INTERIM GEOLOGIC MAP OF UNCONSOLIDATED DEPOSITS IN THE SANTAQUIN QUADRANGLE, UTAH AND JUAB COUNTIES, UTAH

by

Barry J. Solomon

Disclaimer

This open-file release makes information available to the public that may not conform to UGS technical, editorial, or policy standards; this should be considered by an individual or group planning to take action based on the contents of this report. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

This geologic map was funded by the Utah Geological Survey and U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award number G09AC00152. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 570
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
2010

INTRODUCTION

Location and Geographic Setting

The Santaquin quadrangle covers southern Utah Valley, southeastern Goshen Valley, and northern Juab Valley (figure 1). Utah and Goshen Valleys are separated by Warm Springs Mountain and low hills that extend northward to West Mountain in the adjacent West Mountain quadrangle. Mountains extending southward from Warm Springs Mountain separate Goshen and Juab Valleys. A pass between Warm Springs Mountain and the Wasatch Range separates Utah and Juab Valleys, which are both bounded on the east by the Wasatch Range.

The Santaquin quadrangle is largely rural and includes the city of Santaquin and the town of Genola. Summit Creek is the primary stream in the quadrangle, flowing northwest in Santaquin Canyon in the Wasatch Range. The northern end of Mona Reservoir lies in the southwest corner of the Santaquin quadrangle. The reservoir is fed by Currant Creek from the south, and the creek exits the reservoir and flows to the northwest toward Utah Lake through the spillway in the Santaquin quadrangle. Marshy wetlands in the northwest part of the quadrangle are near the southern tip of Utah Lake.

U.S. Interstate 15, the major transportation corridor in the region, runs diagonally from southwest to northeast in the quadrangle and continues to the north along the east side of Utah Lake into the urbanized Wasatch Front. U.S. Highway 6 crosses the interstate at Santaquin and connects with State Highway 68 west of the quadrangle; State Highway 68 provides access to the rapidly developing area west of Utah Lake. Access to the Uinta National Forest and Mount Nebo Wilderness in the Wasatch Range is through a paved road in Santaquin Canyon.

Previous Investigations

Although geologic studies of the Santaquin quadrangle began almost a century ago, most focused on bedrock geology and geologic structure, providing only a superficial overview of the geology of unconsolidated deposits. The earliest published study was an investigation of lamprophyre dikes in the Wasatch Range (Loughlin, 1919). Several theses and dissertations, most of which were conducted by students at Brigham Young University, studied the geology of parts of mountains and hills in the Santaquin quadrangle (see, for example, Muessig, 1951; Elison, 1952; Clark, 1953; Peacock, 1953; Peterson, 1953; Sirrine, 1953; White, 1953; Metter, 1955; Demars, 1956; and Foutz, 1960). Hintze (1962) and Witkind and Weiss (1991) compiled geologic maps of the region that includes the Santaquin quadrangle at respective scales of 1:125,000 and 1:100,000, providing valuable overviews of regional geology, although many questions remain regarding stratigraphic relationships and geologic structure.

Surficial geologic maps by Bissell (1963) (1:48,000 scale) and Miller (1982) (1:100,000 scale) were early attempts to identify the texture of unconsolidated deposits of the Utah Valley and Goshen Valley parts of the Santaquin quadrangle 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.

Although Machette (1992) did not map the Santaquin quadrangle, his Quaternary stratigraphic concepts were extended into the Utah and Juab Valley parts of the quadrangle by Harty and others (1997) at a scale of 1:50,000 (figure 2). The Quaternary geology of the Goshen Valley part of the quadrangle has not been previously mapped in detail. The contacts between some lacustrine units mapped by Miller (1982), Harty and others (1997), and myself were interpreted from the U.S. Soil Conservation Service soil maps (Swenson and others, 1972; Trickler and Hall, 1984).

The geology of several adjacent 7-1/2 minute quadrangles has been mapped at a scale of 1:24,000 (figure 2). These include the Slate Jack Canyon (Jensen, 1986), Mona (Felger and others, 2004), Spanish Fork (Solomon and others, 2007), West Mountain (Clark, 2009), and Goshen Valley North (Clark and others, 2009) quadrangles. I also mapped the geology of unconsolidated deposits in the Payson Lakes quadrangle (Solomon, 2010) as well as the Santaquin quadrangle. Differences between geology along the edges of the Santaquin and some adjacent quadrangles are mostly due to the greater level of detail mapped in the Santaquin quadrangle, but in a few cases are due to different geologic interpretations.

Purpose and Scope

Although the Santaquin quadrangle is largely rural, the area's population is rapidly growing. The quadrangle is only a short commute from the urbanized Wasatch Front of eastern Utah Valley, and also lies in an area that will play an important role in anticipated growth west of Utah Lake. To accommodate this growth and the accompanying demand for travel between areas west and east of the lake, the Mountainland Association of Governments (2009) foresees the need for several new transportation routes. One of these routes may be a new freeway that provides access to the area west of Utah Lake from Interstate 15 east of the lake. Construction of this new transportation corridor, with associated residential and commercial development, will require information about the nature and distribution of geologic hazards. Because most geologic hazards in the area are associated with unconsolidated geologic deposits that serve as foundation materials, this geologic map will serve as a necessary prerequisite to safe and responsible development. Mapping of bedrock geology was beyond the scope of this project; faults that displace unconsolidated deposits and extend into bedrock are mapped, but faults that are entirely in bedrock and do not displace unconsolidated deposits or do not exhibit evidence of Quaternary movement are not mapped.

The Quaternary map of Harty and others (1997) is an important contribution to our knowledge of the geology of unconsolidated deposits in the Santaquin quadrangle, but my map includes significant revisions. Harty and others (1997) mapped the Quaternary geology as part of a program jointly funded by the Utah Geological Survey and the U.S. Geological Survey to provide basic geologic data needed for accurate assessments of paleoseismic history and earthquake hazards associated with the Wasatch fault zone. They eliminated outdated stratigraphic terminology and concepts and updated the fault mapping of Cluff and others (1973). I mapped additional detail in Quaternary deposits on the valley floor, mapped glacial deposits and features in the Wasatch Range, and changed the configuration of some strands of the active Wasatch fault zone. I also reinterpreted deposits east of Santaquin on the northwest margin of Dry Mountain, originally mapped by Demars (1956) as complexly faulted Paleozoic rocks, as mass-movement deposits of large bedrock blocks (QTmb). These mass-movement deposits, as well as others derived from Tertiary rocks, were likely emplaced downslope beginning in the late Tertiary, coincident with the uplift of mountain ranges along the Wasatch fault zone.

Mapping was performed between July 2009, and June 2010, using standard field mapping methods. I used 1:10,000-scale and 1:20,000-scale black-and-white aerial photographs flown in 1958 for the U.S. Department of Agriculture to map the geology of unconsolidated deposits prior to most development in the quadrangle. Air photo mapping was later field checked.

Geologic Summary

Bedrock Geology

Bedrock (R) is exposed in the Wasatch Range east of Juab and Utah Valleys, in Warm Springs Mountain east of Goshen Valley, and in hills and mountains extending north and south of Warm Springs Mountain. The oldest bedrock consists of sedimentary rocks of Permian to Proterozoic age carried on thrusts of the Charleston-Nebo salient in the Cordilleran fold and thrust belt (Hintze, 1962; Witkind and Weiss; 1991; Constenius and others, 2003). These rocks are locally overlain by the Paleocene and Upper Cretaceous North Horn Formation and by Eocene and Oligocene volcanic and volcaniclastic sedimentary rocks. 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 Nephi segment of the Wasatch fault zone (Harty and others, 1997), which separates Juab and Utah Valleys from the Wasatch Range.

Post-Bedrock Geology

Deposits younger than bedrock in the Santaquin quadrangle range in age from Pliocene (?) to Holocene. The oldest of these deposits are large rotated bedrock blocks (megabreccias) (QTmb) and translational earth and debris slides (QTms) that have moved downslope along steep range fronts. The bedrock blocks are composed largely of Paleozoic quartzite, dolomite, and limestone on the northwest margin of Dry Mountain, east of Santaquin. The largest of the earth and debris slides are derived from the North Horn Formation and younger tuffaceous and volcaniclastic sedimentary rocks on the west flank of the Wasatch Range south of Santaquin, although several smaller deposits are derived from Paleozoic rocks. Displacement of rotational and translational mass-movement deposits 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 valleys.

Coalesced middle to upper Pleistocene alluvial-fan deposits (Qaf_4, Qafo) underlie piedmont slopes on valley margins. The fans were deposited during the interlacustral episodes between the last three major lake cycles in the Bonneville Basin (the Pokes Point, Little Valley, and Bonneville lake cycles) and during episodes older than the Pokes Point lake cycle (Machette, 1992). The Pokes Point lake cycle occurred during marine oxygen-isotope stage 12, about 430,000 years ago (Oviatt and others, 1999), and the Little Valley lake cycle, largely contemporaneous with the Bull Lake glaciation (see Chadwick and others, 1997), occurred late in marine oxygen-isotope stage 6, which ended about 130,000 years ago (Scott and others, 1983). The highest levels of the Pokes Point and Little Valley lake cycles are below the elevation of the subsequent Lake Bonneville highstand (Scott and others, 1983) and thus are buried throughout most of the Bonneville basin. Remnants of the fans are exposed above the highest Lake Bonneville shoreline along the base of the Wasatch Range east of Juab Valley and along the base of Dry Mountain east of Santaquin (table 1).

Surficial deposits in the quadrangle were mostly associated with late Pleistocene Lake Bonneville, which was 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. Glacial deposits of Bull Lake and/or Pinedale age (Qg) are found on the eastern flank of Bald Mountain, near its crest in the southeast corner of the Santaquin 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 as it regressed beyond the boundaries of the Santaquin quadrangle. With the regression of Lake Bonneville, streams incised in response to the lowering base level, depositing alluvium in channels and floodplains. Locally, steeper slopes failed, and parts of older, weakened landslide deposits 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 reworked Lake Bonneville sand and silt into an eolian blanket on deltaic gravel (Qes/Qldb) south of Santaquin, and eroded finer-grained desiccated Bonneville lake beds, locally depositing a thin but widespread mantle of calcareous loess on other 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 Santaquin 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. I 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 (unless otherwise noted, dates in this section are calendar dates) during expansion (transgression) of Lake Bonneville. The Stansbury shoreline formed at elevations below those of the Santaquin quadrangle.

The lake continued to rise, entering the quadrangle from the north through Goshen Valley at an elevation of about 4500 feet (1370 m) about 23,000 years ago, and reaching Utah Valley near Santaquin at an elevation of about 4740 feet (1440 m) after rising further. Unlike other major valleys along the Wasatch Front, Juab Valley was inundated by Lake Bonneville only during its climb to the highstand at the Bonneville level. Paleohydrographs of Lake Bonneville constructed from radiocarbon-age data show that the lake reached the topographic threshold of Juab Valley about 18,000 ^{14}C yr B.P. (Oviatt and others, 1992; Harty and others, 1997) (about 21,000 cal yr B.P.). The lake entered Juab Valley from Goshen Valley to the northwest, along present-day Current Creek, where the threshold of Juab Valley is 4870 feet (1480 m). Soon afterward, Lake Bonneville crossed the threshold between Utah and Juab Valleys at 5000 feet (1525 m), 130 feet (45 m) higher than the topographic threshold between Juab and Goshen Valleys.

In the Bonneville Basin, the lake reached its highest level about 18,300 years ago near Zenda, in southern Idaho. This highstand created the Bonneville shoreline, which can be traced over most of northwest Utah (table 1). In the Santaquin quadrangle, the Bonneville shoreline forms wave-built benches on the east side of Juab Valley south of Warm Spring Mountain and east of Santaquin on the margin of Dry Mountain. However, the shoreline is primarily erosional elsewhere, and is commonly covered by younger deposits on the east side of Juab Valley. Sediments entering Lake Bonneville from Summit Creek during the highstand built a small delta at the mouth of Santaquin Canyon, and longshore currents eroded the delta front, building several large gravel spits southwest of Santaquin. Converging currents from Utah and Juab Valleys created a cuspate v-bar near Cedar Hollow (Currey, 1982, Bonneville shoreline location 19), forming the low divide between the two valleys at the Bonneville shoreline highstand at an elevation of 5112 feet (1558 m).

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. In the Santaquin quadrangle, this process rapidly drained the lake from Juab Valley as the water level dropped below the Utah-Juab Valley topographic threshold and the lake also retreated northwest into Goshen Valley down Currant Creek. The lake then stabilized and etched the Provo shoreline on the east side of Juab Valley and north of Santaquin in Utah Valley. 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).

About 14,600 years ago, climatic factors induced further lowering of the lake level within the Bonneville basin (Godsey and others, 2005), the lake level eventually fell below elevations in the Santaquin quadrangle, and levels never rose to such elevations again. 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 Pleistocene highstand of Utah Lake formed at this time north of the Santaquin quadrangle (table 1). After formation of the Gilbert shoreline, Lake Bonneville fell 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 Santaquin quadrangle, near the margin of the Bonneville Basin where water depth was much less than at the basin's center, uplift of both shorelines was significantly less than that recorded by both Currey (1982) and Machette (1992). The maximum elevation of the Bonneville shoreline in the Santaquin quadrangle (in the footwall of the Wasatch fault zone east of Santaquin) is about 5120 feet (1560 m) compared to its threshold elevation of 5092 feet (1552 m) at Zenda, and the maximum elevation of the Provo shoreline in the quadrangle (in the hanging wall of the Wasatch fault zone on the east side of Goshen Valley) is about 4760 feet (1450 m) compared to its threshold elevation of 4737 feet (1444 m) at Red Rock Pass (table 1). Thus, uplift of the Bonneville and Provo shorelines in the quadrangle is about 28 feet (9 m) and 23 feet (7 m), respectively.

Paleoseismology

Quaternary active faults bound the eastern edge of the valleys in the Santaquin quadrangle. The valleys are structural basins formed by late Cenozoic (younger than 18 Ma) displacement along Basin-and-Range faults. These faults include the Long Ridge fault on the east side of Goshen Valley and the Wasatch fault zone (WFZ) on the east side of Utah and Juab Valleys. The Long Ridge fault is a poorly understood fault that forms a range-front escarpment, suggesting to Sullivan and others (1987) that the fault was active in the Quaternary, but they found no evidence for the timing of the most recent large earthquake along the fault. Although the fault is concealed in much of the Santaquin quadrangle, I mapped Holocene displacement along the fault (NE¼ section 8, T. 10 S., R. 1 E., SLBLM), with late Pleistocene regressive Lake Bonneville gravel and sand (Qlgp/R) in the footwall and Holocene alluvial-fan deposits (Qafy) in the hanging wall.

Two segments of the WFZ bound Utah and Juab Valleys to the east: (1) the Provo segment, east of much of Utah Valley, extends southward into Payson Canyon, east of Dry Mountain (Machette, 1992), and (2) the Nephi segment, east of Juab Valley and the southern tip of Utah Valley, extends beyond the Provo segment west of Dry Mountain (Harty and others, 1997). The boundary between the two segments is an en echelon, overlapping right step.

The northern end of the Nephi segment is mapped in the Santaquin quadrangle, where it consists of two strands (northern and southern) separated by a 3-mile-wide (5-km) right step. The northern strand lies on the southeast margin of Utah Valley, east of Santaquin, and extends south along the west side of Dry Mountain. The southern strand lies on the east margin of Juab Valley, consisting of a single trace for much of its length south of the Santaquin quadrangle, but diverging into several subparallel splays within the quadrangle. Prior to 2005, paleoseismic data for the Nephi segment were limited to the southern strand (Hanson and others, 1981; Jackson, 1991). However, the Utah Earthquake Parameters Working Group (Lund, 2005) concluded that "the existing paleoseismic data for the [Nephi segment] are considered poorly constrained, and multiple surface-faulting chronologies are possible depending on which ages are accepted and which are discarded." To resolve the timing, displacement, and magnitude of prehistoric surface-faulting earthquakes on the Nephi segment, the Utah Geological Survey excavated two trenches across a fault scarp on the northern strand of the fault near Santaquin (NW¼ section 6, T. 10 S., R. 2 E., SLBLM) (DuRoss and others, 2008), and the U.S. Geological Survey excavated two trenches across a fault scarp on the southern strand at Willow Creek in the adjacent Mona quadrangle (Machette and others, 2007).

Quaternary fault scarps in the Santaquin quadrangle indicate significant seismic hazards. DuRoss and others (2008), using the relationships of Hanks and Kanamori (1979) and Wells and Coppersmith (1994), estimated a moment magnitude of 7.0 for the most recent surface-faulting earthquake on the northern strand of the Nephi segment near Santaquin. Their paleoseismic data from the trenches near Santaquin indicate that this earthquake produced about 9.8 ± 0.7 feet (3.0 ± 0.2 m) of net vertical tectonic displacement of the ground surface (DuRoss and others, 2008). The earthquake occurred 500 +100/-150 years ago, and a poorly constrained minimum time estimate for the previous earthquake is at least 1500 years ago and likely greater than 6100 to 7000 years ago (DuRoss and others, 2008). They estimated that the long-term vertical geologic slip rate is 0.5 mm/yr and the average recurrence interval is 6000 ± 400 years (DuRoss and others, 2008).

Preliminary interpretations of the timing of major surface-faulting earthquakes at Willow Creek on the southern strand of the Nephi segment indicate that the three most recent of these events occurred about 300, 1230, and less than 2320 years ago (Machette and others, 2007). The maximum average recurrence interval for the two most recent events is less than 1000 years, and Holocene slip rates along the fault are estimated to be from 2.0 to 2.5 mm/yr. These data indicate that the southern strand of the Nephi segment has experienced the most recent major surface-faulting event of any segment of the Wasatch fault zone, and also has the highest documented Holocene slip rate of any segment. Machette and others (2007) caution, however, "that further estimates of repeat times and slip rates await refinement and synthesis of radiocarbon dates and luminescence age estimates from both [Willow Creek] trenches."

Slope Failures

Geologic materials susceptible to slope failure are common in the Santaquin quadrangle. Of particular significance are shale in the Pennsylvanian to Mississippian Manning Canyon Shale, mudstone and claystone in the Cretaceous to Tertiary North Horn Formation, and Tertiary tuffs and tuffaceous sedimentary rocks. Large landslides derived from these geologic units are widespread in the Wasatch Range east of Utah and Juab Valleys, and smaller landslides are found locally on steep slopes on and near Warm Springs Mountain. Once slope failures occur, the resulting landslide deposits have an enhanced susceptibility to move again. Renewed movement of landslides, both historic and prehistoric, along the Wasatch Front in 1998 suggested to Ashland (2003) that these landslides were marginally stable to possibly metastable prior to 1998, possibly as a result of hillside modifications. Therefore, both geologic units that have failed and the resulting landslide deposits, regardless of age, pose an increased risk of future slope failures.

The potential for renewed movement in existing landslides in the Santaquin quadrangle is illustrated by historic landsliding in Spanish Fork Canyon, about 15 miles (24 km) east of Santaquin. Two of the most spectacular historic Utah landslides occurred in the canyon, and the North Horn Formation was a significant source rock for both: the Thistle landslide and the Shurtz Lake landslide. Shroder (1971) first mapped the prehistoric Thistle landslide and recognized evidence of repeated movement. In April 1983, the landslide moved again (Duncan and others, 1986), resulting in the most expensive individual landslide in North American history, in terms of both direct and indirect costs (Schuster, 1996). A similar scenario was encountered nearby in 1997, when prehistoric landslide deposits near Shurtz Lake were reactivated (Ashland, 1997), and both the Thistle and Shurtz Lake landslides moved once more in 1998 following a period of above-normal precipitation (Ashland, 2003).

The Santaquin quadrangle also experienced historic debris flows, occurring on September 12, 2002 (McDonald and Giraud, 2002). The debris flows partly resulted from a wildfire that burned much of Dry Mountain during late summer 2001 and exposed soils with a very high erosion potential, and were triggered by intense thunderstorms. Major debris flows (Qmd_1) originated in five tributaries and deposited debris on alluvial fans (Qafy and Qaf_1) west of Dry Mountain. Debris and floodwater flowed into developed areas, causing property damage in two subdivisions. Conditions conducive to debris flows, including steep mountain canyons with alluvial fans at canyon mouths, are common throughout the Santaquin quadrangle, and the presence of both historic and prehistoric debris flows (Qmd_2) indicate the high hazard potential.

ACKNOWLEDGMENTS

I thank Jon K. King (UGS) for his guidance and many useful comments regarding interpretation of geology. UGS staff members Robert Ressetar and Grant Willis also improved this map through their reviews. Jay Hill (UGS) assisted in preparation of the map and supporting materials.

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial deposits

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 lower reach of Summit Creek near the mouth of Santaquin Canyon, where level-1 deposits are inset into level-2 deposits, and in smaller channels west of Warm Springs Mountain, near Santaquin, and east of Mona Reservoir; mapped in active channels and floodplains, and on minor terraces less than 5 feet (1.5 m) above active channels; locally includes minor colluvial deposits along steep stream embankments; equivalent to the younger part of young stream deposits (Qaly), but differentiated where level-1 deposits 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 on a terrace from 5 to 15 feet (1.5-5 m) above the adjacent active channel along the lower reach of Summit Creek near the mouth of Santaquin Canyon, where level-1 deposits are inset into level-2 deposits; equivalent to the older part of Qaly, but differentiated where level-2 deposits 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 Summit Creek in Santaquin Canyon, south of the flood-control basin (Qf, Qfd) near its mouth, and in small channels scattered throughout the quadrangle; locally includes areas of 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 are too small to show at map scale or where the specific age of post-Lake Bonneville deposits cannot be determined; postdates regression of Lake Bonneville from the Provo shoreline and lower levels in Goshen Valley, and postdates the regression of Lake Bonneville from the Bonneville shoreline in Juab Valley and the Utah Valley part of the Santaquin quadrangle, where regressive lacustrine deposits are absent and young stream deposits are at elevations higher than the Provo shoreline. 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. Deposited in two channels southwest of Goshen Hill incised into transgressive Lake Bonneville deposits (Qlsb, Qlgb/R) and graded to the Provo shoreline; one channel southwest of Santaquin incised into transgressive Lake Bonneville deposits (Qldb, Qlsb, Qlmb) and graded to slightly above the Provo shoreline; and one channel south of Warm Springs Mountain incised into transgressive Lake Bonneville deposits (Qlgb/R) and graded to slightly above the Provo shoreline; at the two locations nearest to Warm Springs Mountain, regressive-phase stream deposits are incised by active stream channels. Exposed thickness less than 15 feet (5 m).

Qalb **Stream deposits, transgressive (Bonneville) phase of Lake Bonneville** (upper Pleistocene) – Poorly to 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 channels east and south of Warm Springs Mountain incised into bedrock, graded to the Bonneville shoreline, and incised by active stream channels. Exposed thickness less than 15 feet (5 m).

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 mouths of several mountain canyons and lower gradient streams on valley floors; 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. Deposits are scattered throughout the quadrangle, but the largest deposits are east of Santaquin, emanating from canyons in Dry Mountain and commonly overlapped by younger alluvial-fan deposits (Qaf_1, Qafy); no Lake Bonneville shorelines are found on these alluvial fans; equivalent to the older part of Qafy, but differentiated where deposits are graded to 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 at the mouths of mountain canyons throughout the quadrangle; young alluvial-fan deposits are mapped more extensively than by Harty and others (1997) west of Wash Canyon and west of Dry Mountain, where shallow channels and vegetation indicate the presence of active fan surfaces; west of Dry Mountain, the debris flows of 2002 (Qmd_1) indicate active fan deposition, and the pattern of young alluvial-fan deposits on this map more accurately reflects the distribution of canyon mouths and active mountain streams. Includes level-1 and level-2 alluvial-fan deposits (Qaf_1 and Qaf_2) that either cannot be differentiated because of map scale or are in areas where the specific age of Holocene deposits cannot be determined; postdates regression of Lake Bonneville from the Provo shoreline and lower levels in Goshen Valley, and postdates the regression of Lake Bonneville from the Bonneville shoreline in Juab Valley and the Utah Valley part of the Santaquin quadrangle, where regressive deposits are absent and young alluvial-fan deposits are at elevations higher than the Provo shoreline; 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) south of Warm Springs Mountain graded to the Provo shoreline and incised by young stream deposits (Qaly), and (2) in and near Santaquin where a large fan was deposited between the Bonneville and Provo shorelines from Santaquin Canyon after the Bonneville flood, and was later incised by younger alluvial-fan deposits (Qafy) along its western margin; equivalent to the younger part of level-3 alluvial-fan deposits (Qaf_3) but differentiated because their relationship to the Provo shoreline is evident and they can be mapped separately. 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 (1) east of Warm Springs Mountain, graded to the highest (Bonneville) shoreline of Lake Bonneville, and (2) west of Dry Mountain, where transgressive fan deposits are mapped as less extensive than those of Harty and others (1997) and are restricted to more incised remnants between younger fans (Qafy, Qaf_2); equivalent to the older part of level-3 alluvial-fan deposits (Qaf_3) but differentiated because their relationship to the Bonneville shoreline is evident and they can be mapped separately. 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). Exposed thickness less than 15 feet (5 m).

Qaf_3 **Level 3 alluvial-fan deposits, Bonneville lake cycle, undivided** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and minor clay. Smaller deposits are mapped west of the mouth of Santaquin Canyon and on the west side of Juab Valley, but the largest deposit is on the east side of Juab Valley; the smaller deposits lie slightly above the Bonneville shoreline and, although the deposits near Santaquin Canyon were mapped by Harty and others (1997) as either older or younger than Lake Bonneville, all exhibit a similar degree of dissection and their topographic position suggests deposition contemporaneous with at least the transgressive phase of the lake; the large deposit on the east side of Juab Valley was mapped by Harty and others (1997) as younger than the lake, but it is overlapped and incised by younger alluvial-fan deposits (Qafy), and is also incised by small streams draining the distal ends of the younger fans; deposition at all deposits may have continued in Juab Valley during the regressive phase of Lake Bonneville after it had left the valley. Level 3 alluvial-fan deposits may include alluvial-fan deposits of both the transgressive and regressive phases of Lake Bonneville that are undifferentiated because correlation with a specific lake phase cannot be established. Thickness probably less than 40 feet (12 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 along the range front east of Santaquin, above the Bonneville shoreline, and on the west side of Juab Valley, where they are cut by the Bonneville shoreline. 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 elsewhere in Utah Valley 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, with a matrix of sand, silt, and clay. Forms small, resistant knobs on the piedmont slope on the east side of Juab Valley overlapped by level-3 alluvial-fan deposits, and resistant deposits on the footwall of a normal fault on the piedmont slope west of Wash Canyon; although Harty and others (1997) mapped these deposits as post-Bonneville fans (Qaf_2), they are much more resistant than overlapping younger fans contemporaneous with Lake Bonneville (Qaf_3) in the footwall of the fault and are therefore older than the lake; Harty and others (1997) mapped the steep, northeast wall of Santaquin Canyon, as well as the overlying gently sloping surface near the canyon mouth as older alluvial-fan deposits, but the canyon wall appears to be underlain by the North Horn Formation as mapped by Hintze (1962) and Witkind and Weiss (1991), and the upper surface is likely a pediment overlain by a thin mantle of younger alluvial-fan deposits (Qafy); the pediment near Santaquin Canyon may be related to a regional period of erosion, with similar landforms and deposits including middle Pleistocene alluvium near Payson Canyon that lies on a dissected terrace unconformably over Neogene sedimentary rock (Machette, 1992; Solomon, 2010), and Pliocene to Holocene pediment-mantle alluvium near Thistle Canyon deposited on the Oligocene and Eocene Moroni Formation (Harris, 1953; Witkind and Page, 1983; Witkind and Weiss, 1991). The B soil horizon of paleosols developed on the older 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).

Colluvial deposits

Qc **Colluvial deposits** (Holocene to upper Pleistocene) – Pebble, cobble, and boulder gravel, commonly clast supported, in a matrix of sand, silt, and clay; angular to subangular clasts, poorly sorted, poorly stratified, locally derived sediment deposited by slopewash, and soil creep in steep-sided stream canyons near Warm Springs Mountain and Black Hollow; includes landslides, rock falls, and debris flows too small to map separately; most bedrock is covered by at least a thin veneer of colluvium, and only the larger, thicker deposits are mapped. Maximum thickness about 15 feet (5 m).

Fill deposits

Qf **Artificial fill** (Historical) – Earth fill used in the construction of embankments for a debris basin at the mouth of Santaquin Canyon; unmapped fill is locally present in most developed areas, but only the largest deposit is mapped. Maximum thickness about 20 feet (6 m).

Qfd **Disturbed land** (Historical) – Land disturbed by borrow pits and sand, gravel, and aggregate operations commonly in nearshore Lake Bonneville deposits (Qlgb), and by the debris basin at the mouth of Santaquin Canyon. The outlines of disturbed land are based on 1958 aerial photographs, updated using the 1998 orthophotographic quadrangle; 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). Thickness unknown.

Glacial deposits

Qg **Glacial deposits, undivided** (upper to middle Pleistocene) – Includes till (moraine deposits) and outwash of various ages (Pinedale and/or Bull Lake ages) deposited east of Bald Mountain and the ridge crest to the north, where distinct shapes of end, recessional, and lateral moraines are not visible; the two deposits to the south were first mapped by Hintze (1962); glacial deposits are downslope of five east-facing cirques separated by sharp-edged arêtes, with cirques reaching elevations greater than 9000 feet (2700 m); 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, Qc) too small to show separately at map scale. Thickness less than 150 feet (45 m).

Lacustrine deposits

Deposits younger than the Bonneville lake cycle

Qly **Young lacustrine deposits** (Holocene to upper Pleistocene) − Silt, clay, and minor fine-grained sand deposited along the margin of Mona Reservoir and the small lake southwest of Santaquin; locally organic rich and locally includes pebbly beach gravel; overlies transgressive sediments of the Bonneville lake cycle. Thickness less than 15 feet (5 m).

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 4720 to 4760 feet (1440-1450 m) on the east side of Goshen Valley and the south end of Utah Valley (north of Santaquin) in the Santaquin quadrangle (table 1). 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).

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 shallow water near shore as linear beaches along the Provo shoreline northeast of Santaquin and in eastern Goshen Valley, where the unit is commonly found as a veneer of reworked clasts derived from underlying Paleozoic rocks (Qlgp/R) at the base of Warm Springs Mountain; commonly interbedded with or laterally gradational to lacustrine silt and clay of the regressive phase (Qlmp). 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 close to the Provo shoreline north of Black Hollow in Goshen Valley, where erosional remnants are incised by young alluvial-fan deposits (Qafy); grades downslope into lacustrine silt and clay of the regressive phase (Qlmp); 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 below the Provo shoreline in quiet water in southern Goshen and Utah Valleys; overlies lacustrine silt and clay of the transgressive phase (Qlmb) and commonly grades upslope into lacustrine gravel, sand, and silt (Qlgp, Qlsp); locally buried by loess veneer; regressive lacustrine shorelines typically poorly developed. Regressive silt and clay in Goshen Valley commonly found as isolated remnants stranded by spring sapping in wetlands south of Utah Lake; more extensive regressive deposits mapped as silt and clay near Genola in the adjacent West Mountain quadrangle (Clark, 2009) are shown as coarser grained in soil-survey data (Trickler and Hall, 1984), and their southward extension in the Santaquin quadrangle is mapped as regressive sand and silt (Qlsp); in Utah Valley, regressive silt and clay extends northward into a more extensive outcrop in the West Mountain quadrangle, although Clark (2009) did not map the Provo shoreline in the southeastern part of the quadrangle and therefore regressive deposits above the shoreline east of Goshen Gap are actually transgressive (Qlmb). 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 5080 to 5120 feet (1550-1560 m) in the Santaquin 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).

Qldb **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; most deltaic beds are found beneath a veneer of eolian sand and silt (Qes/Qldb) at the mouth of Santaquin Canyon, but the steep delta front is exposed southwest of the canyon mouth; northeast of the canyon mouth, transgressive lacustrine gravel and sand (Qlgb) was deposited by longshore currents along the delta front and transported farther southwest beyond the canyon mouth, combining with sediment from the canyon to form a series of prograding spits. Exposed thickness about 45 feet (15 m).

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. Most transgressive gravel and sand deposits are veneers over bedrock and older alluvial-fan deposits (Qlgb/R, Qlgb/Qafo), typically forming wave-cut benches close to the Bonneville shoreline that are commonly partly covered by colluvium derived from adjacent oversteepened slopes, although thicker accumulations of transgressive lacustrine gravel and sand are west of Mona Reservoir and in Little Valley; a wave-built bench of transgressive gravel and sand east of Santaquin extends to the southwest into a series of prograding spits constructed at successively higher levels as the lake rose to the Bonneville shoreline, and longshore currents converging from Utah and Juab Valleys near Cedar Hollow built a cuspate v-bar of transgressive gravel and sand; bedding ranges from horizontal to primary dips of 10 to 15 degrees on steeper 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 Santaquin in Utah Valley and north of Mona Reservoir in Juab Valley; much of this unit was mapped as transgressive silt and clay by Harty and others (1997), but soil surveys (Swenson and others, 1972; Trickler and Hall, 1984) indicate a significant component of sand, and silt and clay deposits (Qlmb) are restricted to the areas in that unit's description; 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. In Utah Valley, transgressive silt and clay was deposited north of Santaquin in deeper water offshore, and in Cedar Hollow in quiet water trapped in a lagoon between large spits to the north and the cuspate v-bar to the south; in Juab Valley, transgressive silt and clay was deposited in deeper water in the closed depression at the north end of the valley and further south near Mona Reservoir; overlies lacustrine gravel, sand, and silt of the transgressive phase (Qlgb and Qlsb). Exposed thickness less than 15 feet (5 m).

Mass-movement deposits

Qmd_1 **Modern debris-flow deposits** (upper Holocene [historical]) – On September 12, 2002, intense rainfall triggered five fire-related debris flows from drainages on Dry Mountain, east and southeast of Santaquin; although many of the debris-flow deposits have since been regraded, they are mapped to illustrate the potential hazard; the following description is summarized from McDonald and Giraud (2002). Debris flows were deposited as narrow linear lobes on alluvial fans (Qaf_1, Qaf_2, Qafy), with narrow, linear, paired levees up to 3 feet (1 m) thick flanking the debris flows on alluvial-fan apices; the main lobes deposited farther downfan were generally less than 2 feet (0.6 m) thick; the debris-flow deposits ranged from clayey gravel near the mountain front to clayey sand in distal deposits; clasts up to about 3 feet (1 m) in diameter in the upper parts of the deposits near the mountain front, where exposures indicated deposits are matrix-supported. Thickness less than 3 feet (1 m).

Qmd_2 **Older debris-flow deposits** (upper to middle Pleistocene) – Unsorted cobble and boulder gravel in a matrix of sand, silt, and clay; mapped in narrow canyons in the Wasatch Range and south of Little Valley, and in larger deposits southeast of Cedar Hollow; the minimum age of the smaller deposits is uncertain, but the deposits near Cedar Hollow are truncated or etched by the Bonneville highstand, indicating a minimum age of late Pleistocene, and their proximity to the large landslide (QTms) west of Pole Canyon suggests partial, more fluid reactivations of older landslide deposits. Thickness less than 60 feet (20 m).

Qms **Younger landslide deposits** (Historical to middle Pleistocene) – Poorly sorted clay- to boulder-sized material in slides, slumps, and minor 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; mapped on Goshen Hill and the west flank of Dry Mountain, derived mostly from Paleozoic rocks, and near Warm Springs Mountain, derived mostly from the North Horn Formation and Tertiary volcaniclastic sedimentary rocks; younger landslide deposits are much smaller than older landslide deposits (QTms). Thickness highly variable, commonly less than 30 feet (10 m).

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 upper Santaquin Canyon, derived from the Permian and Pennsylvanian Oquirrh Formation, and in the southeast part of the quadrangle, derived from the Mississippian Deseret Limestone. Generally less than 20 feet (6 m) thick.

Spring and marsh deposits

Qsm **Spring and marsh deposits** (Holocene to upper Pleistocene) – Fine-grained, 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 grades laterally into undivided lacustrine and alluvial deposits (Qla); mapped where water table is high west of Warm Springs Mountain and south of Utah Lake. 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 drainages scattered throughout the quadrangle that are in bedrock or are underlain by bedrock at shallow depths beneath a veneer of Quaternary deposits, 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).

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 in Goshen Valley, where spring sapping in wetlands strands remnants of regressive Bonneville silt and clay (Qlmp) in undivided lacustrine and alluvial deposits, and near Santaquin and in southernmost Goshen Valley, where distal alluvial-fan deposits (Qaf_1, Qafy, Qafp) grade into lacustrine silt and clay (Qlmp, Qlmb). 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 in scattered areas of the Wasatch Range. Thickness less than 40 feet (12 m).

Stacked-unit deposits

Qc/R **Colluvial deposits over rock** (Holocene to upper Pleistocene/pre-Quaternary) – A thin veneer of colluvium overlies areas between alluvial fans downslope from range-front spurs in Dry Mountain; on air photos the deposits appear white and, although underlying rock is not exposed, their air-photo appearance resembles that of Tertiary rock exposed on the east side of Santaquin Canyon; these deposits correspond to hillslope colluvium mapped by Harty and others (1997) and may be shallow subcrop of Tertiary rock underlying the piedmont between Dry Mountain and Santaquin Canyon. Colluvial deposits are generally less than 3 feet (1 m) thick.

Qes/Qldb

Eolian sand and silt over deltaic deposits (transgressive phase) (Holocene to upper Pleistocene/upper Pleistocene) – Deltaic deposits related to the transgressive (Bonneville) phase of Lake Bonneville are partly concealed by a discontinuous veneer of sand and silt reworked by wind at the mouth of Santaquin Canyon. Eolian deposits are generally less than 3 feet (1 m) thick.

Qlgp/R

Lacustrine gravel and sand (regressive phase) over rock (upper Pleistocene/Paleozoic) – Paleozoic bedrock, at and slightly below the Provo shoreline west of Warm Springs Mountain, partly concealed by a discontinuous veneer of lacustrine gravel and sand related to the regressive phase of Lake Bonneville; lacustrine wave action formed a wave-cut bench at the Provo shoreline that locally exposes a ledge of rock, and closely spaced, well-preserved regressive shorelines are commonly etched below the Provo shoreline. Lacustrine deposits are generally less than 10 feet (3 m) thick.

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 north of Mona Reservoir on a part of the piedmont that lies between modern drainages and has a slope gradient greater than that of adjacent younger alluvial fans (Qaf_1, Qafy). Lacustrine deposits are generally less than 3 feet (1 m) thick.

$Qlgb/Qmd_2$

Lacustrine gravel and sand (transgressive phase) over older debris-flow deposits (upper Pleistocene/upper to lower Pleistocene) – A veneer of lacustrine gravel and sand related to the transgressive phase of Lake Bonneville reworked from an underlying lobe of older debris-flow deposits that extends below the Bonneville shoreline in the northeast corner of Juab Valley. Lacustrine deposits are generally less than 3 feet (1 m) thick.

Qlgb/R

Lacustrine gravel and sand (transgressive phase) over rock (upper Pleistocene/Paleozoic) – Bedrock between the Provo and Bonneville shorelines partly concealed by a discontinuous veneer of lacustrine gravel and sand related to the transgressive phase of Lake Bonneville; bedrock includes (1) resistant Paleozoic bedrock that commonly forms a narrow, steeply sloping wave-cut bench at and very near the Bonneville shoreline west and east of Warm Springs Mountain, (2) similar Paleozoic bedrock underlying Goshen Hill characterized by closely spaced transgressive shorelines etched into the hillside, and (3) softer Cretaceous and Tertiary bedrock, including the North Horn Formation and volcaniclastic sedimentary rocks, that underlies gentler slopes north of Warm Springs Mountain and the area west of Cedar Hollow. Lacustrine deposits are generally less than 10 feet (3 m) thick.

Qlsb/R

Lacustrine sand and silt (transgressive phase) over rock (upper Pleistocene/Paleozoic) – Bedrock below the Bonneville shoreline partly concealed by a discontinuous veneer of lacustrine sand and silt related to the transgressive phase of Lake Bonneville; mapped (1) on the west side of Juab Valley, where the slope transitions from steeper gradients upslope underlain by Paleozoic rocks with a coarser veneer (Qlgb/R) to the gently sloping valley floor underlain by transgressive sand and silt (Qlsb); and (2) on the north end of Juab Valley in a small knob surrounded by transgressive sand and silt (Qlsb). Lacustrine deposits are generally less than 10 feet (3 m) thick.

QUATERNARY-TERTIARY

QTmb **Megabreccia deposits** (Pleistocene to Pliocene?) – Includes large bedrock blocks, rubble, and younger Quaternary landslide deposits too small to map separately; bedrock blocks are comprised largely of Paleozoic quartzite, dolomite, and limestone on the northwest margin of Dry Mountain, east of Santaquin; mapped by Demars (1956), Hintze (1962), and Witkind and Weiss (1991) as highly faulted and deformed bedrock, but a prominent arcuate main scarp lies to the east of the deposit, which has a more subdued upper surface than surrounding bedrock and lies in an amphitheater at least 150 feet (45 meters) below the scarp; displacement of the deposit 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 valleys. Thickness as much as 200 feet (60 m).

QTms **Older landslide deposits** (Pleistocene to Pliocene?) – Poorly sorted clay- to boulder-sized material in slides, slumps, and minor 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; mapped in the Wasatch Range south of Santaquin and east of Juab Valley; the largest deposits southwest of Santaquin Canyon are derived mostly from the North Horn

Formation and Tertiary volcaniclastic sedimentary rocks, although the older landslide southwest of the canyon near the quadrangle margin is likely derived from the Manning Canyon Shale; older landslide deposits are much larger than younger landslide deposits (Qms) and have carbonate soils similar to those on older alluvial-fan deposits (Qafo); displacement of the older landslide deposits 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 valleys. Thickness highly variable, but the largest deposit is several hundred feet thick.

Major unconformity

TERTIARY-PRECAMBRIAN

R **Rock** (Tertiary to Precambrian) − Mapping of bedrock structure and stratigraphy is beyond the scope of this project. Hintze (1962) and Witkind and Weiss (1991) compiled geologic maps of the region that include the Santaquin quadrangle at respective scales of 1:125,000 and 1:100,000, providing valuable overviews of regional geology, although many questions remain regarding stratigraphic relationships and geologic structure. For more information, refer to these maps as well as others cited in the Previous Investigations section of this report. According to these maps, Cretaceous and Tertiary rocks are most common on the east side of Warm Springs Mountain and near Santaquin Canyon; Paleozoic rocks are most common on Goshen Hill, the northern end of Dry Mountain, the west side of Warm Springs Mountain, and in the mountains west and east of Juab Valley; and Precambrian rocks are most common at the base of the western side of Dry Mountain.

REFERENCES

Ashland, F.X., 1997, Reconnaissance of the Shurtz Lake landslide, Utah County, Utah: Utah Geological Survey Report of Investigation 234, 22 p.

Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey Special Study 105, 49 p.

Bills, B.G., Wambeam, T.J., and Currey, D.R., 2002, Geodynamics of Lake Bonneville, *in* Gwynn, J.W., editor, Great Salt Lake—an overview of change: Utah Department of Natural Resources Special Publication, p. 7–32.

Birkeland, P.W., 1984, Soils and geomorphology: New York, Oxford University Press, 372 p.

Bissell, H.J., 1963, Lake Bonneville—geology of southern Utah Valley, Utah: U.S. Geological Survey Professional Paper 257-B, p. B101-B130.

Chadwick, O.A., Hall, R.D., and Phillips, F.M., 1997, Chronology of Pleistocene glacial advances in the central Rocky Mountains: Geological Society of America Bulletin, v. 109, no. 11, p. 1443-1452.

Clark, D.L., 2009, Geologic map of the West Mountain quadrangle, Utah County, Utah: Utah Geological Survey Map 234, 3 plates, scale 1:24,000.

Clark, D.L., Biek, R.F., and Christiansen, E.H., 2009, Geologic map of the Goshen Valley North quadrangle, Utah County, Utah: Utah Geological Survey Map 230, scale 1:24,000.

Clark, R.S., 1953, Structure and stratigraphy of Government Ridge, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 75 p.

Cluff, L.S., Brogan, G.E., and Glass, C.E., 1973, Wasatch fault, southern portion – Earthquake fault investigation and evaluation (A guide to land use planning for Utah Geological and Mineralogical Survey): Oakland, California, Woodward-Lundgren and Associates, 79 p., 23 plates, scale 1:24,000.

Constenius, K.N., 1996, Late Paleogene extensional collapse of the Cordilleran foreland fold and thrust belt: Geological Society of America Bulletin, v. 108, p. 20-39.

Constenius, K.N., Esser, R.P., and Layer, P.W., 2003, Extensional collapse of the Charleston-Nebo salient and its relationship to space-time variations in Cordilleran orogenic belt tectonism and continental stratigraphy, *in* Raynolds, R.G., and Flores, R.M., editors, Cenozoic systems of the Rocky Mountain region:

Denver, Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 303-353.

Crittenden, M.D., Jr., 1963, New data on the isostatic deformation of Lake Bonneville: U.S. Geological Survey Professional Paper 454-E, 31 p.

CRONUS-Earth Project, 2005, Draft sampling plan—Lake Bonneville shorelines sampling trip, July 7-10, 2005 [CRONUS: Cosmic-Ray Produced Nuclide Systematics on Earth Project]: Online, http://tesla.physics.purdue.edu/cronus/bonneville_shoreline_sampling_plan.pdf, accessed August, 2010.

Currey, D.R., 1980, Coastal geomorphology of Great Salt Lake and vicinity, *in* Gwynn, J.W., editor, Great Salt Lake—a scientific, historical, and economic overview: Utah Geological Survey Bulletin 116, p. 69–82.

Currey, D.R., 1982, Lake Bonneville—selected features of relevance to neotectonic analysis: U.S. Geological Survey Open-File Report 82-1070, 30 p., scale 1:500,000.

Currey, D.R., Berry, M.S., Green, S.A., and Murchison, S.B., 1988, Very late Pleistocene red beds in the Bonneville Basin, Utah and Nevada: Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 411.

Currey, D.R., and Burr, T.N., 1988, Linear model of threshold-controlled shorelines of Lake Bonneville, *in* Machette, M.N., editor, In the footsteps of G.K. Gilbert—Lake Bonneville and neotectonics of the eastern Basin and Range Province: Utah Geological Survey Miscellaneous Publication 88-1, p. 104-110.

DeCelles, P.G., 2006, Late Jurassic to Eocene evolution of the Cordilleran thrust belt and foreland basin system, western U.S.A.: American Journal of Science, v. 304, p. 105-168.

Demars, L.C., 1956, Geology of the northern part of Dry Mountain, southern Wasatch Mountains, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 49 p.

Duncan, J.M., Fleming, R.W., and Patton, F.D., 1986, Report of the Thistle Slide Committee to the State of Utah Department of Natural Resources, Division of Water Rights: U.S. Geological Survey Open-File Report 86-505, 95 p.

DuRoss, C.B., McDonald, G.N., and Lund, W.R., 2008, Paleoseismic investigation of the northern strand of the Nephi segment of the Wasatch fault zone at Santaquin, Utah: Utah Geological Survey Special Study 124, 33 p.

Eardley, A.J., Gvosdetsky, V., and Marsell, R.E., 1957, Hydrology of Lake Bonneville and sediments and soils of its basin: Geological Society of America Bulletin, v. 68, p. 1141–1202.

Elison, J.H., 1952, Geology of the Keigley quarries and the Genola Hills area, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 76 p.

Fairbanks, R.G., Mortlock, R.A., Chiu, T., Cao, L., Kaplan, A., Guilderson, T.P., Fairbanks, T.W., Bloom, A.L., Grootes, P.M., and Nadeau, M., 2005, Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired $^{230}Th/^{234}U/^{238}U$ and ^{14}C dates on pristine corals: Quaternary Science Reviews, v. 24, p. 1781-1796, online, http://www.radiocarbon.ldeo.columbia.edu/research/radcarbcal.htm, accessed August, 2010.

Felger, T.J., Machette, M.N., and Sorensen, M.L., 2004, Provisional geologic map of the Mona quadrangle, Juab and Utah Counties, Utah: Utah Geological Survey Open-File Report 428, 23 p., scale 1:24,000.

Foutz, D.R., 1960, Geologic map and cross section of the Wash Canyon area, Utah and Juab Counties, Utah: Provo, Brigham Young University, M.S. thesis, 37 p.

Gilbert, G.K., 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

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

Hanks, T.C., and Kanamori, H., 1979, A moment magnitude scale: Journal of Geophysical Research, v. 84, no. B5, p. 2348-2350.

Hanson, K.L., Swan, F.H., III, and Schwartz, D.P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah (North Creek site): Woodward-Clyde Consultants, sixth semi-annual technical report, U.S. Geological Survey contract report no. 14-08-0001-16827, 22 p.

Harris, H.D., 1953, Geology of the Birdseye area, Thistle Creek Canyon, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 126 p.

Harty, K.M., Mulvey, W.E., and Machette, M.N., 1997, Surficial geologic map of the Nephi segment of the Wasatch fault zone, eastern Juab County, Utah: Utah Geological Survey Map 170, 13 p., scale 1:50,000.

Hintze, L.F., compiler, 1962, Geology of the southern Wasatch Mountains and vicinity—a symposium: Brigham Young University Geology Studies, v. 9, part 1, 104 p., scale 1:125,000.

Hughen, K.A., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Kromer, B., McCormac, F.G., Manning, S.W., Bronk Ramsey, C., Reimer, P.J., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., and Weyhenmeyer, C.E., 2004, Marine04 marine radiocarbon age calibration, 0–26 cal kya BP: Radiocarbon, v. 46, p. 1059–1086.

Jackson, M.L., 1991, The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Study 78, 23 p.

Jarrett, R.D., and Malde, H.E., 1987, Paleodischarge of late Pleistocene Bonneville Flood, Snake River, Idaho, computed from new evidence: Geological Society of America Bulletin, v. 99, p. 127-134.

Jensen, M.E., 1986, Geologic map and section of the Slate Jack Canyon quadrangle, Juab and Utah Counties, Utah: Brigham Young University Geology Studies, v. 33, pt. 1, p. 1-19, scale 1:24,000.

Lips, E.W., Marchetti, D.W., and Gosse, J.C., 2005, Revised chronology of late Pleistocene glaciers, Wasatch Mountains, Utah: Geological Society of America Abstracts with Programs, v. 37, no. 7, p. 41.

Loughlin, G.F., 1919, Two lamprophyre dikes near Santaquin and Mt. Nebo, Utah: U.S. Geological Survey Professional Paper 120-E, p. 101-109.

Lund, W.R., 2005, Consensus preferred recurrence-interval and vertical slip-rate estimates—review of Utah paleoseismic-trenching data by the Utah Quaternary Fault Parameters Working Group: Utah Geological Survey Bulletin 134, 109 p., CD-ROM.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2095, 26 p., 1 plate, scale 1:50,000.

Machette, M.N., Crone, A.J., Personius, S.F., Mahan, S.A., Dart, R.L., Lidke, D.J., and Olig, S.S., 2007, Paleoseismology of the Nephi segment of the Wasatch fault zone, Juab County, Utah—preliminary results from two large exploratory trenches at Willow Creek: U.S. Geological Survey Scientific Investigations Map 2966, 2 sheets.

McDonald, G.N., and Giraud, R.E., 2002, September 12, 2002, fire-related debris flows east of Santaquin and Spring Lake, Utah County, Utah: Utah Geological Survey Technical Report 02-09, 15 p.

Metter, R.E., 1955, Geology of the northern part of the southern Wasatch Mountains, Utah: Columbus, Ohio State University, Ph.D. dissertation, 262 p.

Miller, R.D., 1982, Surficial geologic map along part of the Wasatch Front, Great Salt Lake and Utah Lake Valleys, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1477, 1 plate, scale 1:100,000.

Mountainland Association of Governments, 2009, West lake vision land use and transportation study: Orem, Utah, Mountainland Association of Governments, 64 p.; online, http://www.mountainland.org/Mountainland_Metropolitan_Planning_Organization_%28MPO%29/studies/West_Lake_Final.pdf, accessed June, 2010.

Muessig, S.J., 1951, Geology of a part of Long Ridge, Utah: Columbus, Ohio State University, Ph.D. dissertation, 213 p.

O'Conner, J.E., 1993, Hydrology, hydraulics, and geomorphology of the Bonneville Flood: Geological Society of America Special Paper 274, 83 p.

Oviatt, C.G., 1997, Lake Bonneville fluctuations and global climate change: Geology, v. 25, no. 2, p. 155-158.

Oviatt, C.G., Currey, D.R., and Miller, D.M., 1990, Age and paleoclimatic significance of the Stansbury shoreline of Lake Bonneville, northeastern Great Basin: Quaternary Research, v. 33, p. 291-305.

Oviatt, C.G., Currey, D.R., and Sack, D., 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225-241.

Oviatt, C.G., Miller, D.M., McGeehin, J.P., Zachary, C., and Mahan, S., 2005, The Younger Dryas phase of Great Salt Lake, Utah, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 219, no. 3–4, p. 263–284.

Oviatt, C.G., and Thompson, R.S., 2002, Recent developments in the study of Lake Bonneville since 1980, *in* Gwynn, J.W., editor, Great Salt Lake—an overview of change: Utah Department of Natural Resources Special Publication, p. 1-6.

Oviatt, C.G., Thompson, R.S., Kaufman, D.S., Bright, J., and Forester, R.M., 1999, Reinterpretation of the Burmester Core, Bonneville basin, Utah: Quaternary Research, v. 52, p. 180-184.

Peacock, C.H., 1953, Geologic map and sections of the Government Hill area, Long Ridge, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 96 p.

Peterson, D.O., 1953, Structure and stratigraphy of the Little Valley area, Long Ridge, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 96 p.

Schelling, D.D., Strickland, D.K., Johnson, K.R., and Vrona, J.P., 2007, Structural geology of the central Utah thrust belt, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Guidebook 36, p. 1-29.

Schuster, R.L., 1996, Socioeconomic significance of landslides, *in* Turner, A.K., and Schuster, R.L., editors, Landslides—investigation and mitigation: Washington, D.C., National Research Council, Transportation Research Board Special Report 247, p. 12-35.

Scott, W.E., McCoy, W.D., Shroba, R.R., and Rubin, M., 1983, Reinterpretation of the exposed record of the last two cycles of Lake Bonneville, western United States: Quaternary Research, v. 20, p. 261-285.

Shroder, Jr., J.F., 1971, Landslides of Utah: Utah Geological Survey Bulletin 90, 49 p.

Sirrine, G.K., 1953, Geology of the Warm Springs Mountain, Goshen, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 83 p.

Smith, R.B., and Bruhn, R.L., 1984, Intraplate extensional tectonics of the eastern Basin-Range—inferences on structural style from seismic reflection data, regional tectonics, and thermal-mechanical models of brittle-ductile deformation: Journal of Geophysical Research, v. 89, p. 5733-5762.

Solomon, B.J., 2010, Interim geologic map of unconsolidated deposits in the Payson Lakes quadrangle, Utah County, Utah: Utah Geological Survey Open-File Report 571, scale 1:24,000.

Solomon, B.J., Clark, D.L., and Machette, M.N., 2007, Geologic map of the Spanish Fork quadrangle, Utah County, Utah: Utah Geological Survey Map 227, 3 plates, scale 1:24,000.

Solomon, B.J., and Machette, M.N., 2008, Interim Quaternary geologic map of the southwest (Utah Valley) part of the Springville quadrangle, Utah County, Utah: Utah Geological Survey Open-File Report 524, 33 p., 1 plate, scale 1:24,000.

Stuiver, M., and Reimer, P.J., 1993, Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program: Radiocarbon, v. 35, p. 215-230.

Stuiver, M., Reimer, P.J., and Reimer, R., 2005, CALIB radiocarbon calibration, version 5.0: Online, http://radiocarbon.pa.qub.ac.uk/calib/, accessed June, 2010.

Sullivan, J.T., Foley, L.L., Baltzer, E.M., and Krinsky, C.K., 1987, Seismic sources, maximum credible earthquakes, and related seismic hazards for Monks Hollow damsite: Denver, U.S. Bureau of Reclamation Seismotectonic Report 87-2, 35 p.

Swenson, J.L., Jr., Archer, W.M., Donaldson, K.M., Shiozaki, J.J., Broderick, J.H., and Woodward, L., 1972, Soil survey of Utah County—central part: U.S. Department of Agriculture, Soil Conservation Service, 161 p.

Trickler, D.L., and Hall, D.T., 1984, Soil survey of Fairfield-Nephi area, Utah, parts of Juab, Sanpete, and Utah Counties: U.S. Department of Agriculture, Soil Conservation Service, 361 p.

Wells, D.L., and Coppersmith, K.J., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement: Bulletin of the Seismological Society of America, v. 84, no. 4, p. 974-1002.

White, B.O., 1953, Geology of West Mountain and northern portion of Long Ridge, Utah County, Utah: Provo, Utah, Brigham Young University, M.S. thesis, 187 p.

Willis, G.C., 1999, The Utah thrust system—an overview, *in* Spangler, L.E., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 1-9.

Witkind, I.J., and Page, W.R., 1983, Geologic map of the Thistle area, Utah County, Utah: Utah Geological Survey Map 69, scale 1:24,000.

Witkind, I.J., and Weiss, M.P., 1991, Geologic map of the Nephi 30´ x 60´ quadrangle, Carbon, Emery, Juab, Sanpete, Utah, and Wasatch Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1937, scale 1:100,000.

Zoback, M.L., Anderson, R.E., and Thompson, G.B., 1981, Cainozoic evolution of the state of stress and style of tectonism of the Basin and Range Province of the western United States: Philosophical Transactions of the Royal Society of London, v. A300, p. 407-434.

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

Lake Cycle and Phase	Shoreline (map symbol)	Age: radiocarbon years B.P.	Age: calendar years B.P.	Elevation feet (meters)
Lake Bonneville				
Transgressive Phase	Stansbury	22,000-20,000[1]	27,000-24,000[2]	Not present
	Bonneville (B)	15,000-14,500[3]	18,300[4]-17,400[5]	5080-5120 (1550-1560)
	flood			
Regressive Phase	Provo (P)	14,500-12,000[6]	17,400[5]-14,400[7]	4720-4760 (1440-1450)
	Gilbert	10,500-10,000[8]	12,500-11,500[9]	Not present
Utah Lake				
	Utah Lake highstand (U)	12,000-11,500[10]	-----	Not present

[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.

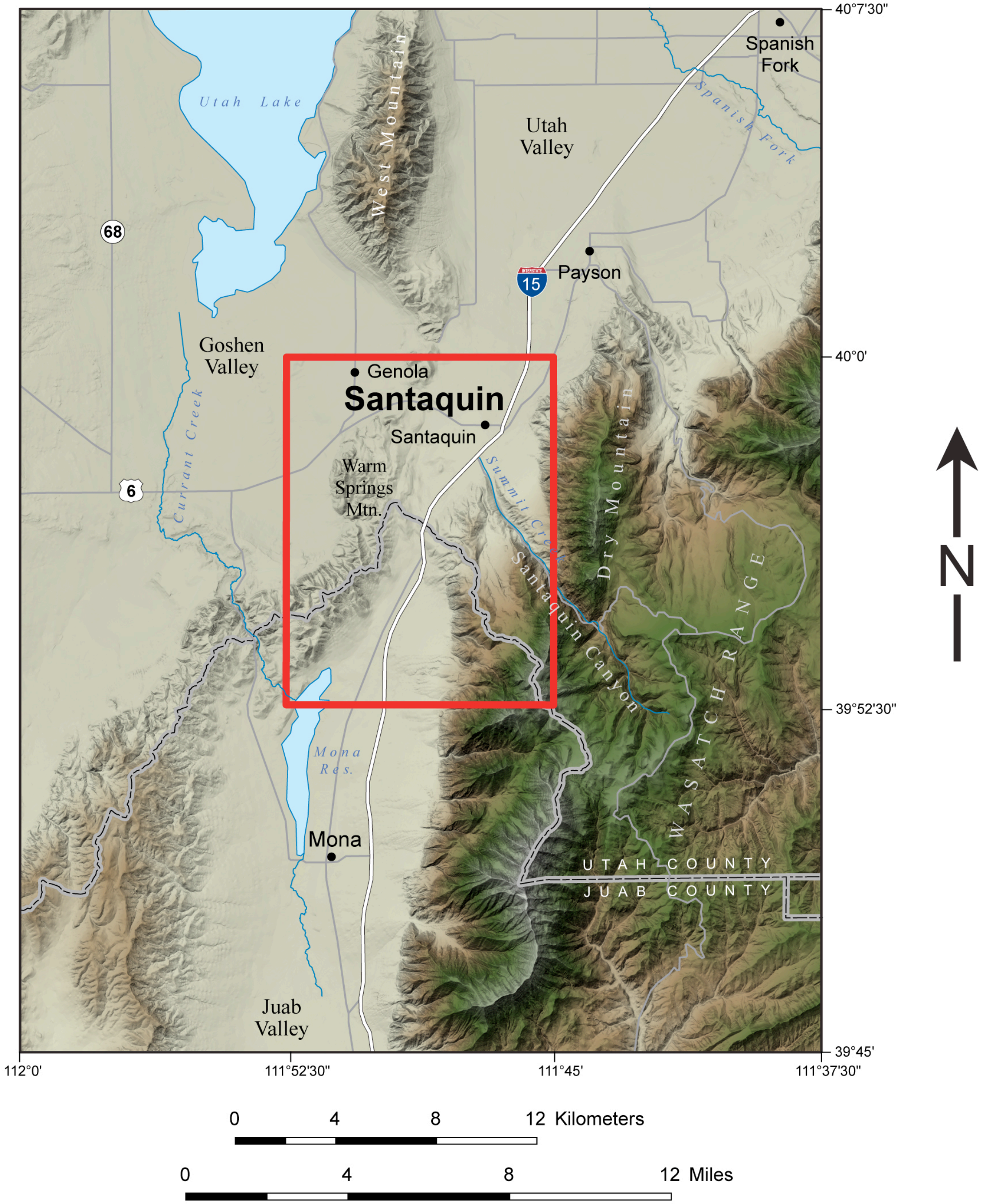


Figure 1. Index map showing the primary geographic features in the vicinity of the Santaquin quadrangle.

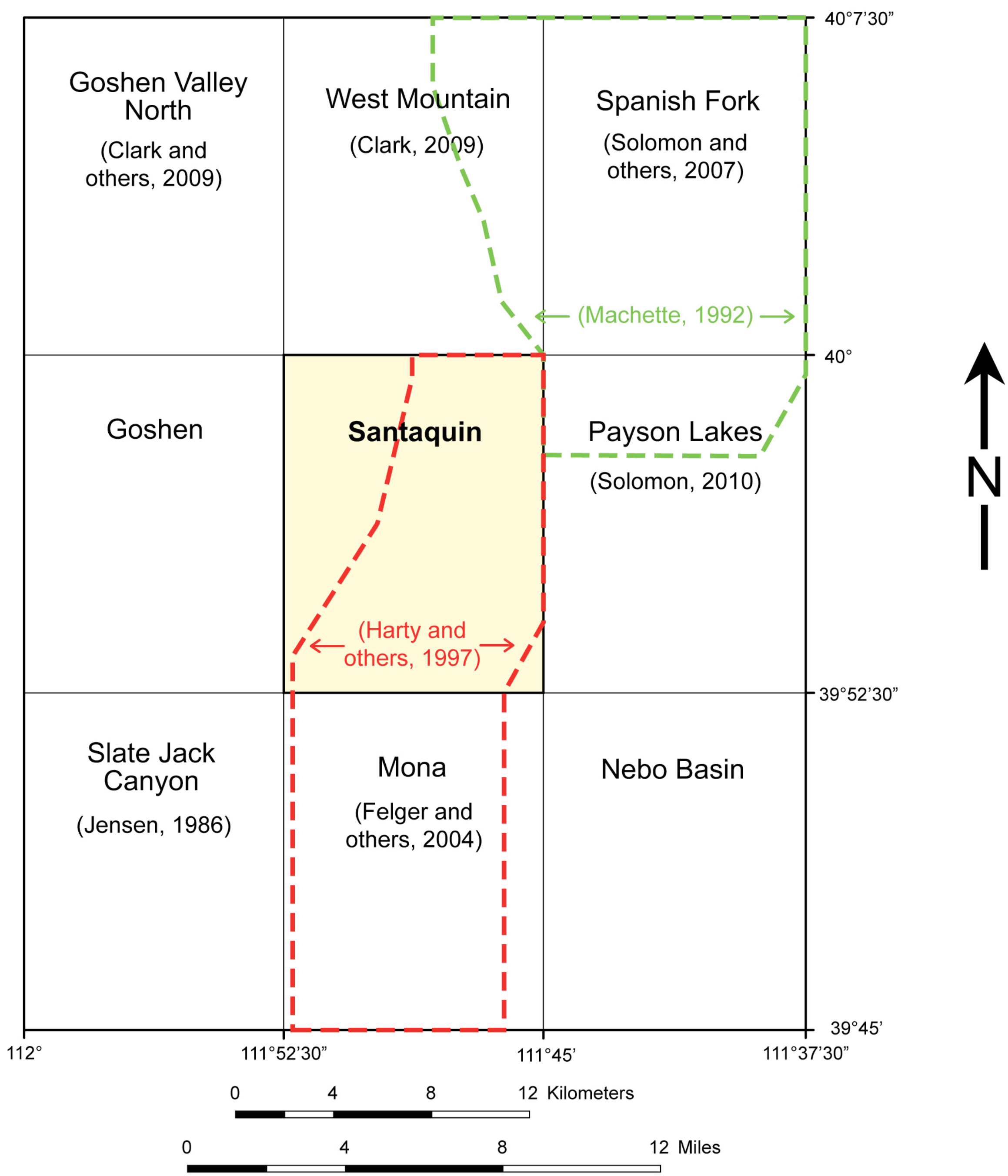


Figure 2. Index map showing selected geologic maps available for the Santaquin and surrounding 7.5′ quadrangles.

GEOLOGIC SYMBOLS

Contact – Dashed where approximately located

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

Cirque

Arête crest

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

y Other transgressive shorelines

P Provo shoreline

x Other regressive shorelines

Crest of lacustrine barrier beach or spit

Landslide scarp – Hachures on down-dropped side

Spring

Prospect

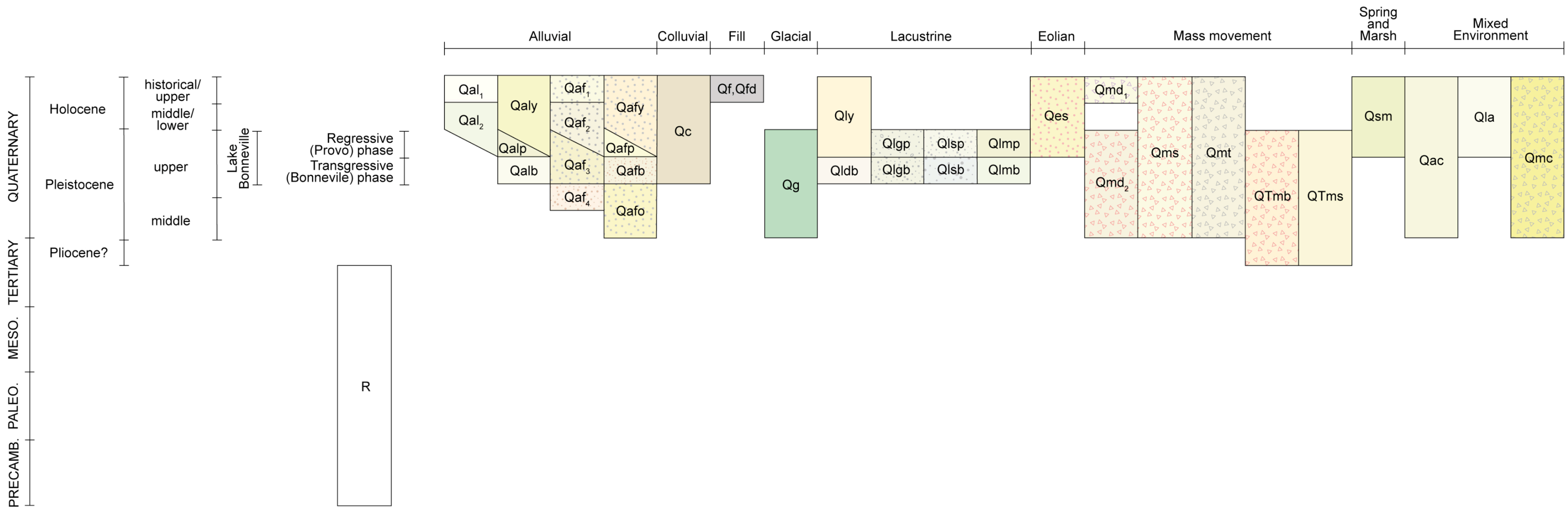
Adit

Shaft

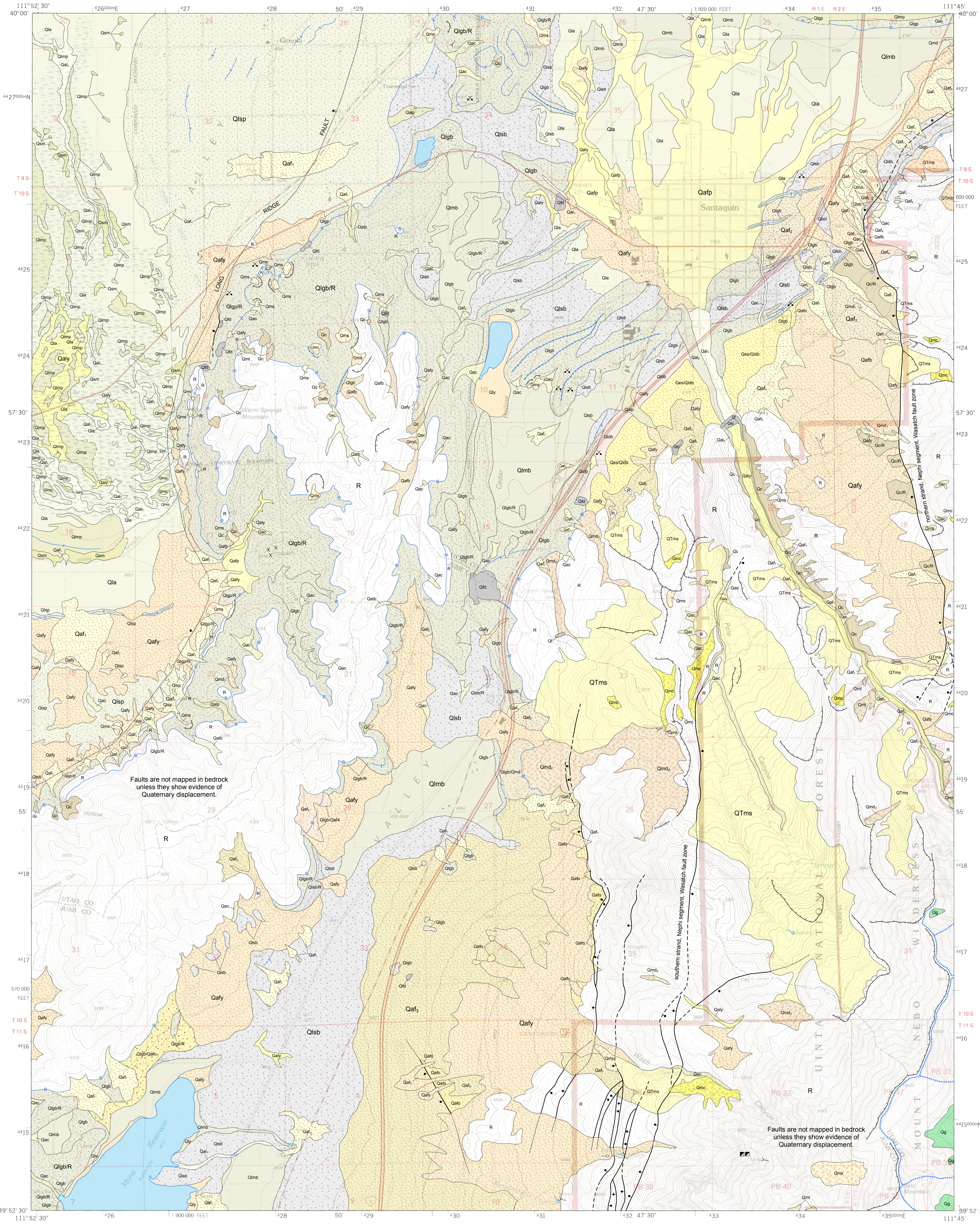
Sand and gravel pit

1 Trench site for Santaquin paleoseismic investigation (DuRoss and others, 2008)

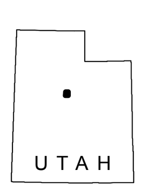
CORRELATION OF MAP UNITS
Santaquin Quadrangle



UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources



This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through U.S. Geological Survey STATEMAP award number 03HQAG0096. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing official policies, either expressed or implied, of the U.S. Government.



QUADRANGLE LOCATION

SCALE 1:24,000

1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

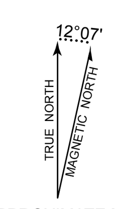
1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET

INTERIM GEOLOGIC MAP OF UNCONSOLIDATED DEPOSITS IN THE SANTAQUIN QUADRANGLE, UTAH AND JUAB COUNTIES, UTAH

by
Barry J. Solomon

2010



APPROXIMATE MEAN DECLINATION, 2010

Base from USGS Santaquin 7.5' Quadrangle (1998)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1886

Cartography: Jay Hill

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

1	2	3
4		5
6	7	8

1. Goshen Valley North
2. West Mountain
3. Spanish Fork
4. Goshen
5. Payson Lakes
6. Slate Jacket Canyon
7. Mona
8. Nebo Basin

ADJOINING 7.5' QUADRANGLE NAMES