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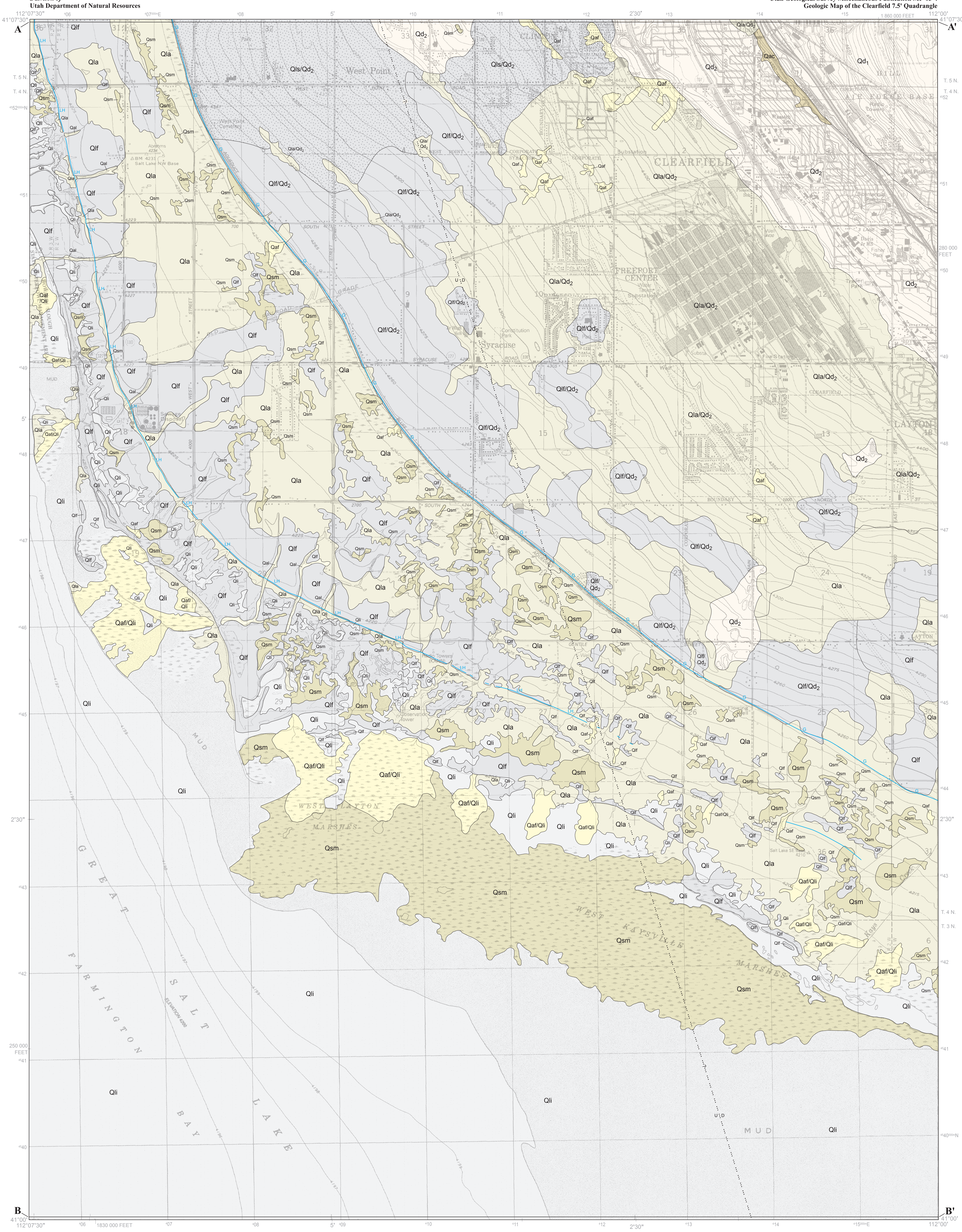


Base from U.S. Geological Survey,
Clearfield 7.5' quadrangle, 1990

SCALE 1:24,000

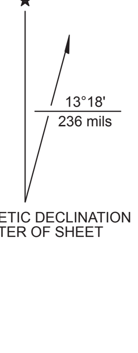
1 0.5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 5 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Grant C. Willis, Program Manager
Douglas A. Sprinkel, Project Manager
James Parker, Cartographer



2005 MAGNETIC DECLINATION
AT CENTER OF SHEET

GEOLOGIC MAP OF THE CLEARFIELD 7.5' QUADRANGLE
DAVIS COUNTY, UTAH

by

Dorothy Sack

2005

QUADRANGLE LOCATION

1	2	3	1.Ogden Bay 2. Roy 3. Ogden 4. Antelope Island N 5. Kaysville 6. Antelope Island 7. Saltaire NE 8. Farmington
4		5	
6	7	8	

ADJOINING 7.5' QUADRANGLE NAMES

ISBN 1-55791-724-8

DESCRIPTION OF MAP UNITS

Quaternary Surficial Deposits

Qac Undifferentiated alluvium and colluvium - Sand-dominated sediment deposited approximately 12.6 ka to present by gravity and sheet wash. Thickness probably less than 8 feet (2.4 m).

Qaf Alluvial-fan deposits - Predominantly fine-grained sediment deposited by shallow, dispersive stream flow from about 12.3 ka to present. Thickness probably less than 10 feet (3 m).

Qal Channel alluvium - Mixed fine-grained sediment deposited in stream channels from about 2.0 ka to present. Thickness probably less than 10 feet (3 m).

Qd_1 Younger deltaic deposits - Sandy sediment of the distal subaqueous portion of the Lake Bonneville Weber River delta deposited during Provo shoreline time, between about 14.5 and 14.0 ka. Maximum thickness may be as much as 70 feet (21 m).

Qd_2 Older deltaic deposits - Sandy sediment of the subaerial and subaqueous portions of the Lake Bonneville Weber River delta deposited during the lake's transgressive phase, from about 27.4 to 20.4 ka. Maximum thickness may be as much as 50 feet (15 m).

Qla Undifferentiated lacustrine and alluvial deposits - Fluvially reworked lake sediments and intermingled lake and alluvial-fan deposits. Poorly sorted sandy fine-grained sediment deposited from about 12.6 ka to present. Thickness probably less than 10 feet (3 m).

Qlf Fine-grained lacustrine deposits - Poorly sorted sand, silt, and clay deposited by Lake Bonneville and Great Salt Lake from about 27.3 ka to present. Thickness probably less than 10 feet (3 m).

Qli Lacustrine mud - Wet, saline, often algae-rich, mixed fine and very fine grained sediment comprising mudflat and lake-bottom environments. Deposited from about 28 ka to the present. Estimated maximum thickness at least 10 feet (3 m).

Qls Lacustrine sand - Sand-dominated sediments deposited from about 12.3 to 12.0 ka during the regressive phase of Lake Bonneville and largely reworked from Qd_2 sediments. Occurs as thin discontinuous mantle over older deltaic deposits (Qd_2). Thickness probably less than 5 feet (1.5 m).

Qsm Marsh deposits - Wet, fine-grained, organic-rich sediments in association with springs, ponds, seeps, and lake-adjacent wetlands. Deposited from about 10.6 ka to present. Thickness probably less than 5 feet (1.5 m).

Qu Undifferentiated surficial deposits - Represents surficial deposits along the line of cross section; includes alluvium, colluvium, deltaic, and lacustrine deposits. Shown only on cross section. Thickness generally less than 400 feet (122 m).

Basin Fill

Qb Quaternary basin fill - Weakly to unconsolidated mixture of alluvial and lacustrine clay, silt, sand, gravel, marl, and thin tuffaceous layers. Includes a thicker, gravel-bearing zone corresponding to the Delta aquifer. Shown only on cross sections. Thickness up to 1,300 feet (400 m).

Tb Late Tertiary basin fill - Weakly to strongly consolidated mixture of conglomerate, sandstone, mudstone, tuffaceous sandstone, tuff, and lacustrine limestone. Shown only on cross sections. Thickness up to 6,700 feet (2,042 m).

Bedrock

Xf Farmington Canyon Complex, undivided - Metamorphic and igneous rocks of Early Proterozoic age. Shown only on cross section. Thickness unknown.

Stacked Geologic Units

Qaf/Qli Stacked geologic units; mapped where surficial deposits are thinly distributed over other surficial deposits; example is of alluvial fan deposits thinly distributed over lacustrine mud

GEOLOGIC SYMBOLS

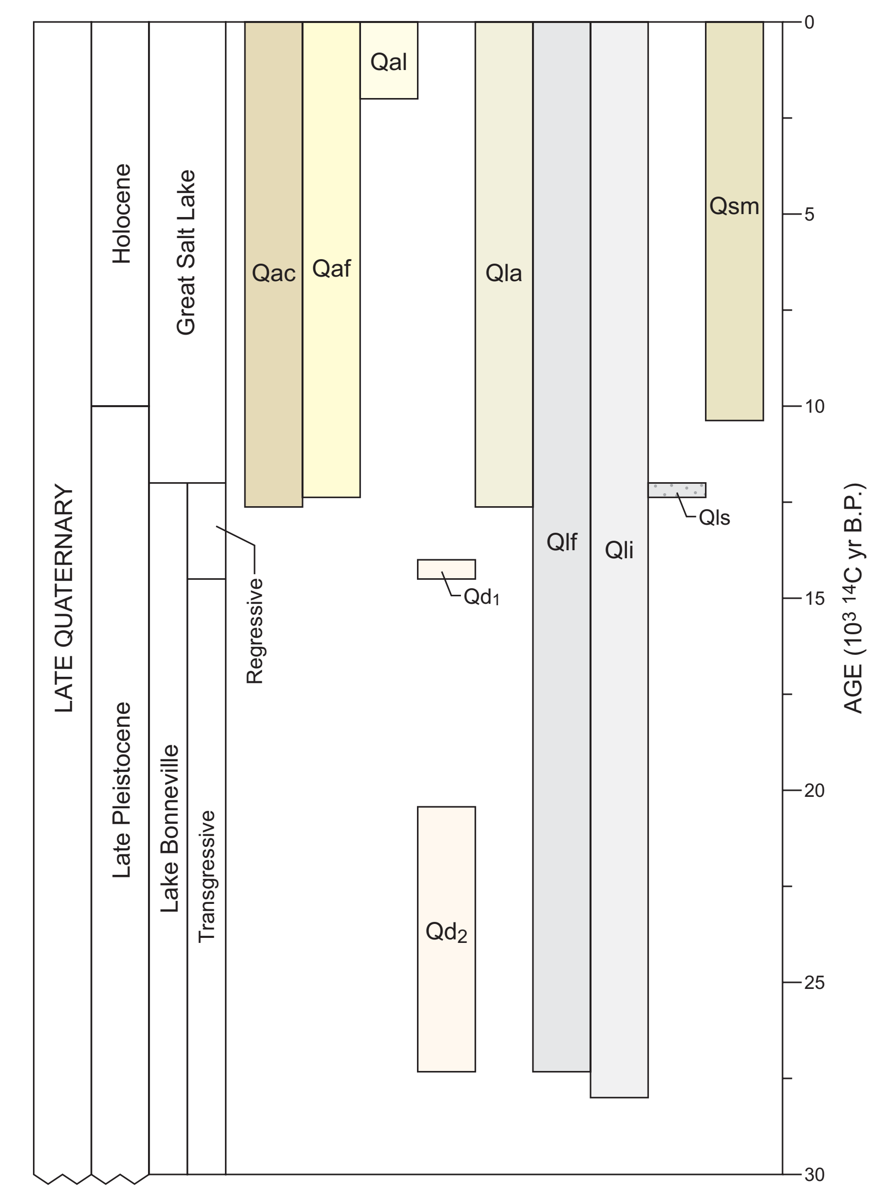
Contact

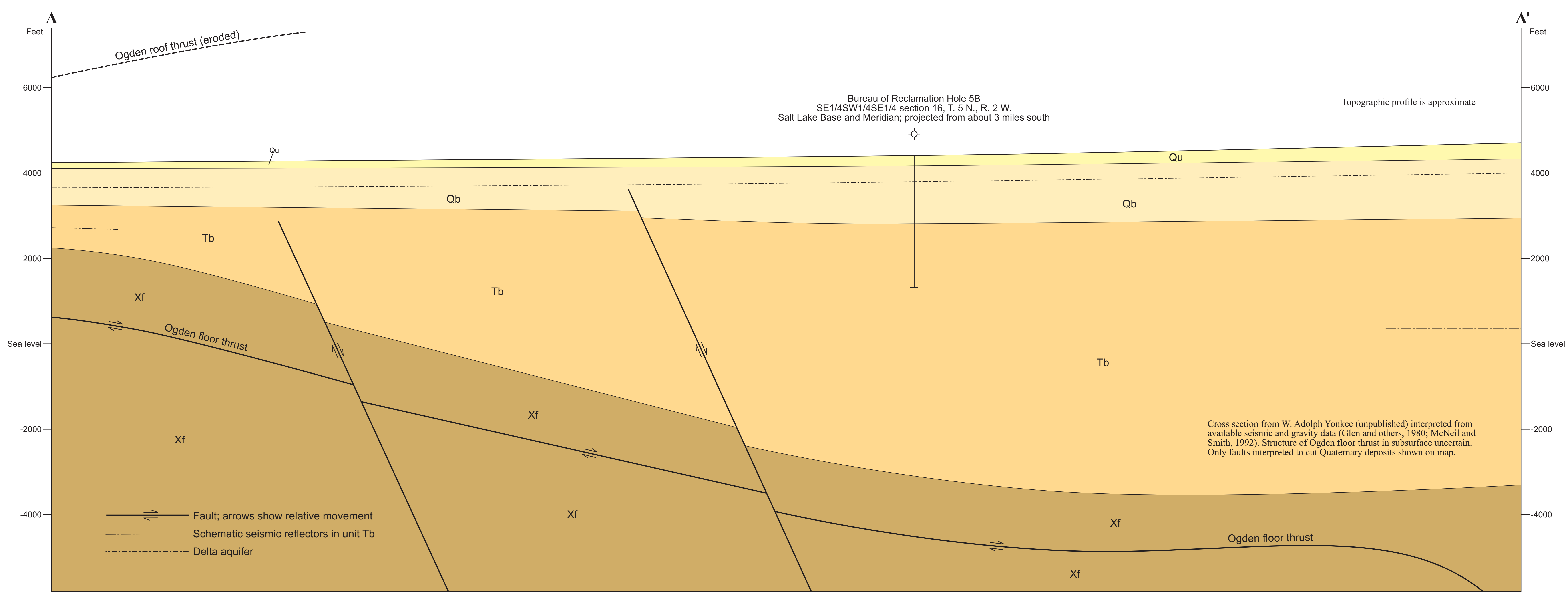
Concealed fault; identified from seismic data; D on downthrown side and U on upthrown side; query indicates approximate position at surface

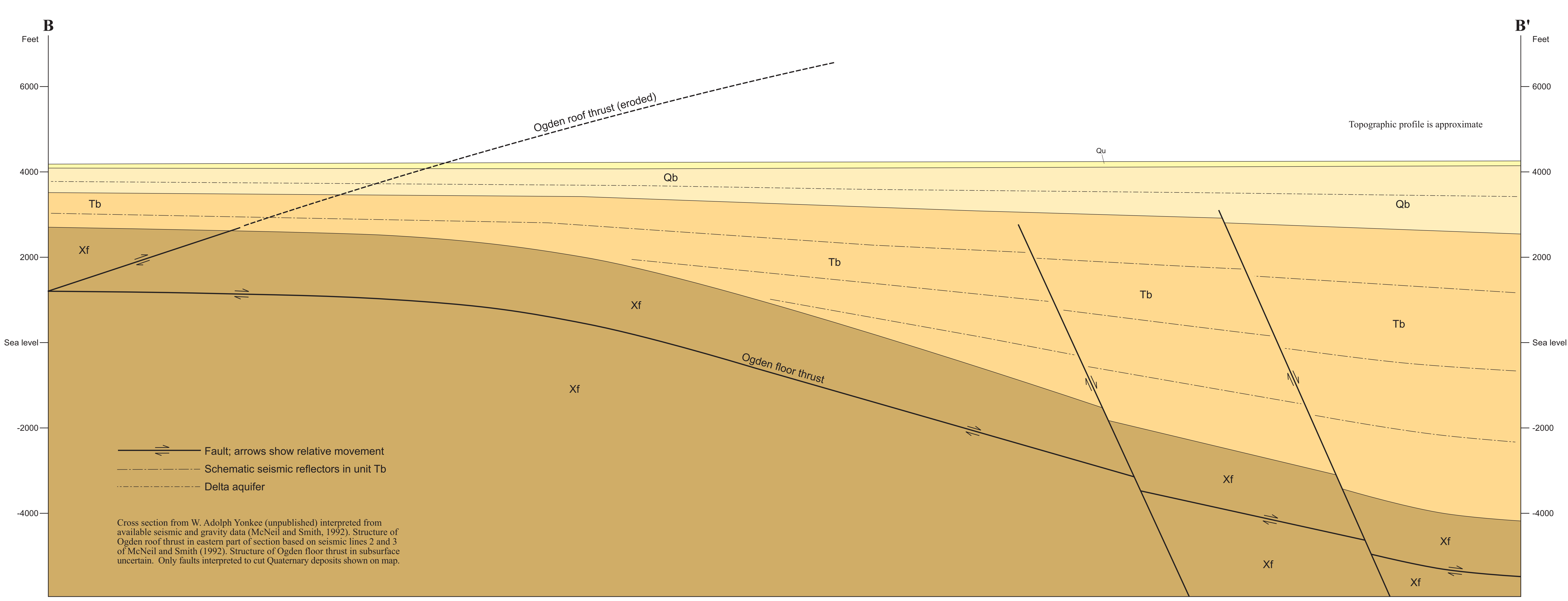
G Gilbert shoreline of Great Salt Lake

LH A late Holocene high shoreline of Great Salt Lake

CORRELATION OF MAP UNITS







GEOLOGIC MAP OF THE CLEARFIELD 7.5′ QUADRANGLE, DAVIS COUNTY, UTAH

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ABSTRACT

The Clearfield quadrangle lies on the eastern shore of Great Salt Lake about 15 miles (25 km) southwest of Ogden. Elevations increase across the quadrangle from about 4,196 feet (1,279 m) beneath Farmington Bay in the southwestern corner of the map to deposits of the Provo-level Weber River delta of Lake Bonneville at about 4,757 feet (1,450 m) in the northeastern corner of the map. The quadrangle consists of an extensive slope composed entirely of unconsolidated late Quaternary deposits that are portrayed on the geologic map in ten map units. The geologic map also indicates preserved portions of two well-developed Great Salt Lake shorelines, the Gilbert shoreline at 4,245 feet (1,294 m) and a high Holocene shoreline that is found between 4,217 and 4,220 feet (1,285-1,286 m). No bedrock crops out and no fault scarps were observed on the quadrangle. Sand and salt constitute the principal geologic resources. Significant potential geologic hazards are primarily related to ground shaking, liquefaction, and mass wasting that could accompany earthquakes generated along the nearby Wasatch fault zone.

Late Pleistocene Lake Bonneville and its mostly Holocene successor, Great Salt Lake, figure prominently in the geology of the Clearfield quadrangle. Weber River deltaic sediments deposited during the transgressive phase of Lake Bonneville constitute the foundation for the largest segment of the quadrangle's extensive slope, the section that lies between the Gilbert shoreline and the regressive-phase Provo deltaic sediments. Unlike the Provo-age deposits, most of the transgressive-phase deltaic sediments have been subjected to some reworking by Lake Bonneville transgressive- and regressive-phase coastal processes and by subsequent fluvial action. Lacustrine sand, fine-grained lake sediments, and undifferentiated lacustrine and alluvial deposits blanket large areas of those older deltaic sediments. In early Great Salt Lake time, the segment of the quadrangle between the mapped high late Holocene shoreline and the Gilbert shoreline consisted of a gently sloping nearshore platform covered by fine-grained lacustrine deposits. Since subaerial exposure those fine-grained lacustrine sediments have been partially replaced by a mixed lacustrine and alluvial unit and by marsh deposits from springs and seeps. Another gently sloping shelf extends from 4,205 feet (1,282 m) up to the bluff of the mapped high late Holocene shoreline. Because this lower relict nearshore platform has been inundated by Great Salt Lake more recently than the higher platform, its lacustrine fines have not been reworked as much by surficial fluvial action. Small headward-eroding streams cut the high Holocene shoreline bluff itself. Below 4,205 feet (1,282 m) lacustrine mud, marsh, and thin alluvial fan deposits dominate the very low gradient slope that borders Great Salt Lake.

INTRODUCTION

The Clearfield quadrangle lies about 15 miles (25 km) southwest of Ogden on the east side of Great Salt Lake between the lake and the Wasatch Range (figure 1). It extends from 41°N. to 41°07′30″N. and from 112°W. to 112°07′30″W. The map area occupies the southeastern corner of both the 1:100,000-scale Promontory Point and the 1:250,000-scale Brigham City U.S. Geological Survey topographic maps. Nearby geologic quadrangle maps include the Ogden 7.5-minute quadrangle (Yonkee and Lowe, 2004) and the Roy 7.5-minute quadrangle (Sack, 2005).

The study area is comprised of lake basin and what can be considered the lower to middle piedmont slope of the Wasatch Range. Elevations (all elevations discussed in this report are relative to modern sea level) increase from southwest to northeast across the map, and range from about 4,196 feet (1,279 m), which is beneath Great Salt Lake, to about 4,757 feet (1,450 m) on a relict Weber River delta of ancient Lake Bonneville. Proceeding from roughly southwest to northeast, the quadrangle consists of part of Great Salt Lake's Farmington Bay, major wetlands called the West Kaysville and West Layton marshes, agricultural lands that are being rapidly suburbanized, urban areas, and military land. The urban and suburban areas include almost all of the city of Clearfield, Syracuse, large parts of West Point and Layton, and small portions of the city of Clinton and Hill Air Force Base. Several major transportation routes, including Interstate Highway 15, some Utah state roads, the Union Pacific Railroad, and the Denver and Rio Grande Railroad, cross the quadrangle. The causeway to Antelope Island begins at a point along the northwestern edge of the map.

The Clearfield quadrangle is located 4.6 to 12.3 miles (7.4-19.8 km) west of the Wasatch fault (Davis, 1983; Nelson and Personius, 1993) and is underlain by part of a deep, north-south-trending, Basin and Range graben that lies buried beneath 0.5 to 2 miles (1-3 km) of basin fill (Feth and

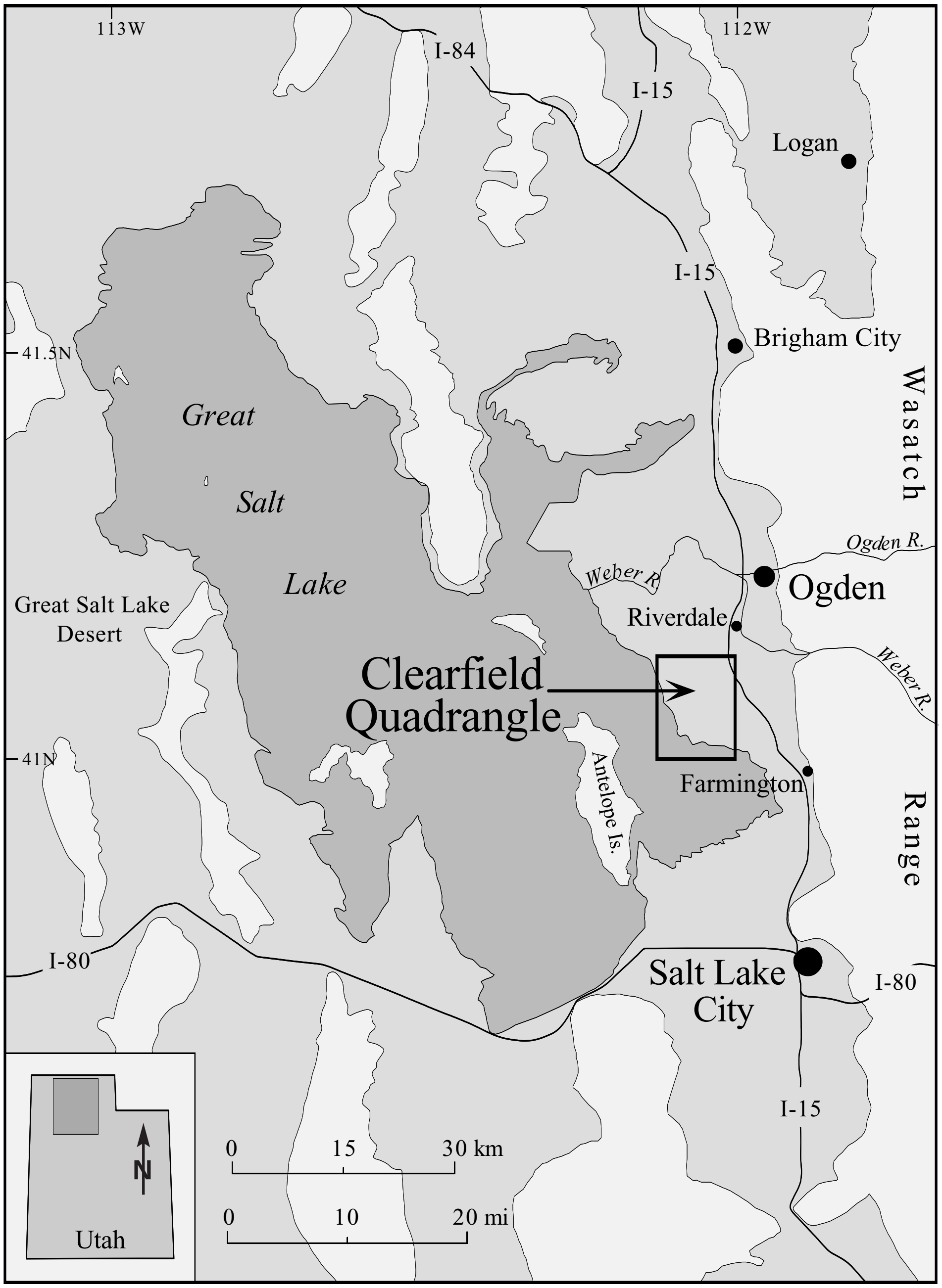

Figure 1. *Location of the Clearfield quadrangle.*

others, 1966; Mabey, 1992; cross sections plate 2). Much of the basin fill probably consists of lacustrine sediments deposited during the multiple lake cycles that the region has experienced during Cenozoic time (Feth, 1955; Morrison, 1966; Eardley and others, 1973; Oviatt and Currey, 1987; Oviatt and others, 1999). Eolian, fluvial, deltaic, and marsh deposits probably also contribute to the basin fill. No bedrock crops out at the surface of the Clearfield quadrangle; all surficial map units are composed of late Quaternary sediments.

The climate of the Clearfield area is transitional between humid continental and semi-arid (table 1) (Stevens and Brough, 1987). Although no meteorological stations are located in the study area, data from the three closest stations, which are found on adjacent quadrangles to the north, east, and west, provide a good indication of Clearfield's climate. Clearly the quadrangle has cold winters, with a mean January temperature of about 28°F (-2°C), and hot summers, with a mean July temperature close to 77°F (25°C). Mean annual temperature is approximately 52°F (11°C) and mean annual precipitation is about 18 inches (45 cm), but all three stations show significant annual variability in precipitation (National Climatic Data Center, 2001). The data in table 1 suggest that the temperature means decrease and that precipitation increases slightly to the north and east across the quadrangle.

Surface water, vegetation, and soils reflect the transitional climate and lower piedmont setting. Small creeks of low gradient and generally low discharge drain the fine-grained, high water-table zone that extends from Great Salt Lake to as high as about 4,245 feet (1,294 m). Some of these are perennial, especially in their lower reaches, but most of them are at least partially sustained by artificial ditches that collect and funnel ground and surface water to the creeks. Kays Creek is the only stream on the map that originates in the Wasatch Range rather than on the piedmont slope. Only the final 1.2 miles (2 km) of Kays Creek, that is, its distal end, is on the quadrangle and it, too, has been artificially cut and straightened. Natural vegetation ranges from shrub-steppe in the higher and better drained areas to marsh vegetation and salt grass adjacent to Great Salt Lake. Soils vary mainly with drainage properties, which depend on the texture of the parent material and proximity to the water table (Erickson and others, 1968; Plantz and others, 1986). Grain size and permeability of soils generally increase with increasing distance up the piedmont slope from Great Salt Lake.

LAKE BONNEVILLE AND GREAT SALT LAKE CHRONOLOGIES

Late Pleistocene Lake Bonneville and its largely Holocene successor, Great Salt Lake, figure prominently in the geology of the Clearfield quadrangle. Major aspects of their histories are reviewed here and summarized in figure 2. All age estimates provided are in radiocarbon years.

The Bonneville lacustral cycle, which began about 30 ka (Oviatt and others, 1992), is the most recent in the series of deep lake cycles that occurred in the Bonneville basin during the Quaternary (Gilbert, 1890; Eardley and others, 1973; McCoy, 1987; Oviatt and Currey, 1987; Oviatt and others, 1999). Between approximately 22 and 20 ka the transgressive phase of Lake Bonneville was interrupted by one or more oscillations that resulted in the formation of the Stansbury shoreline complex (Oviatt and others, 1992) at an elevation of roughly 4,500 feet (1,372 m). The fluctuation had

Table 1. *Selected climatic variables for meteorological stations near the Clearfield quadrangle (National Climatic Data Center, 2001).*

Station Name	N lat./W long. (decimal deg.)	Elev. (m/ft)	Years averaged	Jan. mean temp. (°C/°F)	July mean temp. (°C/°F)	Annual mean temp. (°C/°F)	Annual mean precip. (cm)
Riverdale	41.15/112.00	1,341/4,340	26	-2.5/27.5	23.9/75	10.3/50.5	49.35/19.43
Farmington	40.98/111.90	1,302/4272	30	-2.1/28.2	24.3/75.7	11.0/51.8	48.74/19.19
Antelope Island	40.93/112.17	1,290/4233	21	-1.9/28.6	25.8/78.4	11.0/51.8	39.32/15.48

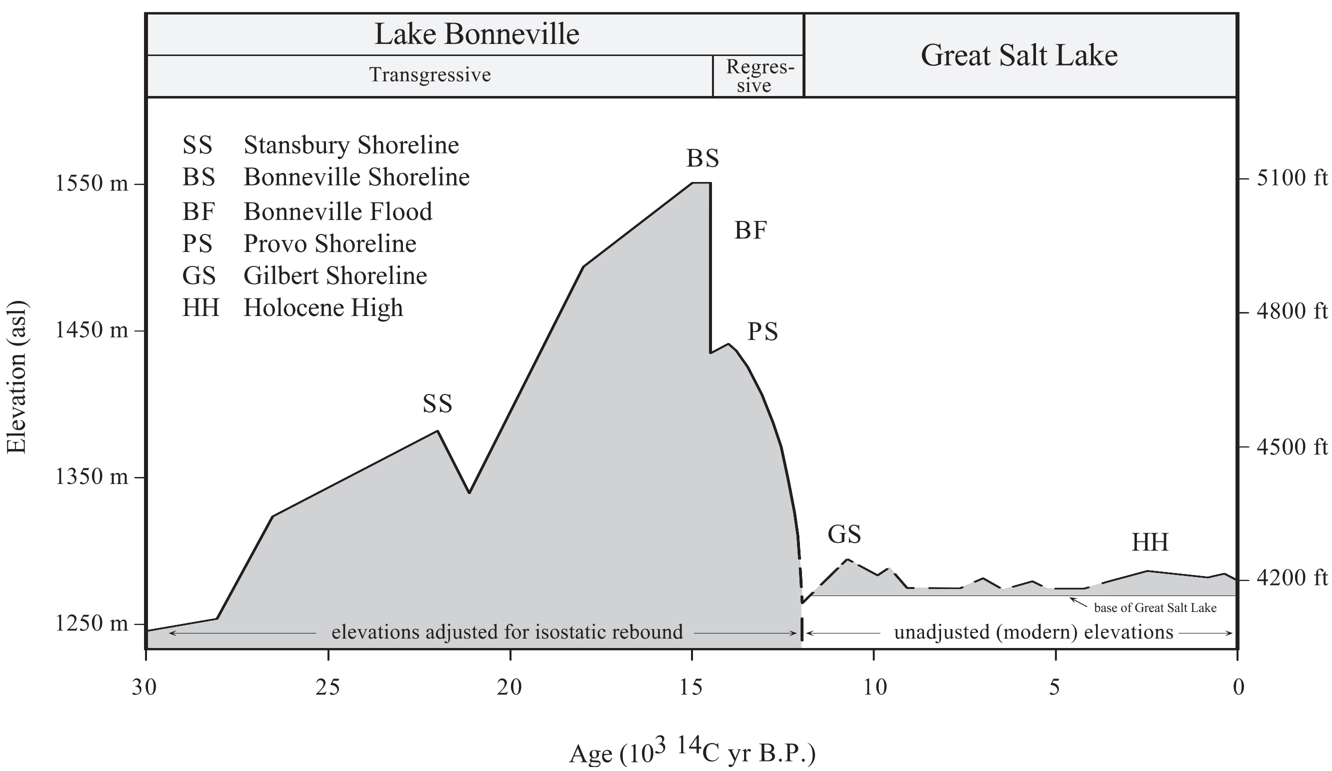

Figure 2. *Generalized chronology of Lake Bonneville (Oviatt and others, 1992) and Great Salt Lake (Currey and others, 1984, 1988; Murchison, 1989; Benson and others, 1992).*

a total amplitude of 150 feet (45 m), and in the vicinity of Great Salt Lake the Stansbury shoreline has been mapped at a wide range of elevations (Currey, 1980; Oviatt and others, 1990; Sack, 1995). The initially closed-basin Lake Bonneville became an open-basin lake about 15 ka when it reached the elevation of the lowest point on its drainage divide, 5,091 feet (1,552 m), and began spilling over into the Snake River drainage basin (Gilbert, 1890; Oviatt and others, 1992). Under this threshold control, the lake created its highest shoreline, the Bonneville. Approximately 14.5 ka, threshold failure caused catastrophic regression of the lake until it became restabilized by a bedrock sill at 4,737 feet (1,444 m), where it formed the Provo shoreline (Gilbert, 1890; Malde, 1968). Lake Bonneville began its rapid, climatically induced regression from the Provo shoreline about 14.0 ka. The Bonneville lake cycle ended, and Great Salt Lake began, close to 12 ka when the water fell to very low levels, probably below the average of modern Great Salt Lake (Currey, 1980; Oviatt and others, 1992).

Almost immediately, Great Salt Lake began a transgression and reached its highest level, the Gilbert shoreline, at about 4,245 feet (1,294 m), very late in the Pleistocene (figure 2) (Eardley and others, 1957; Benson and others, 1992). Between 9.7 and 9.4 ka, during the regression from the Gilbert level, Great Salt Lake may have experienced a small readvance to 4,230 feet (1,289 m) (Murchison, 1989), but the shoreline that formed at 4,221 feet (1,287 m) between 2.5 and 2.0 ka is generally considered Great Salt Lake's Holocene high (Currey and others, 1988). Great Salt Lake then fell to at least 4,210 feet (1,283 m) before reaching its late pre-historic high of 4,217 feet (1,285 m) approximately 400 years ago (Currey and others, 1984; Murchison, 1989). The historic high water level of 4,212 feet (1,284 m) was reached in 1873, 1986, and 1987.

Gilbert (1890) first noted that the present elevation of any given Lake Bonneville shoreline varies around the lake basin due to differential hydroisostatic loading and rebound. Constructing a hydrograph that represents the entire basin, however, requires that for each lake level a single shoreline elevation value is plotted against time. By convention, reconstructions of the chronology of Lake Bonneville, like figure 2, use the elevation that a shoreline had when it was originally formed.

PREVIOUS WORK

Some previous mapping projects have involved the Clearfield area mostly as a small part of small- or medium-scale regional studies. Fremont (1845) published the first map that delineated the Great Salt Lake shoreline with some accuracy, including its crossing of the Clearfield quadrangle area. Gilbert's (1890) Lake Bonneville monograph contains the first map of the extent of that late Pleistocene lake at its two principal deep-water stillstands, the highest level, marked by the Bonneville shoreline, and the prominent Provo shoreline, which lies about 360 feet (110 m) below the Bonneville (Burr and Currey, 1988). Gilbert's (1890, plate XIII) map correctly depicts this location as being completely submerged when the lake stood at both of those levels. Gilbert (1890, plate III) apparently travelled across the quadrangle three times in the course of his Lake Bonneville investigations. Except for the Weber River delta of Lake Bonneville, he made no special mention of any of its geomorphic or geologic features.

In the mid-20th century, Feth (1955) described some of the late Quaternary deposits found between Great Salt Lake and the Wasatch Front in the general vicinity of Ogden from approximately 41°N. to 41°21′N., a region sometimes referred to as the east shore area of Great Salt Lake. Although most of the exposures mentioned and all of his measured sections were located on the Ogden 7.5-minute quadrangle, which borders Clearfield to the northeast, one of nine drillers' well logs presented came from the northwestern part of the Clearfield quadrangle (Feth, 1955, figures 10 and 12). Overall, Feth (1955) noted great heterogeneity in the deposits of the region, abrupt lateral changes in sediment type, and that depositional trends are very difficult to trace from east to west but somewhat easier to correlate from north to south. He found stream channel, flood plain, oxbow, delta, turbidity current, regressive coastal, slack-water lacustrine, mudflow, debris flow, playa, and sublacustrine spring deposits.

Feth went on to lead a major ground water study of approximately the same east shore region (Feth and others, 1966). This later report contains two 1:62,500-scale isoline maps of generalized subsurface grain size data, which were compiled from numerous well logs. In addition, from air photos Feth and others (1966) created a general geologic map of the east shore area at the scale of 1:62,500. Their map and interpretation of the Quaternary geology of the region are based to some extent on the then-current notion that, like deposits of Lake Bonneville, deposits of a hypothesized earlier lake cycle, which was referred to as the Alpine, have surface exposure (Hunt and others, 1953; Morrison, 1965). Davis (1983) further generalized the map units of Feth and others (1966) when he compiled a 1:100,000-scale geologic map of the central Wasatch Front.

Important new small-scale maps delineating the major shorelines of Lake Bonneville and Great Salt Lake were published in the 1980s (Currey, 1980, 1982; Currey and others, 1984). These later maps extend Gilbert's (1890) work by depicting other shorelines in addition to the Bonneville and Provo. They portray the lowest major shoreline of Lake Bonneville, the Stansbury, and the highest shoreline of Great Salt Lake, the Gilbert, crossing the Clearfield area in a northwest to southeast direction (Currey, 1980, 1982; Currey and others, 1984, figure 1). On another map, Currey and others (1984, figure 2) indicated the elevations, rather than preserved shoreline evidence, of other major Great Salt Lake levels. Elevations of the prehistoric high, historic high, and historic average levels of Great Salt Lake lie within the Clearfield study area, but the quadrangle was entirely subaerially exposed when the lake occupied its historic low level of 4,191 feet (1,277 m) in 1963 (Currey and others, 1984).

In addition to the shoreline maps, Currey (1980, 1982) and Currey and others (1984) provided relevant information on regional lacustrine geomorphology. Currey (1980, p. 76-77) singled out the geomorphic expression of the Gilbert shoreline on the Clearfield quadrangle as an excellent example of the erosional bluffs and platforms that could form where the water plane intersected previously deposited, poorly consolidated coastal sediments.

METHODS

The geology of the Clearfield quadrangle (plate 1) was mapped for this report using a combination of field work and the stereoscopic interpretation of vertical air photos. Most of the air photo interpretation was accomplished using 1:11,400-scale, black-and-white photographs taken in 1952. In addition to being at a larger scale than the quadrangle, and therefore appropriate for generalizing onto the 1:24,000-scale base map, they provided visual access to land surfaces that have since been obscured by development. Regional and more contemporary perspectives were obtained by viewing 1988 color infrared and 1997 black-and-white photographs at a scale of 1:40,000.

The Clearfield map units are distinguished using a system of letter, and in some cases number, symbols that begin with an upper case Q to indicate that they are of Quaternary age. The second symbol is a lower case a, d, l, or s, designating an alluvial, deltaic, lacustrine, or marsh environment of deposition. A second lower case letter provides additional information about the characteristics or depositional environment of most of the map units. The deltaic deposits (Qd), however, are subdivided on the basis of relative age using numeric subscripts.

In some parts of the study area one Quaternary map unit thinly covers or is the product of moderate reworking of a different map unit. These areas are portrayed on the map by stacking the appropriate map unit symbols. For stacked units, the designation for the surficial unit is written above the designation for the underlying material. For example, where thin or patchy alluvial fan deposits overlie lacustrine mud, the map area is labelled Qaf/Qli. Locations on the map that consist of stacked units are colored according to the material at the surface.

Relative age control and age estimates for the map units derive primarily from the reconstructed chronology of Lake Bonneville and Great Salt Lake (figure 2 and plate 2). Age estimates for Clearfield map units that are not directly associated with a dated shoreline were made using stratigraphic and geomorphic evidence to infer the maximum and minimum lake levels during their deposition. Age estimates could then be obtained for the inferred shoreline elevations from the Lake Bonneville and Great Salt Lake hydrographs once isostatic rebound effects were subtracted from Lake Bonneville values. The elevations of Lake Bonneville water levels were adjusted for isostatic rebound using the technique of Currey and Oviatt (1985).

ABANDONED SHORELINES

The ground surface of the Clearfield quadrangle displays segments of several subaerially exposed former shorelines of Great Salt Lake and Lake Bonneville, most of which extend for rather limited distances (figure 3). Preserved segments of only the two most prominent and continuous of these shorelines are specifically traced on the geologic map (plate 1). The first is the Gilbert shoreline, which lies at about 4,245 feet (1,294 m), just 3 feet (1 m) higher than its lowest position in the Great Salt basin (Currey, 1982). The Gilbert shoreline is marked by a distinct erosional bluff for almost its entire length on the quadrangle, and for much of its distance is paralleled by Bluff Road (figure 3). The second mapped shoreline is a lower, also predominantly erosional one that appears to be a single, discrete shoreline, but which varies in elevation across the map from 4,217 to 4,220 feet (1,285-1,286 m). Both 4,217 feet (1,285 m) and 4,221 feet (1,287 m) have been cited in the literature as separate Holocene

Figure 3. *View to the west-northwest across the central part of the Clearfield quadrangle from western Layton (foreground) across Syracuse to Great Salt Lake and the causeway to Antelope Island. The ancient Gilbert shoreline bluff of Great Salt Lake (arrow), and Bluff Road along its base, together form the linear feature crossing the photograph from lower left to upper center. Segments of several relict Lake Bonneville shorelines are visible upslope from the Gilbert shoreline to the northeast (right).*

Great Salt Lake levels, the late prehistoric and the Holocene high levels, respectively (Currey and others, 1984, 1988; Murchison, 1989). Enough uncertainty exists in the correlation of the second mapped shoreline on the Clearfield quadrangle to one or both of these levels that on plate 1 it is generically labelled a late Holocene high shoreline.

Below 4,217 feet (1,285 m), several primarily constructional coastal landforms, such as the prominent cuspate barrier complex between about 4,205 and 4,212 feet (1,282-1,284 m), appear on the geologic map as an obvious shoreline zone due to the shape and distribution of map units. These, however, are not portrayed with the symbol for an individual shoreline because they represent multiple, closely spaced, largely historic, and probably frequently reoccupied positions of the continuously fluctuating Great Salt Lake.

The Stansbury shoreline is not delineated on plate 1 even though Currey's (1980) 1:250,000-scale map depicts preserved portions of it crossing the quadrangle in the vicinity of the city of Clearfield. In 1980, Lake Bonneville scholars accepted the interpretation of the Stansbury as a shoreline from the regressive phase of Lake Bonneville, in which case it might be expected to be easily discerned. Researchers, however, have subsequently demonstrated that it formed during the transgressive phase of Lake Bonneville (Currey and others, 1983; Green and Currey, 1988; Oviatt and others, 1990), which would help explain its "lack of clear definition on the landscape" (Oviatt and others, 1990, p. 291). On the Clearfield quadrangle, the approximate elevational range of the Stansbury oscillation is dominated by Weber River deltaic deposits and is not crossed by a discrete, prominent shoreline that can be mapped with confidence at this time as the Stansbury shoreline.

DESCRIPTION OF MAP UNITS

Alluvial Deposits

Undifferentiated Alluvium and Colluvium (Qac)

Qac consists of sediment moved downslope by the combined action of gravity and sheet wash. This map unit is found only in the northeastern part of the quadrangle along the steep scarp of the lakeward edge of the Provo-level delta of the Weber River, Qd_1. Qac deposits are sand-dominated, but finer grain sizes are also present. Estimated thickness of this unit ranges from less than 1 to 8 feet (0.3-2.4 m). Although most of the map unit was probably deposited soon after Lake Bonneville fell through this elevation during its post-Provo regression, approximately 12.6 ka, some sediment may still be accumulating.

Alluvial-Fan Deposits (Qaf)

Primarily fine-grained alluvial-fan deposits are found where small, shallow, braided or switching ephemeral streams tend to spread their load as a fan-shaped deposit over the ground surface rather than confining it within a discrete channel. These alluvial-fan deposits are probably less than 10 feet (3 m) thick, and are especially common where slightly incised channels widen after crossing a shoreline scarp or other relatively abrupt change in slope. The source of the flowing water consists of surface runoff, seepage springs, and even artificial ditches and canals. Below an elevation of 4,205 feet (1,282 m), Qaf commonly occurs as a thin, fan-like, stream or marsh environment spread over lacustrine mud (Qaf/Qli). Those settings often display marsh vegetation but have a stronger appearance of directional flow than is found in areas mapped as marsh (Qsm). In its highest outcrops, deposition of the Qaf map unit could have started as early as about 12.3 ka, when, according to current understanding (figure 2), those elevations first became subaerially exposed during the regressive phase of Lake Bonneville. Alluvial fan deposition continues on the Clearfield quadrangle today.

Channel Alluvium (Qal)

Channel alluvium consists of mixed fine-grained sediments (sand, silt, and clay) deposited by small streams and sheet wash within gully-like stream channels. This unit is estimated to be up to 10 feet (3 m) thick, and may include small, localized mass wasting deposits. The long and narrow map areas of Qal are found at low elevations on the quadrangle, below about 4,225 feet (1,288 m). These channels cut through the mapped late Holocene shoreline of Great Salt Lake at about 4,220 feet (1,286 m), and they date from the time the lake abandoned that shoreline, which may have been as early as 2.0 ka, to the present.

Deltaic Deposits

Younger Deltaic Deposits (Qd_1)

Qd_1 deposits lie in one map area in the northeastern corner of the quadrangle where they occupy the highest elevations on the map. This unit consists of distal subaqueous deposits of the Provo-level delta of the Weber River, and includes the steep scarp of the delta front. The surface of the map unit has a slightly irregular and almost hummocky nature and no evidence of stream channels, which contribute to the formation of, and thus tend to be visible on, relict subaerial portions of deltas. Qd_1 sediments are dominated by sand, but finer, and occasionally coarser, clasts are present. Although several post-Provo regressive-phase shorelines of Lake Bonneville cross the Qd_1 deposits, reworking of the sediments was insignificant due to the rapid fall of the lake and the relatively steep slope of the topography. There appears to have been only limited reworking of the delta surface by postlacustrine sheet wash, gravity, and the wind. Qd_1 sediments may overlie deep-water fine-grained sediments, including an equivalent of Lake Bonneville's white marl (Gilbert, 1890), and Weber River deltaic deposits from the transgressive phase of Lake Bonneville. This younger deltaic sand unit, Qd_1, may be as much as 70 feet (21 m) thick and ranges in age from about 14.5 to 14 ka.

Older Deltaic Deposits (Qd_2)

Between the younger deltaic deposits (Qd_1) and the Gilbert shoreline is a large slope that, despite some surface reworking by subsequent lacustrine and subaerial processes, is interpreted as being fundamentally constructed of Weber River deltaic sediments deposited during part of the transgressive phase of Lake Bonneville, from about 27.4 to 20.4 ka. Most of this slope, referred to in this report as the Clearfield slope, is scored by small shoreline bluffs and mapped as lacustrine fines (Qlf), lacustrine sand (Qls), or mixed lacustrine and fluvial deposits (Qla) stacked over Qd_2 deposits. One broad band just downslope from the younger deltaic sediments and three smaller map areas beyond, however, are mapped as unstacked Qd_2 sediments. These four locations exhibit sand-dominated sediments and an irregular surface topography that includes meander-like curves. These curves are interpreted as channel remnants from the subaerial component of the transgressive-phase Weber River delta, perhaps partially covered by subaqueous deposits of the same transgressive delta sequence. Figure 4 presents a description of Qd_2 sediments as measured in an exposure at Clearfield High School. The column suggests a basically fluvial, but rapidly changing, depositional setting. Maximum thickness of the Qd_2 unit may be as much as 50 feet (15 m).

An important feature that supports the notion of a deltaic foundation for much of the Clearfield slope is the ridge that straddles the boundary between the Clearfield quadrangle and the next quadrangle to the north, Roy. The ridge does not have an official name but forms the crest of the westward projecting point of land on which the community of West Point lies. The vertexes of most of the convex-lakeward contours of the West Point projection, that is, the axis of the ridge, lie just across the map edge on the Roy quadrangle. The West Point ridge extends from the Gilbert shoreline, at about 4,245 feet (1,294 m) on the Clearfield quadrangle, to a high of 4,555 feet (1,388 m) on the Roy quadrangle. The Clearfield slope constitutes the southern flank of the West Point ridge. The size, shape, and position of the ridge relative to the Provo and later components of the Weber River delta (Sack, 2005) are such that the main mass of the ridge cannot be explained as a post-Provo feature. It is interpreted instead as a landscape component created during the transgressive phase of Lake Bonneville, specifically as transgressive-phase deltaic deposits of the Weber River.

The Weber is a major river, the second largest that discharges into Great Salt Lake today and the second largest that discharged into Lake Bonneville. The modern Weber River delta of Great Salt Lake is an expansive, digitate landform extending for 13 miles (21 km) along the lake's eastern shore. The Weber River deposited a very large mass of deltaic sediments during Lake Bonneville's Provo stillstand and during the lake's regressive phase (Gilbert, 1890; Sack, 2005). The Weber River also flowed into the basin during the transgressive phase of Lake Bonneville and should have left some depositional evidence, such as deltaic, fan-delta, or underflow fan deposits, of its transgressive positions. Deltaic sediments could have been deposited throughout the transgression, but perhaps especially during stillstands and oscil-

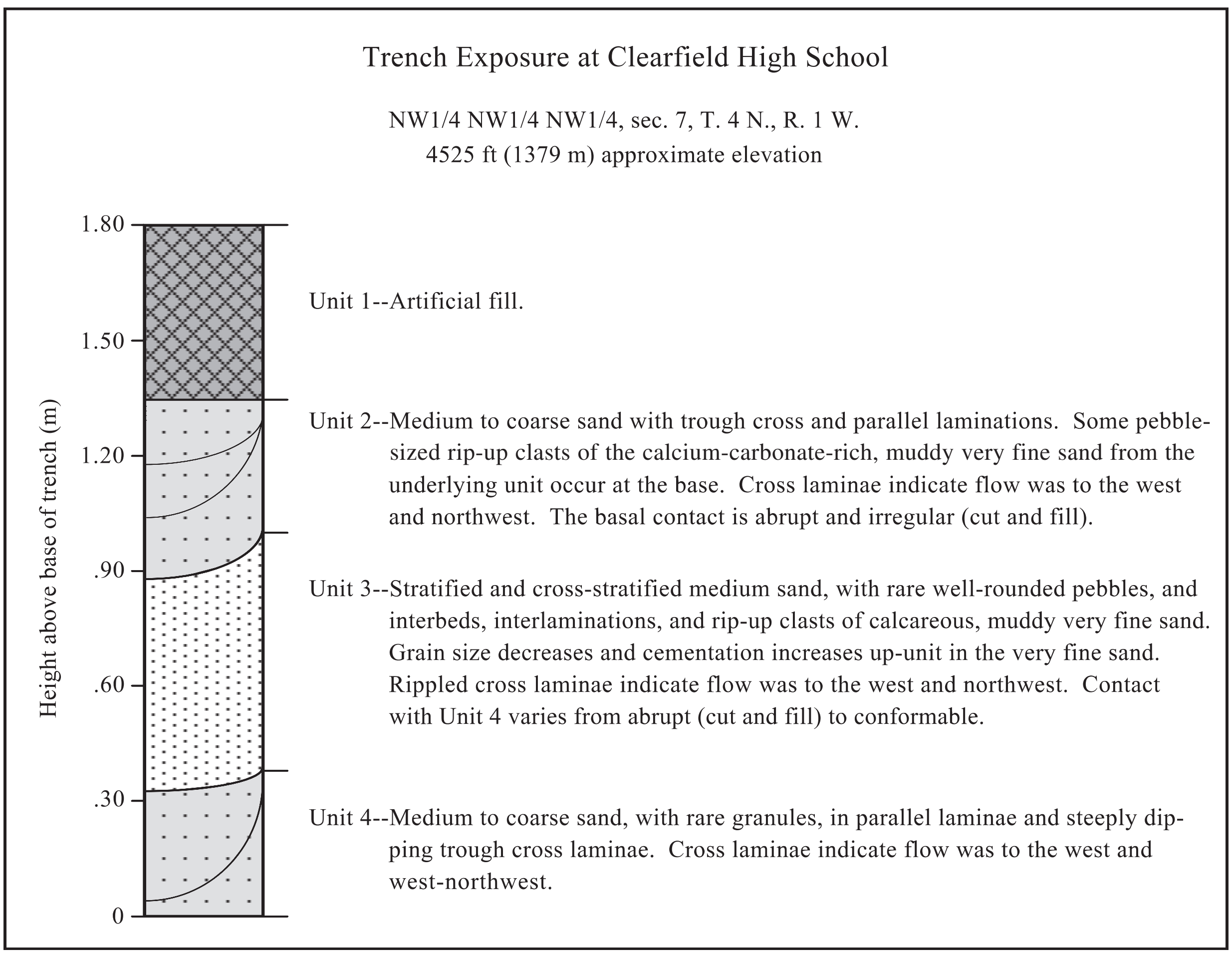

Figure 4. *Measured stratigraphic column in the older deltaic sediments (Qd_2), represented here by units 2-4.*

lations. Although the river may not have had sediments from higher deltas and embayments to rework during the transgressive phase of Lake Bonneville like it did during the regressive phase (Gilbert, 1890), the effectively wetter climate that enabled Lake Bonneville to expand would also have caused an increase in river discharge and load. Additional support for the transgressive deltaic origin of the West Point ridge and its lateral component on the Clearfield quadrangle, the Clearfield slope, comes from the position of the axis of the West Point ridge approximately due west of the mouth of Weber Canyon, the sandy texture of unstacked Qd_2 deposits (figure 4), and the meandering channel-like depressions in the Qd_2 map areas.

Because of the subsequent deep-water and regressive phases of Lake Bonneville, much of the area of Qd_2 deposits on the Clearfield quadrangle has been thinly covered with lacustrine fine-grained sediments (Qlf/Qd_2) and/or somewhat reworked by coastal and surface runoff processes (Qla/Qd_2). Where exposures of these stacked deposits were observed, the Qd_2 sediments ranged from fine sand to silt. The measured column described in figure 5 shows a typical example of this stacked sequence (Qlf/Qd_2). At that exposure, lacustrine fines (Qlf), which includes a clastic-rich version of Lake Bonneville white marl, thinly covers a massive to parallel-laminated silt that is interpreted as transgressive-phase deltaic sediment (Qd_2). The white marl is incorporated within the Qlf map unit because it was not found at the surface on the Clearfield quadrangle.

It is possible that some of the irregular topography observed in Qd_2 deposits is the result of mass wasting. About 10 miles (16 km) to the southeast of Clearfield, in the Farmington area, previous workers described Lake Bonneville beds of silty clay, clayey silt, and very fine sand that failed on a gentle slope by lateral spreading triggered by earthquake-induced liquefaction (Van Horn, 1975; Hylland and Lowe, 1998). Those researchers, however, reported some geomorphic features that are consistent with liquefaction-induced landslides (Van Horn, 1975; Hylland and Lowe, 1998) that were not observed on the Clearfield quadrangle.

Lacustrine Deposits

Undifferentiated Lacustrine and Alluvial Deposits (Qla)

In many places on the quadrangle local fluvial action, such as from sheet wash, gullies, and shallow ephemeral channels, have reworked, or intertongue complexly with, lake sediments and shoreline bluffs so that neither depositional environment dominates. These are mixed lacustrine and alluvial deposits, symbolized Qla. The textural class of this unit varies, but is generally some mixture of fine-grained sediments. Thickness of this unit is probably less than 10 feet (3 m). In some places, Qla deposits have a grayish-brown color and overlie the marly Qlf sediments that appear as unit 2 in figure 5. Much of this map unit represents the downslope washing of surface lacustrine fines. A portion of the lacustrine component may have originated during the transgressive phase of Lake Bonneville. The fluvial action, however, did not develop until subaerial exposure, therefore map areas of Qla are estimated to have originated between 12.6 ka and the present.

Fine-Grained Lacustrine Deposits (Qlf)

Poorly sorted deposits of lacustrine sand, silt, and clay, finer overall than the lacustrine sand unit (Qls) and coarser than lacustrine mud (Qli), are mapped as Qlf. Qlf may be as much as 10 feet (3.0 m) thick and locally includes what is interpreted as a clastic-rich version of Lake Bonneville white marl (Gilbert, 1890), calcium carbonate precipitated during the lake's deeper levels (figure 5). Qlf is found above the Gilbert shoreline primarily as a thin cover of regressive lacustrine fine-grained deposits overlying the older deltaic sediments (Qlf/Qd_2), but some transgressive fines, such as the white marl equivalent, are also present. Below the mapped late Holocene shoreline, Qlf is predominantly a Great Salt Lake shoreline deposit. Qlf sediments may be as old as about 27.3 ka, when Lake Bonneville transgressed over the quadrangle, and as young as the most recent high-stand of Great Salt Lake.

Lacustrine Mud (Qli)

Low-relief surfaces of wet, saline, often algae-rich, fine and very fine grained sediments are mapped as lacustrine mud. These are high water table, lake-marginal areas that are either barren or sparsely vegetated with salt grass or other lake-marginal halophytes. Common textural classes include muddy very fine sand, very fine sandy silt, and very fine sandy mud. These mudflats are most extensive below an elevation of 4,205 feet (1,282 m), a zone that is still periodically inundated by Great Salt Lake, but smaller map areas are found as high as 4,217 feet (1,285 m), the approximate elevation of the late prehistoric high level of Great Salt Lake (Currey and others, 1984). The very fine grained Qli deposits are primarily lake bottom and quiet water deposits of Lake Bonneville and the deeper stages of Great Salt Lake. They continue to be reworked slightly on the gently shelving former lake bottom topography by waves and currents of the oscillating margin of Great Salt Lake (figure 6). Age of the unit, therefore, ranges from about 28 ka to present. Estimated thickness varies from less than 1 foot (0.3 m) at its highest exposures to 10 feet (3 m) or more beneath Great Salt Lake.

Lacustrine Sand (Qls)

Sand-dominated lake deposits lie along the northern edge of the map between the Gilbert shoreline and the 4,450 foot (1,356 m) contour on and near the axis of the West Point ridge. Qls represents a limited reworking of the older sandy deltaic sediments (Qd_2) by Lake Bonneville coastal processes as the water level fell through this zone late in the lake's regressive phase, from about 12.3 to 12.0 ka. The coastal reworking probably helped to smooth over irregularities in the delta surface, and it left some shoreline bluffs on the slope, but suggestions of meandering channels can still be seen in places when viewing large-scale air photos stereoscopically. This unit appears on the map only as the stacked unit, Qls/Qd_2. Qls is typically less than 5 feet (1.5 m) thick.

Marsh Deposits (Qsm)

Fine-grained, saturated, fetid, organic-rich sediments and muck that occur in association with springs, ponds,

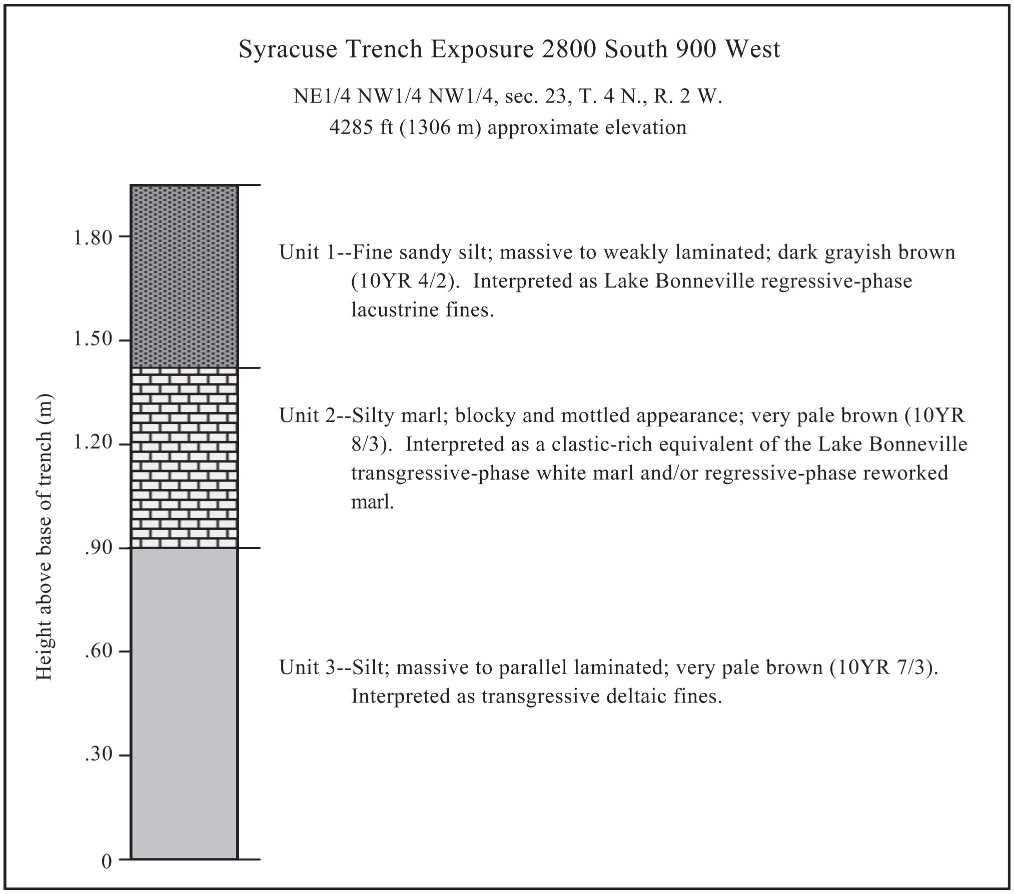

Figure 5. *Measured stratigraphic column in Qlf/Qd$_2$ sediments. Units 1 and 2 represent lacustrine fine-grained deposits (Qlf). Unit 3 is interpreted as fine-grained deltaic sediments (Qd$_2$) deposited during the transgressive phase of Lake Bonneville.*

Figure 6. *Driftwood showing the 1986-87 high water line of Great Salt Lake in coastal flats of lacustrine mud (Qli) and fines (Qlf), as it appeared in 2000. View is to the north.*

Figure 7. *Liquefaction potential map (after Anderson and others, 1994).*

seeps, and lake-adjacent wetlands are mapped as Qsm deposits. Areas of Qsm are found only below the Gilbert shoreline and primarily represent lacustrine fine-grained sediment or lacustrine mud that has been altered by a shallow, flooded environment. Qsm deposits are probably less than 5 feet (1.5 m) thick. Marsh deposits have been accumulating on the quadrangle since Great Salt Lake retreated from the Gilbert shoreline, which may be about 10.3 ka (Currey, 1990) or as recently as 10.0 ka (Oviatt and others, 2003).

QUATERNARY HISTORY

Shortly before the Bonneville lake cycle, about 30 ka, the Weber River probably flowed fairly directly from its canyon mouth in the Wasatch Range westward to the low-level standing water body that existed in the Great Salt Lake basin. Without the present large mass of Lake Bonneville deltaic deposits to skirt around, there would have been little reason for the river to take the extremely circuitous route to the lake that it does today. Although there might have been some relief left in the landscape from deltaic and coastal landforms of the previous deep-lake cycle, landscape evolution research in the Bonneville basin has demonstrated that this is unlikely (Sack, 1992, 1995). The pre-Bonneville Weber River very likely meandered over a flood plain before splitting into the multiple distributary channels of a deltaic plain adjacent to the lake. The river may have changed course through avulsion at times, but the lakeward bulge of the Great Salt Lake coastline at the quadrangle (figure 1), that is, the unusual width of the piedmont in this area, indicates that the Weber River flowed across it and deposited fluvial and deltaic sediment here commonly. As Lake Bonneville rose, a major component of the sediment-laden river was probably directed westward in the vicinity of the northern boundary of the quadrangle, thus beginning construction of the West Point ridge with the Clearfield slope comprising its southern flank. As the lake continued its relatively slow transgression (figure 2), the locus of this Qd_2 sedimentation shifted higher and eastward. The most extensive accumulations of Qd_2 sediments probably formed in association with lake-level stillstands and oscillations and consisted of sediment from subaerial and subaqueous delta components. Lacustrine fine-grained sediments (Qlf) likely capped the sequence in some locations, further muting channeled and sloughed zones of the deltaic environment. In deeper water, some very fine-grained sediments (Qli) probably settled out of the water column onto the low-gradient lake bottom.

Sedimentation rates on the quadrangle decreased as Lake Bonneville rose to its highest levels far up Weber Canyon in the Wasatch Range to the east leaving the Clearfield quadrangle 400 to 917 feet (122-279 m) underwater. The Weber River's course within the Wasatch Range became a large embayment of Lake Bonneville and a settling basin that collected much of the river's clastic load (Gilbert, 1890). While the lake was at its highest levels the white marl precipitated out of the open lake water, and a mix of very fine-grained clastic sediments and calcium carbonate might have begun accumulating in the study area.

The Bonneville flood and restabilization of the lake at the Provo level occurred about 14.5 ka (Oviatt and others, 1992). This new threshold-controlled lake level, however, was still to the east of the submerged quadrangle. Upstream, the Weber River eroded and transported lakeward the newly exposed canyon lake sediments in great quantities. The river constructed a huge delta at the Provo level with part of the subaqueous component extending onto the northeastern part of the Clearfield quadrangle as Qd_1 sediments. Elsewhere in the Bonneville basin, white marl mixed with fine clastic particles is very commonly found downslope from the Provo shoreline (e.g., Sack, 1990), and part or all of the clastic-rich marl found overlying Qd_2 sediments at the Syracuse exposure (figure 5) and similar locations might have been deposited at this time.

When climate change caused Lake Bonneville to fall from the Provo level about 14.0 ka, it fell quickly (figure 2). Some positions of the falling water line are recorded on the steep, subaqueous portion of the Provo delta as minor shorelines. Local steepening by an erosional shoreline may have instigated slope processes responsible for the zone of undifferentiated alluvium and colluvium (Qac) at the lower edge of the Qd_1 map unit. The drop in lake level caused the Weber River to incise its own deltaic sediments but at a location to the north and east of Clearfield so that a regressive deltaic sequence does not appear on the map. The continued regression of Lake Bonneville is marked instead by relatively minor shorelines crossing the Clearfield slope and a surficial reworking of some of the deltaic deposits, leaving lacustrine sand (Qls) or fine-grained deposits (Qlf) stacked over the older deltaic sediments (Qd_2). With subaerial exposure of the Clearfield slope, sheet wash and small-scale fluvial action have reworked the older deltaic and overlying lacustrine deposits in varying amounts leaving small alluvial fans (Qaf) and large areas of mixed lacustrine and alluvial deposits (Qla/Qd_2). At the end of the Bonneville lake cycle, a smooth slope crossed only by minor shorelines and displaying a lakeward decrease in gradient extended all the way to the lake. In its lower reaches this slope was probably dominated by Qlf and Qli sediments.

When Great Salt Lake rose from very low water levels sometime after 12.0 ka, it transgressed over a surface of low but increasing slope that was well adjusted to coastal processes and composed mainly of lacustrine fines. Erosion along the advancing shoreline cut into the unconsolidated material that comprised the slope. Most of this sediment was transported a short distance lakeward. Eventually the lake reached and hovered around an elevation of 4,245 feet (1,294 m), where it created the high bluff of the Gilbert shoreline through erosion of the unconsolidated sediments of the Clearfield slope. These eroded sediments were also transported and redeposited lakeward contributing to the formation of the shelf-like topography, arcuate in map view, that lies between the Gilbert and the later 4,217 to 4,220 foot (1,285-1,286 m) shoreline. In a similar fashion, perhaps as early as 2.3 ka the lake readvanced at least once from lower levels to the 4,217 to 4,220 foot (1,285-1,286 m) position, eroded that shoreline bluff, and transported sediment lakeward to create the nearshore platform of the high Holocene shoreline. Subsequent low-level readvances are marked by the distribution of Qlf deposits on that lower shelf.

Since subaerial exposure of the Gilbert-level platform, sheet wash and shallow streams have reworked much of the original Qlf deposits into the Qla map unit. Springs, seeps, and other high water-table settings have converted some of the areas to marsh deposits. Since Great Salt Lake retreated from the mapped high Holocene shoreline, similar processes have acted on its platform. In addition, small stream channels (Qal) have cut through that shoreline and through fine-grained sediments located upslope and downslope from it. Lacustrine mud (Qli), lacustrine marsh deposits (Qsm), and thin alluvial fan deposits (Qaf) dominate the very low gradient, occasionally flooded zone between the average position of Great Salt Lake, at about 4,200 feet (1,280 m), and 4,205 feet (1,282 m). Most of these alluvial fans have their apexes at 4,205 feet (1,282 m) at points where small channels break through low-level shoreline features. Discrete channels cannot be maintained below that level because of the very low gradient and high cohesion of the mudflats.

ECONOMIC RESOURCES

Sand and salt constitute the principal traditional geologic resources on the quadrangle; the wetlands adjacent to

Great Salt Lake are ecologically valuable. Deltaic and lacustrine sand (Qd_1, Qd_2, and Qls) could be minable for the construction industry, but future pit operations seem unlikely due to the area's rapid rate of suburbanization. No analyses to determine the suitability of these deposits as construction or road-metal materials were conducted or found in the literature. Kopp's (1987) petrographic study aimed at determining the suitability of sand and gravel in Davis County for use as aggregrate in concrete did not include samples from the Clearfield quadrangle.

The salt industry has already been important to the study area. Syracuse, Utah, was apparently named after a brand of salt produced there in the 19th century (Leonard, 1999). That salt company, and a succession of later ones, ponded Great Salt Lake water on the mudflats west of Syracuse to extract salt via solar evaporation (Clark and Helgren, 1980). According to Gwynn and Sturm (1980), the quadrangle has some of the site attributes needed today for the economic extraction of salts and metals from Great Salt Lake brine by solar ponding, but it is not ideal, and their map excludes it as a potential solar ponding site.

POTENTIAL GEOLOGIC HAZARDS

Geologic hazards in the study area consist of those related to seismic events (earthquakes) and those related to fluctuating levels of Great Salt Lake. No fault scarps were observed on the quadrangle, but interpretation of seismic reflection data suggests that a possible buried fault (cross section A-A′ plate 2) under the quadrangle cuts Quaternary deposits, and therefore would be a potential earthquake source. Because of the possible buried fault and the quadrangle's proximity to the Wasatch fault zone, ground shaking and accompanying liquefaction and mass wasting pose significant hazards to this area (figure 7) (Van Horn, 1975; Hecker and others, 1988; Anderson and others, 1994). Earthquakes may also trigger seiches in Great Salt Lake. Seiches are standing waves in which water sloshes back and forth across an entire lake basin or embayment. Flooding due to climatically induced high levels of Great Salt Lake will likely occur periodically. The upper limit of potential flooding impacts is 4,217 feet (1,285 m), the elevation at which Great Salt Lake overflows to the Great Salt Lake Desert. Very low levels of Great Salt Lake and vegetation loss due to drought could provide source material for dust storms.

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