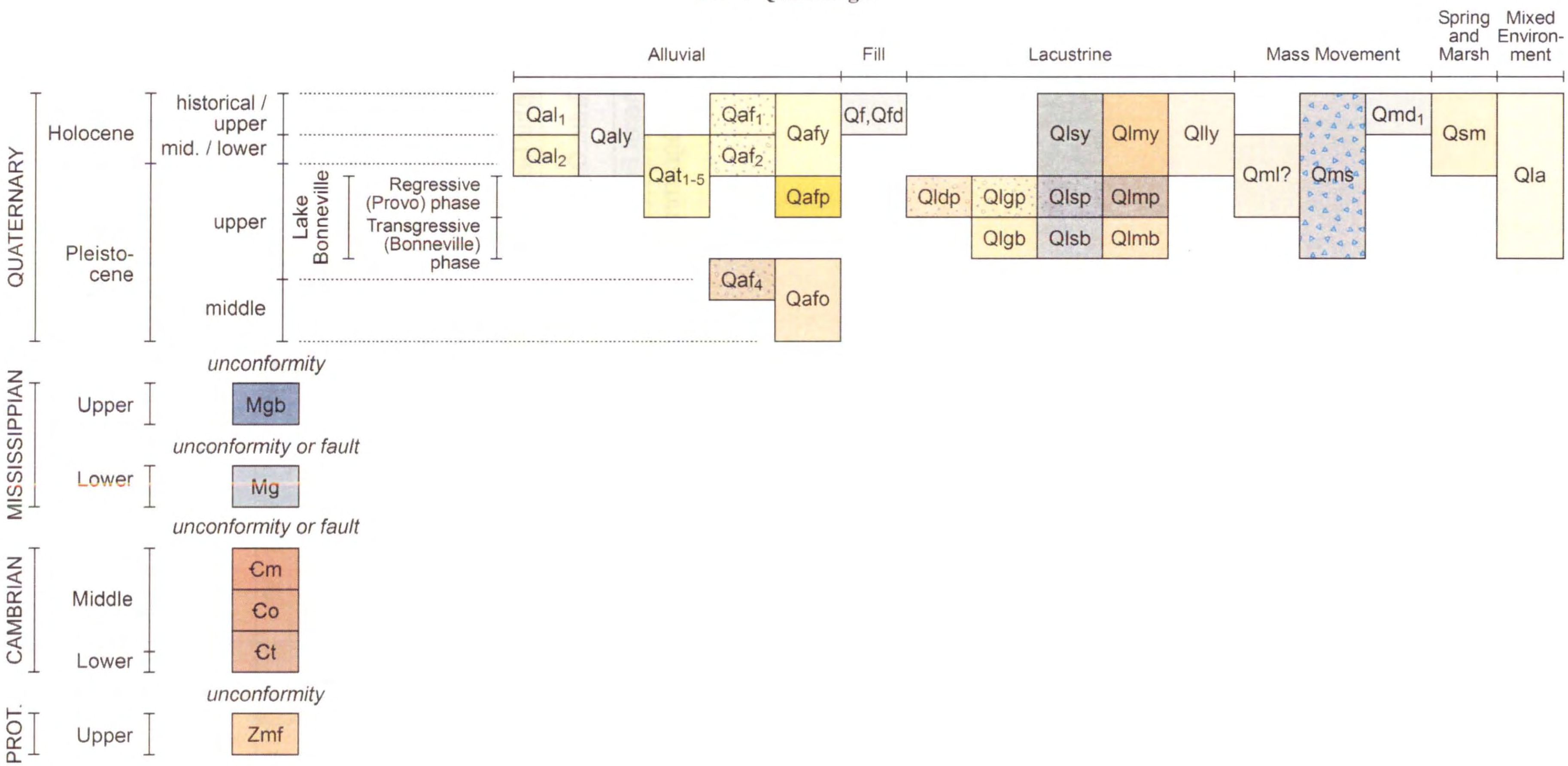

Figure 2. Index map showing selected geologic maps available for the Provo and surrounding 7.5' quadrangles.

## LITHOLOGIC COLUMN
## Provo 7.5' Quadrangle

| SYSTEM | SERIES | FORMATION | SYMBOL | THICKNESS Feet (Meters) | LITHOLOGY |
|---|---|---|---|---|---|
| MISSISSIPPIAN | Upper | Great Blue Limestone | Mgb | <100 (<30) | Exposed thickness |
| MISSISSIPPIAN | Upper | Humbug Formation | Mh | 520 (160) | Not exposed |
| MISSISSIPPIAN | Upper / Lower | Deseret Limestone | Md | 585 (175) | |
| MISSISSIPPIAN | Lower | Gardison Limestone | Mg | 600 (180) | Top and bottom not exposed |
| MISSISSIPPIAN | Lower | Fitchville Dolomite | Mf | 100-265 (30-80) | Not exposed |
| CAMB. | Middle | Maxfield Limestone | Ꞓm | 350-595 (105-180) | Regional unconformity |
| CAMB. | Middle | Ophir Formation | Ꞓo | 100-290 (30-90) | |
| CAMB. | L. | Tintic Quartzite | Ꞓt | 1170 (355) | |
| P. | U. | Mineral Fork Tillite | Zmf | 0-200+ (0-60+) | |

Thicknesses are diagrammatic, no fixed scale.

## CORRELATION OF MAP UNITS
### Provo Quadrangle



## GEOLOGIC SYMBOLS
### Provo Quadrangle

Contact  Dashed where approximately located

Normal fault – Dashed where approximately located, dotted where concealed; bar and ball on down-dropped side

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

W  Other shorelines of Utah Lake

Crest of lacustrine barrier beach or spit

Landslide scarp – Hachures on down-dropped side

20  Strike and dip of inclined bedding (from Baker, 1973)

20  Strike and dip of inclined bedding (from Hintze, 1978)

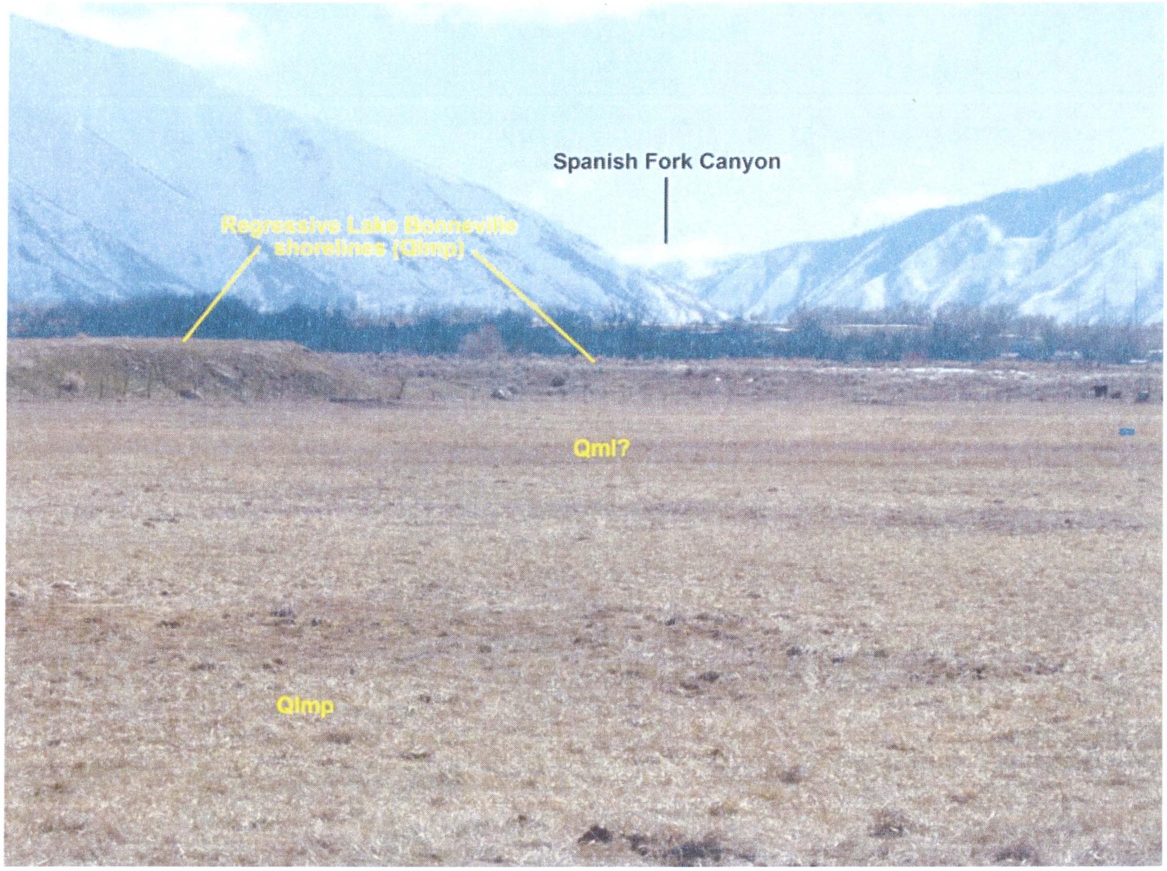
Sand and gravel pit

Spring

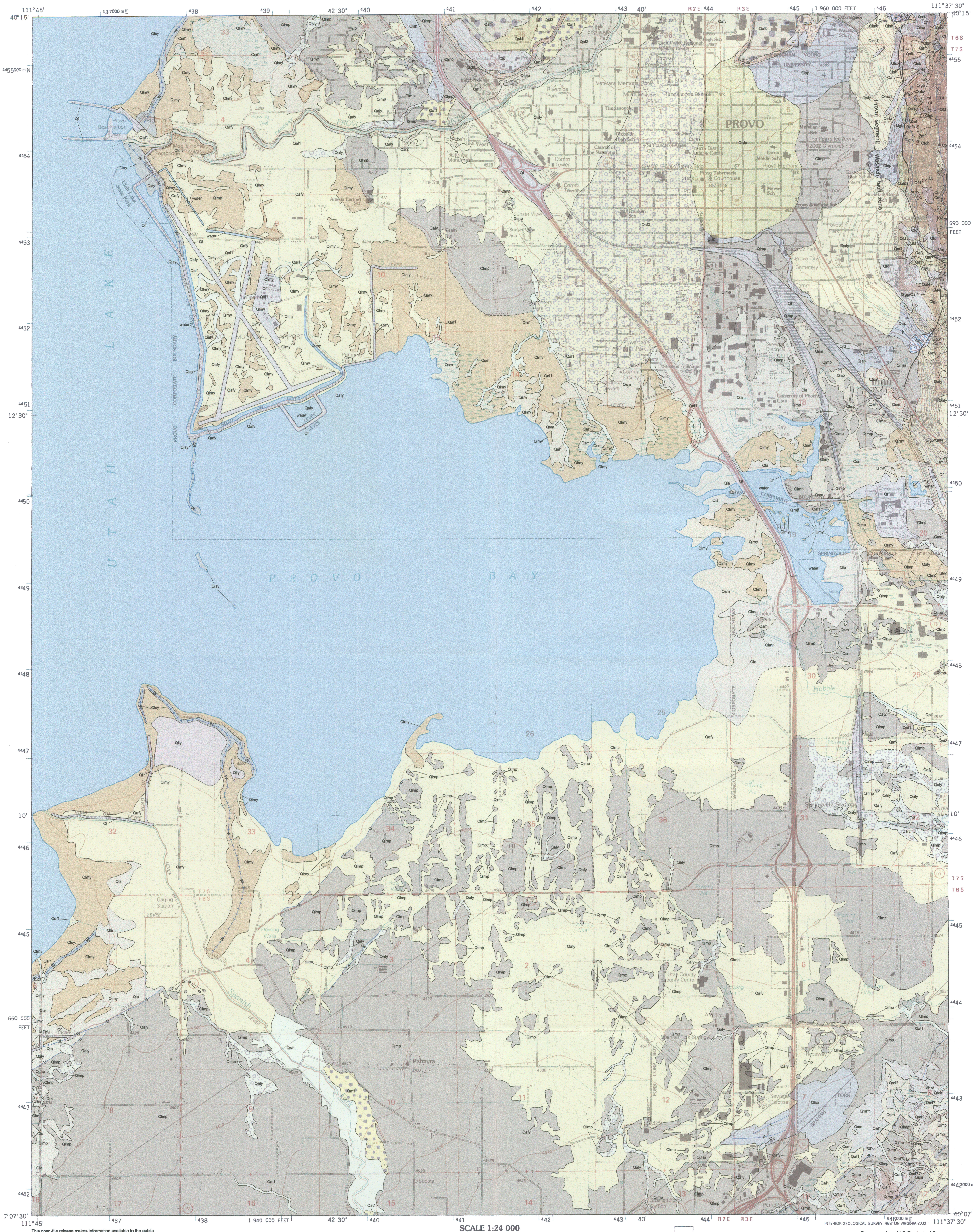
SP-1  Trench sites for lateral-spread investigations (Harty and Lowe, 2003)

*View to the east of a marsh (Qsm) on the north side of Provo Bay.*

*View to the southeast of a slip surface along the Wasatch fault zone east of Provo, about 0.3 miles (0.5 km) south of the mouth of Slide Canyon. The slip surface, dipping about 45°W, is polished carbonate-clast breccia derived from the Mississippian Great Blue Limestone. Bruhn and others (2005) described details of the exposure, referring to the site as the Seven Peaks fault scarp (photograph by Francis Ashland, UGS).*




*Looking southeast across the Springville-Spanish Fork feature. Two of the three discontinuous lineaments that cross the feature are visible, interpreted as regressive shorelines of late Pleistocene Lake Bonneville; shoreline scarps are accentuated because headward erosion of soft, fine-grained lake sediments due to spring sapping stopped when shorelines armored by thin gravels were encountered. Possible lateral spread deposits (Qml?) lie near the lineaments and grade to regressive lacustrine silt and clay in the foreground.*




 This open-file release was funded by the Utah Geological Survey and U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number 06HQAG0037. 

GN MN
0°27' 8 MILS
13½° 240 MILS

UTM GRID AND 2001 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

MILES: 1 .5 0 1
FEET: 1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10 000
KILOMETERS: 1 .5 0 1 2
METERS: 1000 0 1000 2000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
TO CONVERT FROM FEET TO METERS, MULTIPLY BY 0.3048

# Interim Geologic Map of the Provo 7.5' Quadrangle, Utah County, Utah
## 2008

by
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UTAH
QUADRANGLE LOCATION

| | | |
|---|---|---|
| 1 | 2 | 3 |
| 4 | | 5 |
| 6 | 7 | 8 |

1 Pelican Point
2 Orem
3 Bridal Veil Falls
4 Lincoln Point
5 Springville
6 West Mountain
7 Spanish Fork
8 Spanish Fork Peak

ADJOINING 7.5' QUADRANGLE NAMES

Base map from U.S.Geological Survey Provo 7.5' quadrangle, 1998
Geologic data and basemap in NAD 1927
Aerial Photo and Field Mapping: Barry J. Solomon 2006-2007 and Michael N. Machette 1992
Bedrock Geology modified from Baker (1973) and Hintze (1978)
Digital Cartography: Paul Kuehne