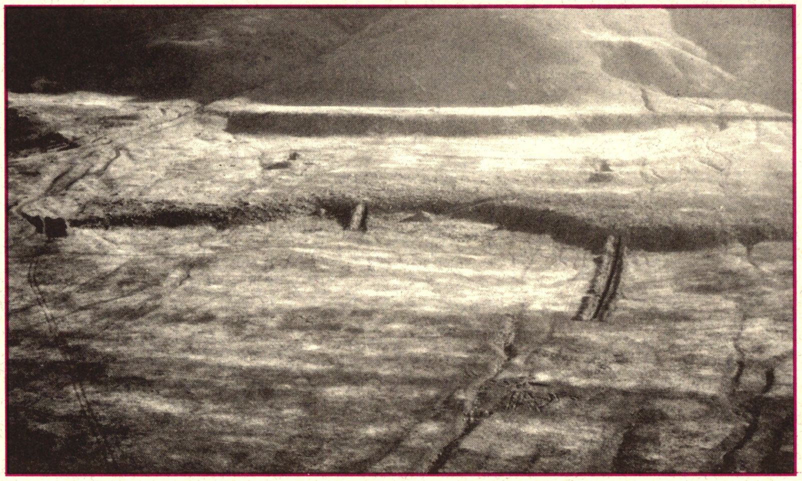
PALEOSEISMOLOGY OF UTAH, VOLUME 6

THE OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH: SURFICIAL GEOLOGY AND PALEOSEISMICITY

edited by
William R. Lund



Special Study 88 **1996**
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

UTAH CENTENNIAL 1896-1996

Lund
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FOREWORD

This Utah Geological Survey Special Study, *The Oquirrh Fault Zone, Tooele County, Utah: Surficial Geology and Paleoseismicity*, is the sixth report in the *Paleoseismology of Utah* series. This series makes the results of paleoseismic investigations in Utah available to geoscientists, engineers, planners, public officials, and the general public. These studies provide critical information on earthquake timing, recurrence, displacement, slip rate, and fault geometry which can be used to characterize potential seismic sources and evaluate the long-term earthquake hazard presented by Utah's Quaternary faults.

The two reports in this Special Study provide critical geologic and paleoseismic information on the Oquirrh fault zone, a Quaternary fault in eastern Tooele County, west-central Utah. The Oquirrh fault zone has long been recognized as a potential source of large earthquakes which could affect military and hazardous waste facilities, nearby towns, and populous areas of the more distant central Wasatch Front.

The first report, "Surficial Geology of the Oquirrh Fault Zone, Tooele County, Utah" by Barry J. Solomon, describes the geology along the fault zone. The report is accompanied by a 1:24,000-scale surficial geologic strip map of the fault zone (plate 1). The map shows the relation of fault scarps to geologic deposits of different ages and to prominent shorelines of Pleistocene Lake Bonneville. Large-scale geologic maps of this type are a critical component of comprehensive paleoseismic studies. The structural and stratigraphic relations they portray often tell us much about the timing of past surface-faulting earthquakes, and provide important information when selecting trench sites for detailed paleoseismic investigations.

The second report, "Paleoseismic Investigation of the Oquirrh Fault Zone, Tooele County, Utah" by Susan S. Olig and others, presents the results of two detailed paleoseismic trench investigations, one each on the northern and central sections of the fault zone. Results of those investigations provide new information on the size, timing, and recurrence of surface-faulting earthquakes on the Oquirrh fault zone in late Pleistocene and Holocene time. Such information is necessary to evaluate the earthquake hazard presented by the fault zone and to make decisions regarding hazard mitigation.

William R. Lund, Series Editor
Utah Geological Survey

also in the Paleoseismology of Utah Series

Utah Geological Survey Special Study 75, 1991, Paleoseismology of Utah, Volume 1: Fault behavior and earthquake recurrence on the Provo segment of the Wasatch fault zone at Mapleton, Utah County, Utah by W.R. Lund, D.P. Schwartz, W.E. Mulvey, K.E. Budding, and B.D. Black.

Utah Geological Survey Special Study 76, 1991, Paleoseismology of Utah, Volume 2: Paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah and the Pole Patch trench site, Pleasant View, Utah by S.F. Personius.

Utah Geological Survey Special Study 78, 1991, Paleoseismology of Utah, Volume 3: The number and timing of Holocene paleoseismic events on the Nephi and Levan segments of the Wasatch fault zone, Utah by Michael Jackson.

Utah Geological Survey Special Study 82, 1994, Paleoseismology of Utah, Volume 4: Seismotectonics of north-central Utah and southwestern Wyoming by Michael W. West.

Utah Geological Survey Special Study 83, 1994, Paleoseismology of Utah, Volume 5: Neotectonic deformation along the East Cache fault zone, Cache County, Utah by James P. McCalpin.

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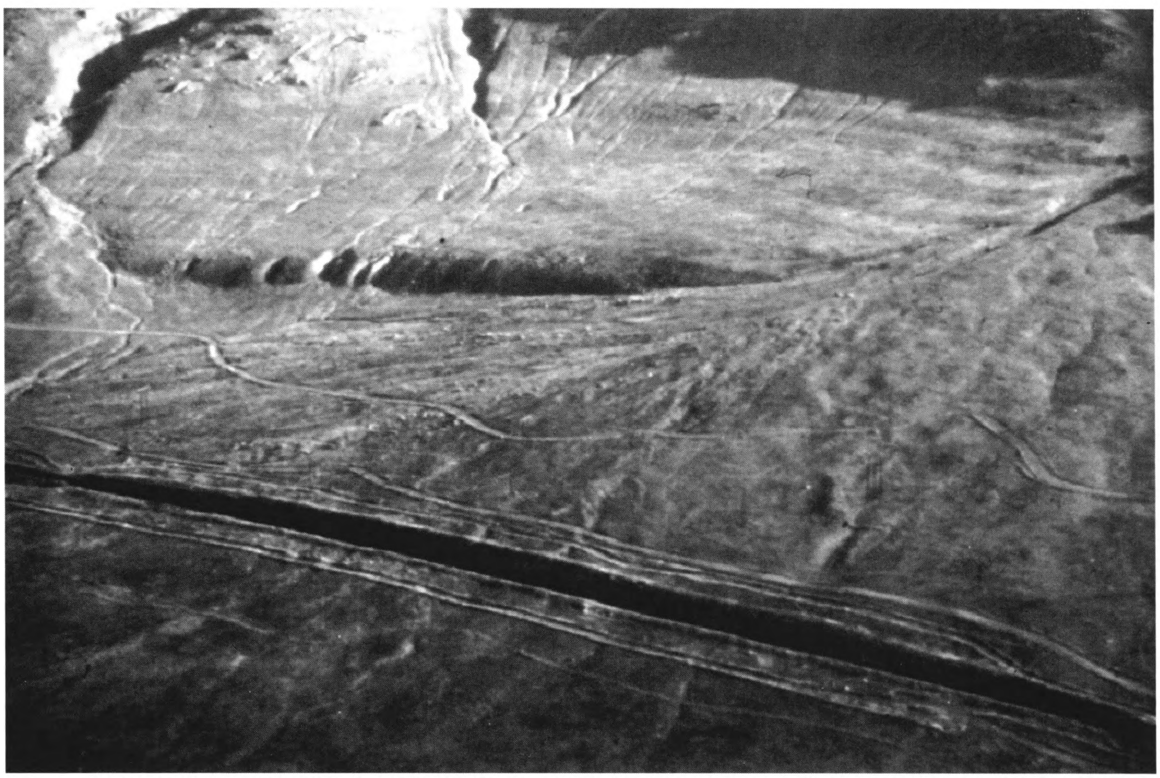

Aerial view of the scarps on the northern linear section of the Oquirrh fault zone near Rogers Canyon (photo by Susan S. Olig).

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SURFICIAL GEOLOGY OF THE OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH

by
Barry J. Solomon

ABSTRACT

The Oquirrh fault zone extends discontinuously for 19 miles (31 km) along the northwest margin of the Oquirrh Mountains, Tooele County, north-central Utah. The west-dipping normal fault forms prominent scarps in Quaternary lacustrine and alluvial deposits in the northern and central parts of the fault zone, and a sharp bedrock-alluvial contact in the southern part of the fault zone. Surface faulting offsets some Holocene deposits.

Scarps in the northern part of the Oquirrh fault zone trend generally north-south, and are commonly overlain by latest Pleistocene to Holocene alluvial-fan deposits. Scarps in the central part of the fault zone lie on an elevated spur, the Erda salient, that extends west from the range front and is mostly underlain by deposits of latest Pleistocene Lake Bonneville. The scarp in the southern part of the fault zone borders an indentation in the range, the Pine Canyon reentrant, that is above the Lake Bonneville highstand and generally underlain by Pliocene to Pleistocene alluvial-fan deposits.

Several other buried faults in the vicinity of the Oquirrh fault zone have been mapped in valley fill in previous studies. These faults are postulated on the basis of hydrologic, geophysical, and topographic evidence, but they do not cut surficial deposits. They may be older than, and unrelated to, the Oquirrh fault zone. However, some of them, particularly the Occidental fault, may have been reactivated by later movement on the Oquirrh fault zone.

INTRODUCTION

The Oquirrh fault zone lies at the base of the Oquirrh Mountains on the eastern edge of Tooele Valley, east-central Tooele County, Utah (figure 1). Geomorphologist G.K. Gilbert first recognized faulting along the west front of the Oquirrh Mountains in July 1880 during his visit to the Tooele area (Hunt, 1982, p. 170):

> "Approaching Tooele there is a fine view of the fault scarp in the embayment of the mts (mountains)....I am not sure there have been any post-Bonneville movement but think there is."

Gilbert (1890) assumed that faults along the Oquirrh range front in Tooele Valley were continuous with similar faults along the range front in Rush Valley. He traced the fault zone for a distance of about 25 miles (40 km) from Lake Point, at the northern end of the Oquirrh Mountains, to the vicinity of Mercur Canyon in east-central Rush Valley.

Atwood (1916) agreed that the north end of the range adjacent to Tooele Valley was faulted. However, he attributed the southern spurs of the Oquirrh Mountains, which project at varying lengths into Rush Valley, to be the product of erosion. Later, Gilluly (1928) interpreted the Oquirrh Mountains range front adjacent to Rush Valley as the product of a combination of step faulting, en echelon faulting, and linear discontinuity of individ-

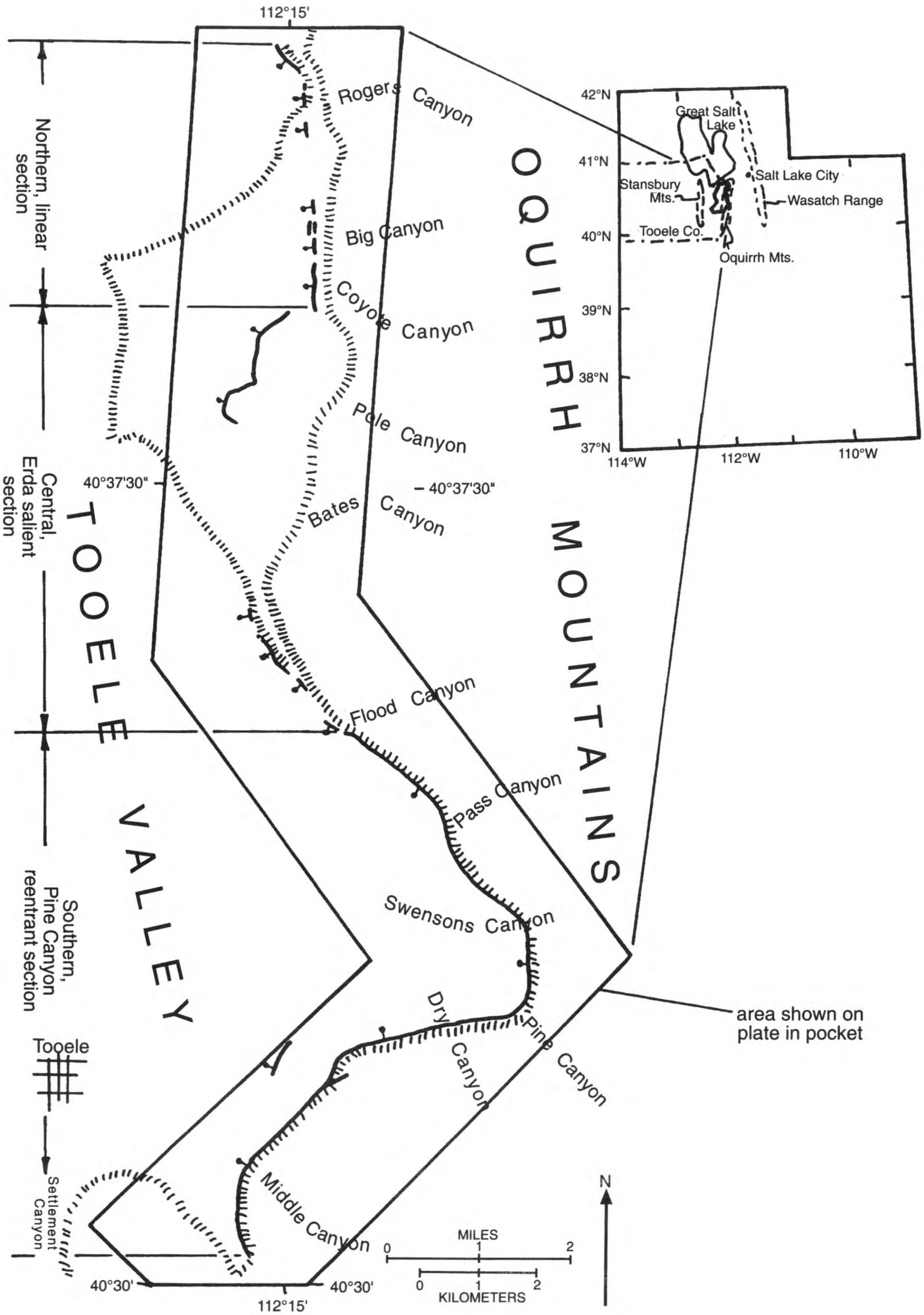

Figure 1. Index map of the Oquirrh fault zone, showing outline of mapped area (heavy line), significant slope breaks (hachures) along the range front, fault scarps (with bar and ball on downthrown side), and the three geographic sections of the fault zone discussed in the text.

ual faults. Cook and Berg (1961) associated the Rush Valley faults with a continuous, 60-mile- (100-km-) long gravity gradient of 10 milligals per mile that bounds the western front of the East Tintic, Boulter, and southern Oquirrh Mountains, and called the structure the Oquirrh-Boulter-Tintic fault zone.

Bucknam (1977) initiated the modern investigation of faulting along the western Oquirrh Mountains range front. He systematically mapped suspected fault scarps in unconsolidated deposits of the Tooele 1°x 2° quadrangle on aerial photographs. Bucknam (1977) agreed with Gilluly (1928) that distinct fault zones separated by a zone of unfaulted Quaternary sediment bound the Oquirrh Mountains range front in Tooele and Rush Valleys. Everitt and Kaliser (1980) designated the range-front fault zone in Tooele Valley as the Oquirrh marginal fault zone, and the range-front faults in Rush Valley as the northern and southern Oquirrh-Boulter-Tintic fault zones. The two Rush Valley fault zones are separated from each other by a discontinuity in surface rupture.

Barnhard and Dodge (1988) renamed the Oquirrh marginal fault zone as the northern Oquirrh fault zone, consistent with its geographic position near the north end of the Oquirrh Mountains. They attempted to interpret the paleoseismicity of the fault zone, discussed geomorphic evidence for recurrent faulting, and estimated the age of the most-recent event by comparison of scarp profiles along the fault zone with regression-equation lines for scarps elsewhere of known age. Barnhard (1988) referred to the same surface ruptures as the Oquirrh fault zone, recognizing that "northern Oquirrh Mountains" is informal nomenclature, and fault names should refer to formally named geographic features. This name is used here.

This report and accompanying map discusses and shows the surficial geology along the Oquirrh fault zone and provides basic geologic data needed to make reliable assessments of earthquake hazards. The map, at a scale of 1:24,000, is a compilation of portions of geologic maps previously published at the same scale (figure 2). Tooker and Roberts (1971a, 1971c, 1988) and Tooker (1980) mapped the bedrock in the Oquirrh Mountains. Their results are generalized and reproduced here with the exception of minor modifications to the contact between bedrock and Quaternary deposits. They also mapped Quaternary deposits and scarps of the Oquirrh fault zone, but these were significantly modified by Solomon (1993) who remapped the Quaternary geology on 1:20,000-scale aerial photographs, and field checked the air-photo mapping.

QUATERNARY HISTORY

Tooele Valley occupies a structural basin in the Basin and Range physiographic province (Stokes, 1977), and is also a geomorphic subbasin of the Bonneville Basin, an area of interior drainage for much of the past 15 million years. Several successive lakes existed in the Bonneville Basin during this time, but the Quaternary geology of the valley is dominated by late Pleistocene surficial deposits of Lake Bonneville (Gilbert, 1890; Eardley and others, 1957; Currey and others, 1984; Currey and Oviatt, 1985; Solomon, 1993). The Bonneville lacustral cycle was coincident with the last global ice age of marine isotope stage 2, and lasted from about 28,000 to 13,000 years ago (Currey, 1990; Oviatt and others, 1992). Static levels of Lake Bonneville and the present Great Salt Lake are recorded by shoreline complexes, some of which are mapped within the Oquirrh fault zone. These shorelines are useful datums for evaluating latest Pleistocene and Holocene structure and stratigraphy.

Lake Bonneville began to rise from levels close to those of Holocene Great Salt Lake about 28,000 years ago (Oviatt and others, 1992), and transgression was well underway about 26,000 years ago (Currey and Oviatt, 1985). The Pilot Valley shoreline in northwest Utah marks a lacustrine oscillation during the early transgressional phase of Lake Bonneville (Miller and others, 1990), but this shoreline was not identified in Tooele Valley. The lake experienced a major, climatically induced oscillation between 22,000 and 20,000 years ago that produced the Stansbury shoreline (Oviatt and others, 1990), the oldest shoreline recognized in the Oquirrh fault zone (table 1). Shoreline deposits at the south end of Tooele Valley (the unnamed shoreline complex of Burr and Currey, 1988, 1992), and the equivalent shoreline elsewhere in the valley, mark what seems

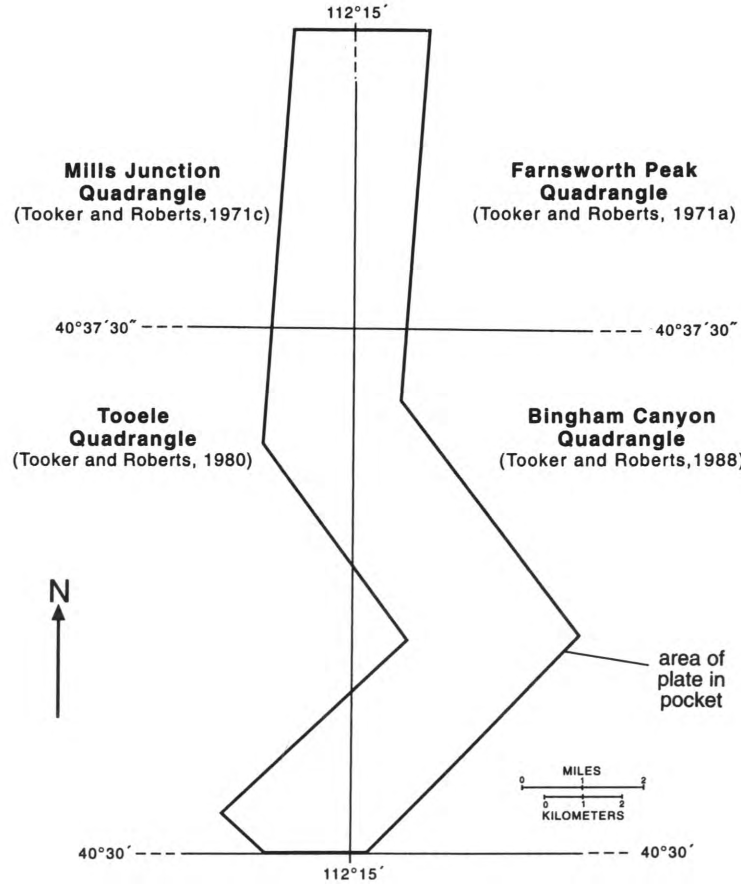

Figure 2. *Index map of 7.5-minute geologic quadrangle maps covering the Oquirrh fault zone. Geologic maps of Thomas (1946), Everitt and Kaliser (1980), and Solomon (1993) cover the entire fault zone.*

to be one or more important stillstands or moderate oscillations during the transgressive phase of the Bonneville lake cycle as the lake rose above the Stansbury level. Sack (1990), who referred to similar deposits reported elsewhere in Utah by previous researchers, applied the term "sub-Provo" to these deposits in Tule Valley of west-central Utah. This transgressive sub-Provo lake level formed between 20,000 and 17,700 years ago, and was so named because it lies just below the later, regressive Provo shoreline.

Lake Bonneville occupied its highest shoreline, which Gilbert (1875) named the Bonneville beach, after 16,400 years ago, and perhaps as late as 15,000 years ago (Currey and Oviatt, 1985). This shoreline was established by the stabilization of the lake level at an external basin overflow threshold. Prior to the lake transgression, Tooele Valley's drainage was integrated with that of adjacent Rush Valley (Gilluly, 1929). During the highest stage of Lake Bonneville, Rush Valley was an embayment separated from Tooele Valley by a strait between the two valleys near Stockton.

Headward erosion of the Snake River-Bonneville Basin drainage divide caused the catastrophic incision of the Zenda threshold in southern Idaho, which lowered the lake level 340 feet (105 m) in less than one year (Malde, 1968; Currey and others, 1983; Jarrett and Malde, 1987). After this rapid drop in the lake's surface elevation, Rush Valley was separated from Lake Bonneville behind a barrier bar that blocked the strait near Stockton. Rush Valley then became the site of a succession of independent pluvial lakes that include Lake Shambip, Lake Smelter, and Rush Lake (Burr and Currey, 1988, 1992).

Following this rapid regression, Lake Bonneville stabilized at a lower level controlled by the Red Rock Pass threshold. The prominent Provo shoreline formed at this level in Tooele Valley and elsewhere in the Bonneville Basin (Gilbert, 1875, 1890). Persistent landsliding in the flood-scoured threshold area caused the lake to fluctuate and form gravel beach ridges at different levels of the Provo shoreline complex (Burr and Currey, 1988, 1992; Burr, 1989). About 14,000 years ago climatic factors caused regression of the lake from the Provo level (Currey and Oviatt, 1985). In less than 2,000 years the lake dropped below the elevation of present Great Salt Lake. Transgression subsequently renewed and the earliest post-Bonneville oscillation, known as the Gilbert, began about 12,000 years ago (Murchison, 1989). The lake regressed sometime between 9,400 and 9,700 years ago, but rose again between 3,440 and 1,400 years ago. The rise resulted in the highest static lake level reached during the Holocene, commonly referred to as the Holocene high (Murchison, 1989).

In the Oquirrh fault zone, surficial Quaternary deposits that predate the highstand of Lake Bonneville are preserved above the highest shoreline of the lake. At lower elevations, subsurface equivalents underlie lacustrine deposits on piedmont slopes. These older surficial deposits include coarse- to fine-grained alluvial fans (Qaf_2, Qaf_3, and QTaf) and stream terraces (Qat_1, Qat_2, and Qat_3). Deposits from Quaternary lake cycles older than Lake Bonneville may be present at depth in the Oquirrh fault zone (Oviatt and Currey, 1987), but they are not found at the surface. Latest Pleistocene Lake Bonneville deposits are common in the western portion of the Oquirrh fault zone, and grade northward to Holocene deposits of Great Salt Lake. Lacustrine deposits include a thin veneer of material reworked from older alluvium (Qla), with local, thicker accumulations of fine- (Qlf) to coarse-grained (Qlg) sediments. Alluvium younger than the Lake Bonneville highstand (Qa, Qac, Qaf_1, and Qal), originating from drainages in the Oquirrh Mountains, locally overlies lacustrine and older alluvial deposits along the mountain front.

FAULTS AND QUATERNARY GEOLOGY

Exposures of the Oquirrh fault zone consist of a single, sinuous fault strand with discontinuous down-to-the-west normal fault scarps. The fault zone extends for 19 miles (31 km) along the western edge of the northern Oquirrh Mountains (figure 1). Helm (1994) postulates that the ends of the Oquirrh fault zone are controlled by older transverse crustal structures that also influence segment boundaries on adjacent normal fault zones (figure 3). The north end of the Oquirrh fault zone apparently

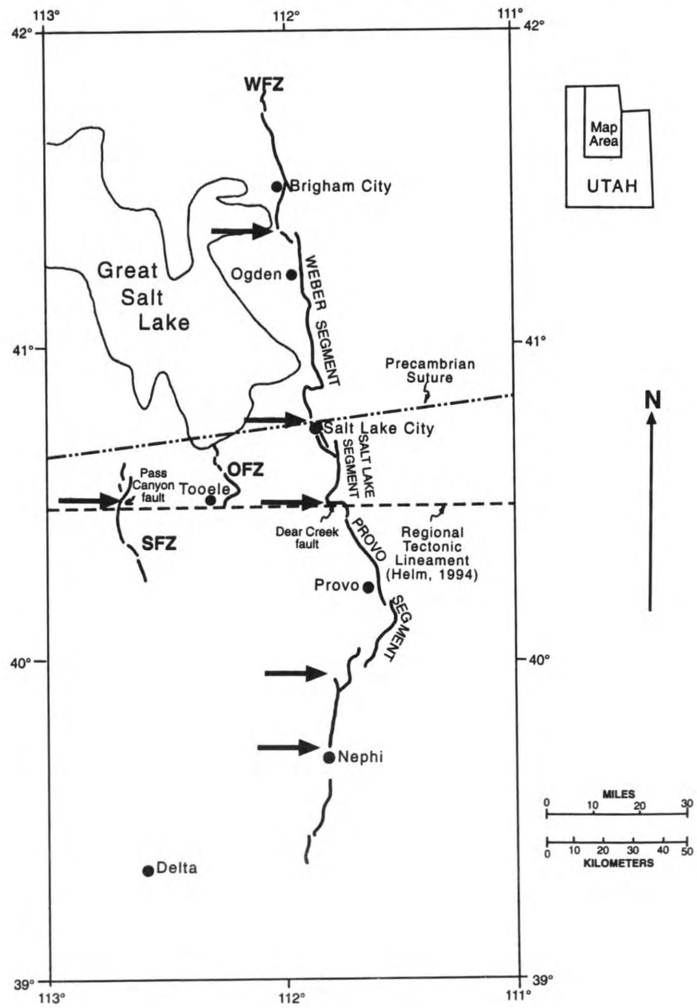

Figure 3. Transverse crustal structures that may influence fault zones in north-central Utah (modified from Helm, 1994, figures 1.14 and 2.2). Arrows point to fault-segment boundaries.

terminates at a supposed Precambrian suture that separates Proterozoic terrane accreted to an Archean craton. This same suture coincides with the north end of the Stansbury fault zone 25 miles (40 km) to the west, and with the Weber-Salt Lake City segment boundary of the Wasatch fault zone 25 miles (40 km) to the east. The south end of the Oquirrh fault zone apparently terminates at a lineament that crosses the Stansbury fault zone at the Pass Canyon fault, a segment boundary, and the Wasatch fault zone at the Deer Creek fault, which separates the Salt Lake and Provo segments.

The Oquirrh fault zone can be divided into three sections based on distinct topographic and geologic features (figure 1). This division is geographic and does not necessarily imply either segmentation of the fault zone or independent surface rupture on each section. The three sections are: (1) a northern section with roughly linear fault scarps in unconsolidated Quaternary lacustrine and alluvial deposits near the range front, (2) a central section with fault scarps in unconsolidated Quaternary lacustrine and alluvial deposits on the margin of an elevated spur (salient) that extends outward from the range front near Erda, and (3) a southern section with a fault scarp that forms the contact between bedrock and alluvium along an indentation (reentrant) in the range front with its axis near Pine Canyon. Paleoseismic studies have been conducted in the northern and cental sections, but have not been conducted in the southern section.

Northern, Linear Section

The northern section of the Oquirrh fault zone is 3.0 miles (4.8 km) long, from the vicinity of Lake Point to Coyote Canyon (plate 1). Its northernmost scarp is 1.0 mile (1.6 km) northeast of Lake Point and strikes N. 30° W. (figure 4). About 0.8 miles (1.3 km) to the south, the fault strike changes to N. 5° W., and scarps along the range front continue this trend intermittently for another 2.2 miles (3.5 km). Near the mouth of Coyote Canyon, the strike of the fault abruptly changes to N. 45° E. at the boundary between the northern and central sections of the Oquirrh fault zone. Two springs are present near the change in fault trend. The springs may result from upward seepage of ground water along one continuous fault or along the intersection of two independent faults; further study is needed to establish the relationship.

The surficial geology of the northern section is characterized by numerous latest Pleistocene to Holocene alluvial fans (Qaf_1) that extend westward from the range front for about a mile (1.6 km). The fan deposits locally bury the fault. Undifferentiated lacustrine and reworked, older alluvial deposits (Qla) are also common along this section of the fault zone and are cut by the fault. A narrow, unfaulted band of lacustrine gravel (Qlg) is typically present east of the fault zone between the Provo and Bonneville shorelines. These Quaternary units are in depositional contact with Paleozoic bedrock.

Six prominent lacustrine shorelines are found along the Oquirrh fault zone (table 1). They are all present near the northern section. The Bonneville, Provo, and sub-Provo shorelines are at higher elevations than the fault scarps, and the Gilbert shoreline and Holocene high are at lower elevations. Fault scarps are at both higher and lower elevations than the Stansbury shoreline, but their projected intersection east of Lake Point is concealed by younger alluvial fans (plate 1).

Barnhard and Dodge (1988) found evidence for recurrent faulting at the north end of the Oquirrh fault zone. They described three localities where the trace of the most-recent surface faulting diverges from an older scarp, and measured eight profiles on the compound scarp and four on single-event scarps. The compound scarp (maximum height 10.8 meters [35.4 ft]) is as much as twice as high as the most-recent single-event scarp (maximum height 4.8 meters [15.7 ft]). Olig and others (1994, this volume) excavated three trenches (BC-1, 2, and 3) across scarps at the north end of the Oquirrh fault zone, near the mouth of Big Canyon (plate 1). The trenches exposed faulted Lake Bonneville sediments and thick wedges of scarp-derived colluvium associated with the most-recent surface-faulting earthquake (MRE). Olig and others (1994, this volume) measured 2.2 meters (7.2 ft) of net vertical displacement (NVD) for the MRE. Based on a series of radiocarbon ages, they estimated that the

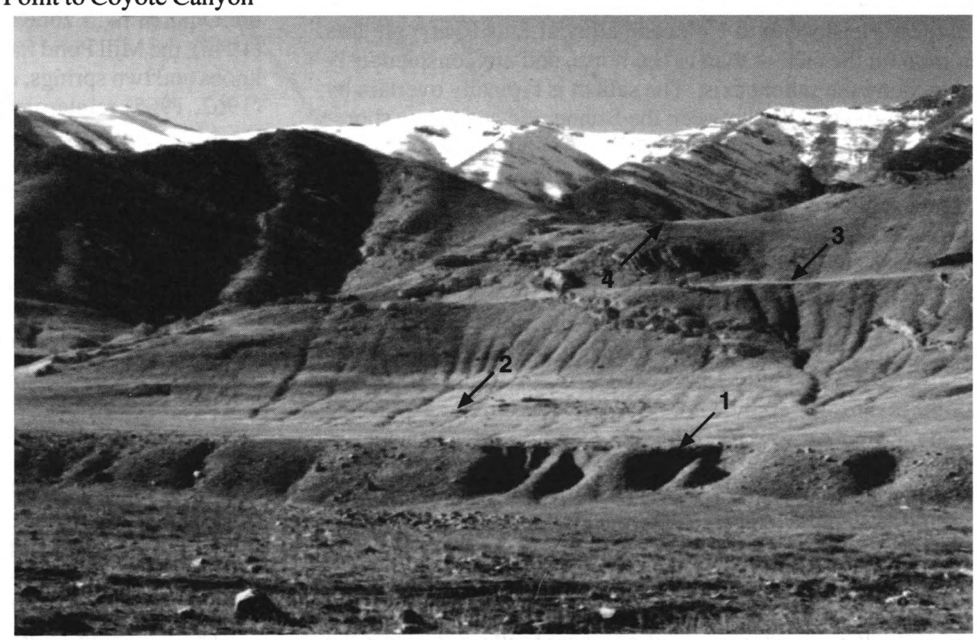

Figure 4. *Part of the northern, linear section of the Oquirrh fault zone, north of Rogers Canyon and 0.8 miles (1.3 km) east of Lake Point. The fault scarp (arrow 1) in undifferentiated lacustrine and alluvial deposits (Qla) is about 8 feet (2.4 m) high. The Stansbury shoreline of Lake Bonneville (arrow 2) forms a poorly defined notch near the base of the slope above the fault scarp; the Provo shoreline (arrow 3) forms the prominent bench midway up the foothills; the Bonneville shoreline (arrow 4), usually the most prominent of the Lake Bonneville shorelines in Tooele Valley, is poorly developed here in resistant bedrock.*

MRE occurred between 4,300 and 6,900 ^{14}C years ago (4,800 and 7,900 cal B.P.).

Only one other fault has been described in the valley fill near the north end of the Oquirrh fault zone. Tooker and Roberts (1971c) mapped a concealed down-to-the-west normal fault, about 0.6 miles (1.0 km) west of the Oquirrh fault zone near Lake Point (figure 5). However, their fault coincides with a linear lacustrine shoreline, and Solomon (1993) found no evidence of surface faulting in that area. Therefore, Tooker and Roberts' (1971c) fault is not included on the surficial geologic map of the Oquirrh fault zone.

Central, Erda Salient Section

South of Coyote Canyon near the town of Erda, the central section of the Oquirrh fault zone diverges from the range front and is found on a salient which extends from the Oquirrh Mountains to Adobe Rock (plate 1). The salient axis trends N. 45° W. The salient coincides with a relative gravity high, with gravity contours parallel to the salient margins (Johnson, 1958). Fault scarps are subparallel to the salient margins but cut across topographic contours. The scarps on the salient nose are as much as 1.1 miles (1.8 km) from the bedrock-alluvial contact along the mountain front, and continue intermittently around the salient southward for 4 miles (6 km). There is a gap 2 miles (3 km) long between fault scarps on the southwest salient margin but, where present near Flood Canyon at the south end of the salient, the scarps trend generally N. 25° W. (plate 1). A spring is present at the south end of the gap, reflecting upward seepage of ground water in the fault zone.

Latest Pleistocene to Holocene alluvial fans (Qaf_1) are less common on the salient than to the north, and are conspicuously absent along the salient axis. The salient is typically overlain by lacustrine gravel (Qlg) between the Bonneville and Provo shorelines, and by undifferentiated lacustrine and reworked, older alluvial deposits (Qla) below the Provo shoreline on the salient margins. Isolated Paleozoic bedrock knobs are clustered on the axis and southern margin of the salient. Fault scarps are commonly restricted to undifferentiated lacustrine and alluvial deposits (Qla), but offset one alluvial fan (Qaf_1) in the SW¼ section 36, T. 2 S., R. 4 W. The Bonneville shoreline is consistently at higher elevations than the fault scarps, the Stansbury shoreline is consistently lower, and the Provo and sub-Provo shorelines are offset by fault scarps. The Gilbert shoreline bounds the salient to the north and extends southwestward out of the mapped area, where it is associated with a spit that is a prominent feature of the regressive phase of Lake Bonneville (Eardley and others, 1957). A smaller spit at the Stansbury level is present just west of the map boundary, extending southward from the salient nose (figure 6) (Solomon, 1993).

Barnhard and Dodge (1988) studied the central section of the Oquirrh fault zone at three localities where fault scarps cross the Provo shoreline. They measured four scarp profiles for the MRE at these localities and compared them with regression-equation lines for the approximately 9,000-year-old fault scarps in the Drum Mountains, Utah, and the 15,000-year-old Bonneville shoreline scarp. The comparison, and relation between the Oquirrh fault scarp and Provo shoreline, suggested to Barnhard and Dodge (1988) that the age of the MRE on the Oquirrh fault zone was close to, but not more than, 13,500 years ago. This is older than the age of the MRE determined at Big Canyon by Olig and others (1994, this volume), but Barnhard and Dodge (1988) may have profiled multiple-event scarps. Older parts of the scarps were likely modified by Lake Bonneville erosion and deposition, and this additional scarp degradation may have led to an overestimate of the age of the MRE.

Olig and others (1994, this volume) excavated one trench (PC-1) across a scarp on the central section near the mouth of Pole Canyon (plate 1). The trench exposed stratigraphic and structural evidence for both a pre-Bonneville lake-cycle penultimate earthquake (PE) and a post-Bonneville MRE. Indirect stratigraphic evidence was also present for an antepenultimate event (APE). Olig and others (1994, this volume) measured 2.7 meters (8.9 ft) of NVD associated with the MRE and 2.3 meters (7.5 ft) of NVD associated with the PE. They estimated that the PE occurred between 20,300 and 26,400 ^{14}C years ago, and the APE occurred sometime before 32,800 ^{14}C years ago. Stratigraphic evidence at the Pole Canyon trench supported the age of the MRE determined at Big Canyon, but no suitable material was found at Pole Canyon for radiocarbon dating.

Several other faults have been mapped and described in valley fill near the central section of the Oquirrh fault zone (figure 5), but Solomon (1993) found no evidence that any of these faults displace surficial deposits and they are not shown on plate 1. These faults include the Mill Pond fault, the Erda fault, and four unnamed faults. The longest fault near the central section is the Mill Pond fault, a north-trending structure on the western margin of the salient, about 0.6 miles (1.0 km) west of the Oquirrh fault zone map boundary. As mapped by Thomas (1946), the Mill Pond fault passes near several Paleozoic bedrock knobs and two springs, and acts as a ground-water barrier. Gates (1962, 1965) reinterpreted ground-water data in the vicinity of the Mill Pond fault and suggested a northwest trend for that structure, an orientation reproduced by Tooker and Roberts (1971c). Everitt and Kaliser (1980) mapped a fault with apparent surface displacement which approximately coincides with the southeastern extension of the Mill Pond fault as mapped by Gates (1965) in the E½ section 26, T. 2 S., R. 4 W. However, Solomon (1993) mapped unfaulted Holocene alluvial fans in the same location as part of Everitt and Kaliser's (1980) fault. The linear feature mapped as a fault by Everitt and Kaliser (1980) may actually be minor lacustrine shorelines which are locally common.

The Erda fault was described, but not mapped, by Thomas (1946) as a north-trending structure about 2.5 miles (4.0 km) west of the Mill Pond fault. Thomas (1946) indicated that the Erda fault acted as a ground-water barrier, but Gates (1965) discounted the presence of the Erda fault based on gravity data and the piezometric water surface in 1962.

The unnamed faults near the central section of the Oquirrh fault zone (figure 5) include: (1) a small, north-trending fault mapped by Thomas (1946) near Paleozoic bedrock knobs on the west flank of the salient, about 2 miles (3 km) west of the Oquirrh range front and 0.25 miles (0.4 km) east of the Mill Pond fault; (2) a northeast-trending fault mapped by Tooker and Roberts

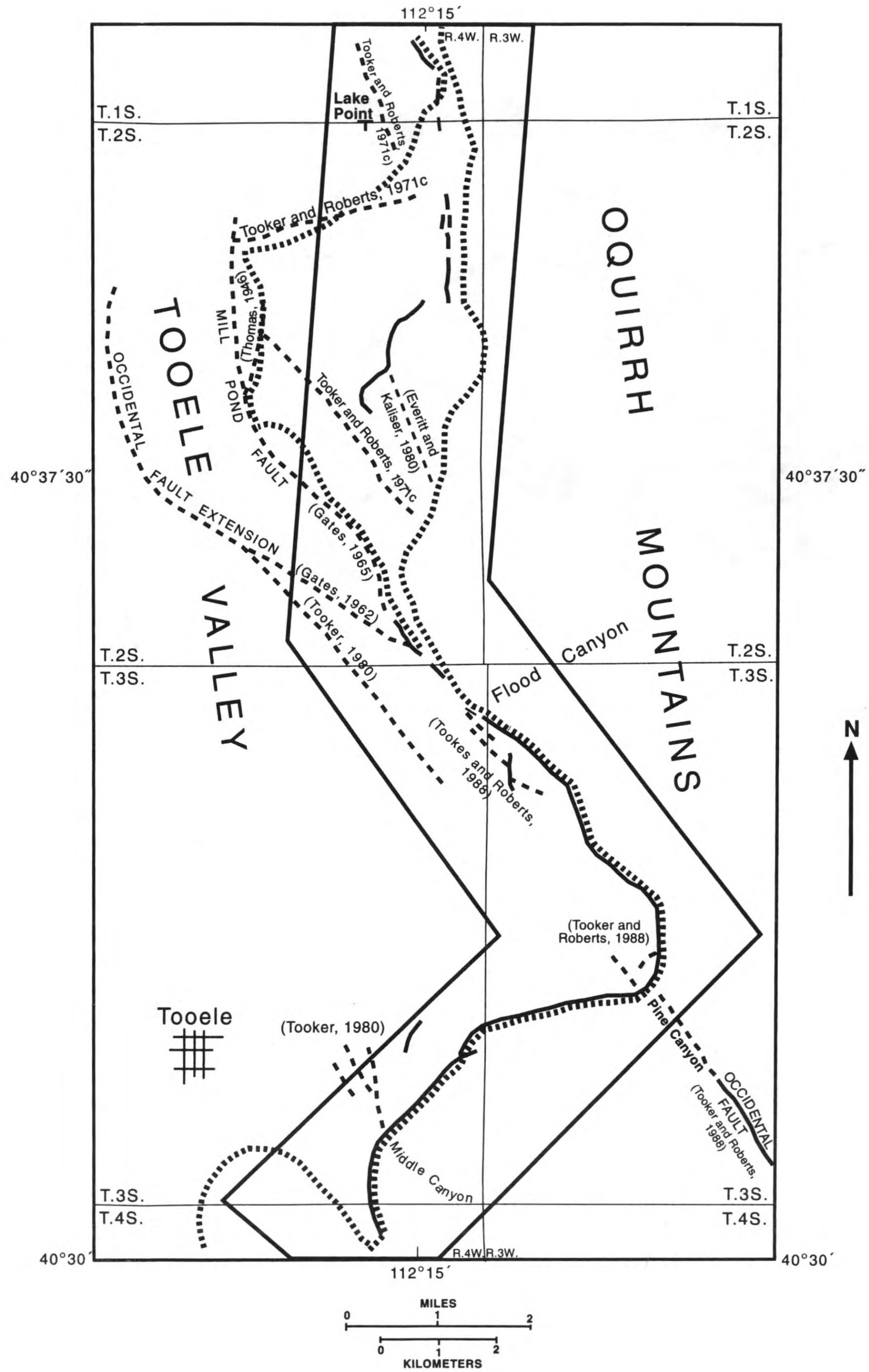

Figure 5. Index map of the Oquirrh fault zone (unlabeled solid line [and other reported faults] dashed except for the Occidental fault). Most reported faults do not offset the surface, but those northwest of Flood Canyon may be associated with a subsurface bedrock platform that underlies the Erda salient.

Figure 6. A spit at the Stansbury level of Lake Bonneville extends south from the Erda salient, 0.7 miles (1.1 km) east of Stansbury Lake. Spit morphology indicates a southerly direction of longshore current (Currey, 1980). The west side of the spit (arrow) has been excavated for gravel.

(1971c) along the salient's north margin; (3) a northwest-trending fault mapped by Tooker and Roberts (1971c) about 0.6 miles (1.0 km) northeast of the Mill Pond fault and, at its southern extremity in the SE¼ section 23, T. 2 S., R. 4 W., remapped as two small faults by Everitt and Kaliser (1980); and (4) a northwest-trending fault mapped by Everitt and Kaliser (1980) in the W½ section 24, T. 2 S., R. 4 W.

Although Solomon (1993) found no evidence that any of these faults offset surficial material, previously cited hydrologic data suggest that some of them may exist in the subsurface. These older faults may have uplifted a bedrock platform coincident with the relative gravity high mapped by Johnson (1958), which underlies the Erda salient. The linear salient margins, parallel gravity contours, and intra-salient lineaments reflect underlying bedrock structure. The platform was subsequently submerged in Lake Bonneville. Scattered Paleozoic bedrock knobs project through the younger lacustrine deposits, but the continuity of Lake Bonneville shorelines demonstrates the absence of recent surface faulting.

Southern, Pine Canyon Reentrant Section

The southeast-trending scarp of the Oquirrh fault zone on the south margin of the Erda salient continues to the southeast and merges with a range-front scarp. The range-front scarp bounds a topographic reentrant with its apex at the mouth of Pine Canyon (figure 7). The north limb of the reentrant is 3.5 miles (5.6 km) long, and the south limb 4.0 miles (6.4 km) long. On the north limb, the scarp trends generally N. 40° W. between Flood and Swensons Canyons, but curves toward the south between Swensons and Pine Canyons. On the south limb, the scarp forms an arcuate pattern and trends from about N. 70° E. near Pine Canyon to almost north-south near Middle Canyon, where the south end of the Oquirrh fault zone is 2.0 miles (3.2 km) southeast of Tooele City. A spring is found at the south end of the fault.

The range-front scarp in the reentrant is entirely above the Lake Bonneville highstand. The piedmont slope below the scarp is on older alluvial-fan deposits (QTaf), which are incised by alluvial channels and locally overlain by alluvial deposits that are both older and younger than the Lake Bonneville highstand. The relative age of these alluvial deposits was determined by the relative elevation of adjacent geomorphic surfaces, degree of dissection, and relation to the Bonneville shoreline. Deposits that predate the Lake Bonneville highstand are Pleistocene alluvial fans (Qaf_2 and Qaf_3) and terraces (Qat_1, Qat_2, and Qat_3). Deposits that postdate the Lake Bonneville highstand are latest Pleistocene to Holocene alluvial fans (Qaf_1), alluvial channels and flood plains (Qal), and slopes with mixed alluvial and colluvial components (Qac). Unconsolidated deposits in fault contact with Paleozoic bedrock are predominantly QTaf, but locally include Qat_2, Qat_3, and Qac. Units Qat_2 and Qaf_3 are in fault contact in a small area on the south side of Pine Canyon, and QTaf is faulted 1.9 miles (3.1 km) further southwest. Units Qaf_1, Qal, and Qac locally overlie and conceal the fault.

No detailed paleoseismic investigations have been conducted in this section of the Oquirrh fault zone, but Olig and others (1994, this volume) suggest that the range-front scarp of the southern section is part of the same rupture segment as scarps further north. They reached this conclusion because their estimates of expected fault-rupture length, based on earthquake magnitudes estimated from observed fault displacements in trenches, exceed the combined length of the northern and central sections. Therefore, they assume that this southern section of the fault zone must be part of a single seismographic fault segment.

Farmin (1933) and Thomas (1946) concluded that the fault scarp along the north limb of the Pine Canyon reentrant was an extension of the Occidental fault. The Occidental fault is mapped in bedrock from the head of Pine Canyon, southeast across the Oquirrh Mountains summit, into the west edge of the Bingham mining district (James and others, 1961) (figure 5). Gates (1962) proposed a further extension of the Occidental fault into Tooele Valley, northwest from the north limb of the reentrant, and then northward to the shore of Great Salt Lake. Gates (1962) cited as evidence for the fault differences in water-level

Figure 7. *A slag pile (arrow 1) near the International smelter in the Pine Canyon reentrant was graded to the level of the Bonneville shoreline of Lake Bonneville during reclamation activities (Braxton and Buck, 1989). The foreground is underlain by undifferentiated lacustrine and alluvial deposits (Qal). The midground, between the shoreline and bedrock in the Oquirrh Mountains, is underlain by pre-Bonneville alluvial-fan deposits (QTaf). The alluvial-fan deposits and bedrock are in fault contact along the reentrant limbs, which exhibit faceted spurs (arrow 2).*

fluctuations, chemical quality of ground water, altitude of the piezometric surface, and gravity on either side of a discontinuous ridge in the Erda area. On the Oquirrh fault zone map (plate 1), the ridge coincides with several Paleozoic bedrock knobs that are aligned diagonally to the northwest near the center of section 35, T. 3 S., R. 4 W. Later, Gates (1965) mapped the valley extension of the Occidental fault as originally described by Gates (1962), and Tooker and Roberts (1971c) mapped the northern portion of the fault where it was postulated by Gates (1962) in the Mills Junction quadrangle south of the lake shore. However, Tooker (1980) mapped the valley portion of the Occidental fault as an extension of the bedrock fault from the mouth of Pine Canyon, rather than as an extension of the bedrock-alluvial fault on the north limb of the reentrant as mapped by Gates (1962) (figure 5). Thus, the valley extension of Tooker (1980) is aligned with a linear stream channel about 0.4 miles (0.6 km) southwest of the discontinuous ridge coincident with the extension proposed by Gates (1962).

Data from new wells drilled in the vicinity of the valley extension of the Occidental fault suggested to Razem and Steiger (1981) that the fault is not a barrier to ground-water movement, and differences in chemical quality are a function of depth rather than faulting. They concluded, however, that the fault probably exists and may be partly responsible for a steep hydraulic gradient in the area. Solomon (1993) found no evidence that a valley extension of the Occidental fault offsets surficial deposits, and agrees with Razem and Steiger (1981) that the fault probably exists but predates the deposition of surficial deposits. As with other older, previously described faults in the valley, Lake Bonneville shorelines demonstrate the continuity of surficial beds overlying the valley extension of the Occidental fault.

Several smaller faults were also mapped near the Pine Canyon reentrant in previous studies (figure 5). Near Middle Canyon, in section 26, T. 3 S., R. 4 W., Tooker (1980) mapped three northwest-trending linear scarps as faults. Everitt and Kaliser (1980) mapped the same scarps as features of "erosional or undetermined origin," but Solomon (1993) recognized the scarps as risers along the edges of three adjacent terrace levels (Qat_1 through Qat_3 in this study). At the mouth of Flood Canyon, in section 1, T. 3 S., R. 4 W., and sections 6 and 7, T. 3 S., R. 3 W., Tooker and Roberts (1988) mapped four northwest-trending faults, but three of these coincide with the Bonneville shoreline complex mapped by Solomon (1993) and the fourth coincides with a stream channel. Tooker and Roberts (1988) also mapped two small faults in Quaternary alluvium near the mouth of Pine Canyon, in section 20, T. 3 S., R. 3 W., but Solomon (1993) found no evidence of faulting; the linear features are related to stream channels. However, one small scarp in the reentrant vicinity is apparently fault related. North of Middle Canyon, in sections 24 and 25, T. 3 S., R. 4 W., Everitt and Kaliser (1980) mapped a fault that was confirmed by Solomon (1993). The linear scarp is about 0.4 miles (0.6 km) long, trends N. 20° E., shows down to the west displacement, and cuts across contours above the Bonneville shoreline (plate 1). The relationship between this small fault and the main trace of the Oquirrh fault zone, 0.6 miles (1.0 km) to the southeast, is undetermined.

DESCRIPTION OF MAP UNITS

Plate 1 shows bedrock units, major bedrock structural relations, surficial deposits, piedmont fault scarps, and six regional shorelines in and adjacent to the Oquirrh fault zone. Each shoreline is actually a complex of shorelines that record minor lake fluctuations. With the exception of the sub-Provo, the highest static level of each shoreline complex is mapped; the most prominent shoreline of the sub-Provo is mapped (table 1).

I designated map units with a combination of upper-case letters, lower-case letters, and numerical subscripts (table 2). Upper-case letters represent the age of the unit; the units are subdivided into Paleozoic sedimentary rocks within each of three thrust nappes (sheetlike, thrust-transported rock sequences), Tertiary intrusive igneous rocks, unconsolidated or semi-consolidated deposits that encompass parts of both the Quaternary and Tertiary, and Quaternary unconsolidated deposits. A lower-case letter follows the age designation and describes either: (1) the

Table 1.
Age, elevation, and occurrence of prominent lacustrine shorelines in Tooele Valley. References for shoreline ages are cited in text. Elevations are of the highest static level of each shoreline complex, except for the most prominent level of the sub-Provo. Shoreline elevations in the Bonneville basin vary because of differential crustal rebound from isostatic compensation as Lake Bonneville receded (Crittenden, 1963; Currey, 1982), and from regional tectonics. NL - Northern, linear section of the Oquirrh fault zone OFZ; CES - Central, Erda salient section of the OFZ; SPR - Southern, Pine Canyon reentrant section of the OFZ.

Shoreline	**Age (years B.P.)**	**Elevation (ft)**	**Occurrence**		
			NL	**CES**	**SPR**
Stansbury	22,000 - 20,000	4,495 - 4,510	Above and below OFZ	Below OFZ	Below OFZ
Sub-Provo	20,000 - 17,700	4,795 - 4,805	Above OFZ	Above and below OFZ	Below OFZ
Bonneville	16,400 - 15,000	5,215 - 5,280	Above OFZ	Above OFZ	Below OFZ
Provo	15,000 - 14,000	4,855 - 4,875	Above OFZ	Above and below OFZ	Below OFZ
Gilbert	12,000 - 9,400	4,255 - 4,265	Below OFZ	Below OFZ	Below OFZ
Holocene highstand	3,440 - 1,400	4,221	Below OFZ	Below OFZ	Below OFZ

Table 2.
Symbols used for geologic map units.

SEDIMENTARY ROCKS		
Upper-Case Letter: age		
M = Mississippian	IP = Pennsylvanian	P = Permian
Lower-Case Letter: thrust nappe		
p = Pass Canyon	b = Bingham	r = Rogers Canyon
IGNEOUS ROCKS		
Upper-Case Letter: age	**Lower-Case Letter: lithology**	
T = Tertiary	p = Intrusive porphyritic dikes and sills	
UNCONSOLIDATED AND SEMI-CONSOLIDATED DEPOSITS		
Upper-Case Letter: age	T = Tertiary	Q = Quaternary
First Lower-Case Letter: depositional environment	**Second Lower-Case Letter: depositional subenvironment or material modifier**	
a = alluvial	c = colluvial component	l = low-level flood plain and channel
	f = fan	t = terrace
f = fill	t = tailings and slag	
l = lacustrine	a = alluvial component	g = gravel
	f = fine-grained (mud)	
m = mass movement	t = talus	
p = playa	m = mud	
Numerical subscript: relative age indicator of similar deposits		
1	youngest	
2	intermediate age	
3	oldest	

name of the thrust nappe on which Paleozoic rocks are found, (2) the texture of Tertiary igneous rocks, or (3) the general environment of deposition of Tertiary and Quaternary unconsolidated or semi-consolidated deposits. A second lower-case letter associated with unconsolidated or semi-consolidated units either describes the subenvironment of deposition or is a material modifier. Material modifiers also supply information about the depositional subenvironment because many geologic materials are characteristically deposited in certain geologic environments. Some map units are further represented by a numerical subscript which indicates relative age within a group of similar deposits. The approximate correlation of Quaternary map units and their relation to lacustrine shorelines is given in figure 8.

Bedrock

Bedrock units exposed in the Oquirrh Mountains are not shown in detail on this map. The entire bedrock section, which ranges from Mississippian to Tertiary in age, is divided into four generalized units. The outcrop pattern of these units provides information about source rocks for alluvial and colluvial units and major structural relations within the Oquirrh Mountains. Descriptions and thicknesses of units are summarized from Tooker and Roberts (1971a, 1971c, 1988) and Tooker (1980). For more information, consult these detailed bedrock geologic maps of the area (figure 2).

Rogers Canyon Nappe (PMr)

An allochthonous (thrust-transported), complexly folded and faulted sequence of sedimentary rocks on the Rogers Canyon nappe crops out in the northeast part of the mapped area from Bates Canyon northward. The sequence is underlain by the North Oquirrh thrust fault system, one of several regional thrust faults produced during the late Mesozoic Sevier orogeny (the process by which geologic structures within fold-belt mountainous areas were formed) (Tooker, 1983). Part of the North Oquirrh thrust fault system is mapped in the E½ section 25, T. 2 S., R. 4 W., and in the NW¼ section 30, T. 2 S., R. 3 W. (plate 1).

Rocks on the Rogers Canyon nappe include the Lake Point Limestone and the Erda, Kessler Canyon, and Park City Formations. These rocks consist predominantly of sandstone, quartzite, limestone, and dolomite, and are about 9,840 feet (3,000 m) thick. Gordon and Duncan (1970) consider the Lake Point Limestone to be Upper Mississippian (late Chester) and Lower Pennsylvanian (Morrow), the Erda Formation to be Middle Pennsylvanian (Desmoines), the Kessler Canyon Formation to be Lower Permian (?) and Upper Pennsylvanian (Missouri), and the Park City Formation to be Lower Permian. All units on the Rogers Canyon nappe except the Park City Formation are part of the Oquirrh Group, a sequence of Paleozoic marine strata more than 3 miles (5 km) thick that make up most of the Oquirrh Mountains (Tooker and Roberts, 1970).

Bingham Nappe (IPb)

Complexly folded and faulted sedimentary rocks on the Bingham nappe crop out in the southeast part of the mapped area, south of Pole Canyon. These rocks are in the upper plate of the Midas thrust fault system, another regional thrust fault produced during the Sevier orogeny (Tooker, 1983). The Midas thrust fault system is not mapped near the Oquirrh fault zone; the north edge of the Bingham nappe is bounded in the mapped area (SW¼ section 16, SE¼ section 17, NE¼ section 20, and NW¼ section 21, T. 3 S., R. 3 W.) by a younger extensional feature named the Tooele fault by Tooker and Roberts (1988) (plate 1).

Rocks on the Bingham Nappe are divided into the Butterfield Peaks Formation and the Bingham Mine Formation. Both for-

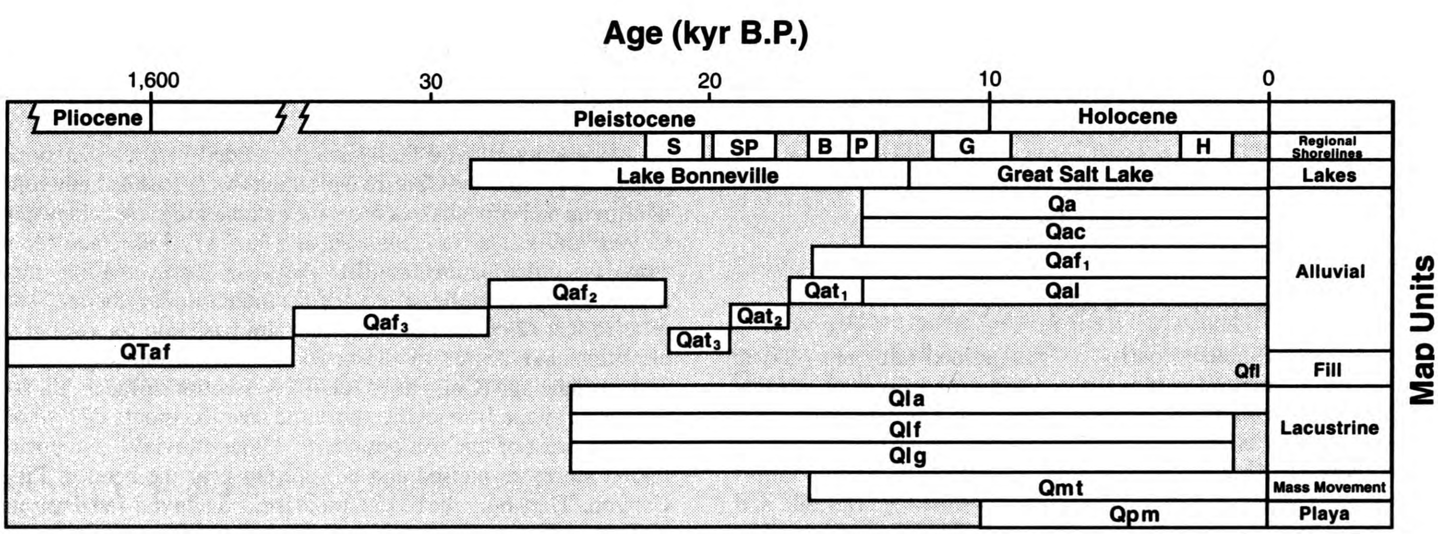

Figure 8. *Approximate correlation of surficial geologic map units, and relation to lacustrine shorelines in the Oquirrh fault zone (S-Stansbury, SP-sub-Provo, B-Bonneville, P-Provo, G-Gilbert, H-Holocene highstand).*

mations consist predominantly of sandstone, quartzite, and limestone. At their type localities, the Butterfield Peaks Formation is about 8,990 feet (2,740 m) thick and the Bingham Mine Formation is about 7,320 feet (2,230 m) thick (Tooker and Roberts, 1970). Gordon and Duncan (1970) consider the Butterfield Peaks Formation to be Middle Pennsylvanian (Desmoines) and the Bingham Mine Formation to be Upper Pennsylvanian (Missouri). Both units are part of the Oquirrh Group.

Pass Canyon Nappe (Pp)

An allochthonous, complexly folded and faulted sequence of sedimentary rocks on the Pass Canyon nappe crops out in the east-central part of the mapped area between Bates and Pole Canyons. This nappe is underlain by an unexposed, unnamed thrust fault produced during the Sevier orogeny (Tooker, 1983). In the mapped area (plate 1), the Pass Canyon nappe is bounded on the north by part of the North Oquirrh thrust fault system and on the south by the Tooele fault.

Tooker and Roberts (1988) provisionally divided rocks on the Pass Canyon nappe into the Dry Fork unit, consisting predominantly of sandstone, siltstone, shale, and quartzite, and the Flood Canyon unit, consisting predominantly of sandstone, quartzite, dolomite, and limestone. It is not possible to determine a reliable thickness for these rocks because of their structural complexity. Welsh and James (1961) believe the rocks of the Pass Canyon nappe are a Lower Permian (Wolfcamp) part of the Oquirrh Group.

Porphyritic Dikes and Sills (Tp)

Undifferentiated small dikes and sills form a northeast-trending zone south of Tooele in the Markham Peak Member of the Upper Pennsylvanian Bingham Mine Formation, in the Bingham nappe. The northeast margin of this zone is in the southwest corner of the mapped area. These intrusive bodies are 3 to 15 feet (1-5 m) thick and are mainly quartz monzonite to quartz latite porphyries; some are terminated by northeast-trending normal faults. The most prominent sill, which crops out about 0.5 miles (0.8 km) northwest of intrusive bodies in the map area, has been dated at 38.6 million years, making it Oligocene in age (Moore, 1973).

Alluvial Deposits

Undifferentiated Alluvium (Qa)

Undifferentiated, coarse- to fine-grained alluvium (Qa) is present on gentle slopes near the confluence of several streams that drain the Oquirrh Mountains between Pass and Pine Canyons. Deposits are associated with low-order stream channels that lack well-defined flood plains. Undifferentiated alluvium is primarily sandy, with lesser amounts of boulders, gravel, silt, and clay. Deposits are generally less than 10 feet (3 m) thick. The unit is present below the Bonneville shoreline, obscures shorelines etched into the adjacent piedmont slope, and is thus of post-Bonneville age. The deposits range in age from latest Pleistocene to latest Holocene.

Alluvium and Colluvium (Qac)

Alluvium with a significant colluvial component (Qac) is locally present in Pole and Pine Canyons in first-order drainages and on wash slopes. The unit contains poorly sorted clay, silt, sand, gravel, cobbles, and boulders, and includes stream-reworked colluvium. Deposits are coarser on steeper slopes and are generally less than 10 feet (3 m) thick. These deposits are latest Pleistocene to latest Holocene in age.

Alluvial-Fan Deposits Younger Than the Bonneville Shoreline (Qaf_1)

Alluvial-fan deposits that postdate the highstand of Lake Bonneville (Qaf_1) include coarse- to fine-grained alluvium and debris-flow sediments deposited on piedmont slopes primarily after regression of the lake from the Bonneville shoreline. Most younger alluvial-fan deposits are found below the Bonneville level and obscure regressive shorelines. Fan apices are typically at either the Bonneville or Provo shoreline scarps. The small deposits of Qaf_1 found above the Bonneville level between Flood and Middle Canyons may partially consist of sediment deposited before Bonneville-shoreline time. In some places, individual alluvial fans are differentiated within alluvial-fan deposits younger than the Bonneville shoreline. These fans may represent multiple periods of deposition, but their relative ages are generally similar and all are included in this unit.

The deposits contain mostly sand and gravel reworked from underlying lake beds, and their texture generally becomes finer down the fan slope. Qaf_1 deposits are thickest near fan apices and thin to a feather edge toward the basin, but are generally less than 10 feet (3 m) thick. The deposits have been accumulating from latest Pleistocene time to the present.

Alluvial-Fan Deposits Older Than the Bonneville Shoreline (Qaf_2, Qaf_3, and QTaf)

Coalescing alluvial fans have developed bajadas that slope gently away from the Oquirrh Mountain front. Isolated outcrops of alluvial-fan deposits that form the bajadas are present between Coyote and Bates Canyons east of Stansbury Lake, and more extensive outcrops are found to the south between Flood and Middle Canyons in the vicinity of the International smelter. The relative age categories of these fans are based on their relative elevation and degree of dissection. Alluvial-fan deposits of intermediate age (Qaf_2) have relatively smooth surfaces and are truncated by the Bonneville shoreline near the mouth of Middle Canyon, west of the map boundary. Older alluvial-fan deposits (Qaf_3) are more incised and are present near the head of Pine Canyon. They bury the oldest, most incised alluvial-fan deposits (QTaf). Alluvial-fan deposits older than the Bonneville shoreline are generally less than 20 feet (6 m) thick in mountain-front locations, but thicken away from the mountain front and probably underlie lacustrine sediments in the valley. These alluvial-fan deposits do not crop out below the highest shoreline of Lake Bonneville; the fans were abandoned when, or before, the lake regressed from that level.

There has been considerable confusion regarding the age of abandoned alluvial-fan deposits in Tooele Valley. Thomas (1946) originally included them in the Salt Lake Formation of Pliocene and Pleistocene (?) age. This age was based on the stratigraphic position of the deposits between a Miocene (?) tuff unit and Pleistocene Bonneville lake beds. Slentz (1955a) redefined deposits in Tooele and Jordan (Salt Lake) Valleys that are younger than the Eocene Wasatch Formation but older than Pleistocene Lake Bonneville deposits as the Salt Lake Group of Tertiary age, and restricted the youngest alluvial-fan deposits in the group to the Harkers Fanglomerate of Pliocene age. The age of the Harkers Fanglomerate was based on stratigraphic position, geomorphic expression, and lithologic characteristics (Slentz, 1955a, 1955b). Tooker and Roberts (1971b) renamed the unit, at its type section in Harkers Canyon on the eastern margin of the Oquirrh Mountains in Jordan Valley, the Harkers Alluvium "because of its great size distribution and unindurated nature." They also assigned an early Pleistocene age to the unit because of its unconsolidated nature and stratigraphic position. This nomenclature and age were extended to similar deposits on the western margin of the Oquirrh Mountains in Tooele Valley (Tooker and Roberts, 1971a, 1988, 1992; Tooker, 1980). However, in western Tooele Valley on the eastern margin of the Stansbury Mountains, Rigby (1958) variously described similar deposits as Quaternary alluvium, Quaternary alluvial fanglomerate and gravel, Quaternary and Tertiary alluvial gravel, and Tertiary Salt Lake Formation, the latter unit consisting of the consolidated portion of the deposits.

No fossil or other evidence has been found in these alluvial-fan deposits to provide a definitive age. Because they occupy a stratigraphic position between consolidated deposits of known Tertiary age and unconsolidated latest Pleistocene lake beds, Solomon (1993) assigned a Pleistocene age to younger, less incised deposits in Tooele Valley (Qaf$_2$ and Qaf$_3$), whereas older, more incised deposits (QTaf) may be as old as Pliocene.

Alluvium in Channels and Flood Plains (Qal)

Alluvial-channel and flood-plain deposits (Qal) consist of sand, silt, and clay beds with thin gravel layers and lenses. Deposits are generally less than 10 feet (3 m) thick. These deposits typically extend from alluvial channels in bedrock to channels and associated flood plains on adjacent piedmont slopes. When the deposits extend through the Bonneville shoreline, they are found in channels that dissect the Bonneville abrasion platform. The deposits are predominantly of post-Bonneville shoreline age, but range from latest Pleistocene to latest Holocene.

Alluvial-Terrace Deposits (Qat$_1$, Qat$_2$, and Qat$_3$)

Alluvial-terrace deposits form thin veneers, less than 10 feet (3 m) thick, on lithologically similar older alluvial-fan deposits. Terrace deposits are found on long, narrow, gently inclined surfaces elevated above active channels and flood plains. These surfaces are bounded along their edges by steep slopes, or risers. Three terrace levels are present along major drainages in the map area. The relative age of each terrace deposit is based on the degree of terrace incision, relative elevation of adjacent geomorphic surfaces, and relation of terraces to the highest shoreline of Lake Bonneville. The youngest alluvial-terrace deposits (Qat$_1$) are truncated by the Bonneville shoreline near the mouths of all major canyons between Pole and Middle Canyons. Alluvial-terrace deposits of intermediate age (Qat$_2$) parallel younger terrace deposits at higher elevations along Middle Canyon, and along Dry, Pine, and Swensons Canyons, near the International smelter. Terrace deposits near the smelter were extensively modified during reclamation of the smelter and associated tailings (Braxton and Buck, 1989). The oldest alluvial-terrace deposits (Qat$_3$) are found only near Middle Canyon, where Everitt and Kaliser (1980) mapped three linear scarps "of erosional or undetermined origin" that are actually risers along the edges of the three terrace levels.

All alluvial-terrace deposits predate the regression of Lake Bonneville from its highest level, but the oldest alluvial-terrace deposits (Qat$_3$) are incised into intermediate age alluvial-fan deposits (Qaf$_2$) near Middle Canyon. Thus all alluvial-terrace deposits are of latest Pleistocene age.

Lacustrine Deposits

Undifferentiated Lacustrine and Alluvial Deposits (Qla)

Much of the surficial material within the piedmont zone below the Bonneville shoreline is mapped as undifferentiated lacustrine and alluvial deposits (Qla). This unit consists of alluvial-fan deposits of pre-Bonneville lake-cycle age that were reworked by lacustrine processes. As a result, the mapped area contains alluvial-fan deposits overlain by a thin cover of lacustrine sediment, generally less than 10 feet (3 m) thick. The lacustrine sediment is coarser grained in the proximal piedmont sector, and finer grained in the distal sector, because the pre-lake fan material was finer near the distal end of the fan. Geomorphically, the unit consists of still recognizable pre-Bonneville alluvial fans etched by Lake Bonneville shorelines. This unit is of latest Pleistocene to earliest Holocene age.

Lacustrine Mud (Qlf)

Fine-grained lacustrine deposits (Qlf) present in northern and central Tooele Valley are exposed in the northwest corner of the Oquirrh fault zone near Lake Point. This unit is generally less than 30 feet (9 m) thick, and consists of silt and clay with subordinate sand and marl. The unit was deposited in quiet water, either offshore in deeper water of Lake Bonneville, or nearshore in the bay of Great Salt Lake in northeastern Tooele Valley. At the north end of Tooele Valley near Great Salt Lake this unit contains elliptical depressions from 5 to 50 feet (2 to 15 m) in diameter (Solomon, 1993). Many of the depressions are surrounded by a raised rim of sand, and springs emanate from some of them. Depressions without springs are commonly plugged with dark, peaty clay. These features superficially resemble paleo-liquefaction-induced sand blows, but they may also be due to upward ground-water flow under artesian pressure (Obermeier and others, 1990). This unit is of latest Pleistocene to earliest Holocene age.

Lacustrine Gravel (Qlg)

Shoreline gravel deposited by Lake Bonneville and Great Salt Lake (Qlg) is generally thin, but may be up to 30 feet (9 m) thick in some barrier beaches, and up to 200 feet (60 m) thick in elevated benches along the Oquirrh Mountains east of Erda. The gravel is derived from alluvial fans along the range front, and is typically interbedded with significant layers of sand and minor amounts of cobbles. The proportion of sand increases, and the proportion of cobbles decreases, with distance from the mountains. This reflects distance from bedrock source areas, as well as the finer grain size of the distal portions of underlying alluvial-fan deposits. Most lacustrine gravel was deposited during the transgressive phase of Lake Bonneville and is of latest Pleistocene age, but gravel beaches at low elevations northwest of Lake Point were deposited by Great Salt Lake and are of Holocene age. Oolitic sand is an important constituent of the Holocene gravel beaches.

Mass-Movement Deposits

Talus (Qmt)

Talus (Qmt), or rock-fall debris, is found in scattered locations along the western slope of the Oquirrh Mountains north of Flood Canyon. The debris has accumulated where the Bonneville shoreline abrasion platform undercuts bedrock outcrops. Talus is as much as 30 feet (9 m) thick, and is latest Pleistocene to latest Holocene in age.

Playa Deposits

Playa Mud (Qpm)

Playa mud (Qpm) consists of poorly sorted clay, silt, and small amounts of sand. Locally, accumulations of gypsum, halite, and other salts form on the playa surface. Deposits of playa mud are generally less than 10 feet (3 m) thick. The deposits are present along the shores of Great Salt Lake in the northwestern corner of the mapped area. Playa muds are Holocene deposits.

Fill Deposits

Tailings and Slag (Qft)

In the map area, tailings consist mostly of silty fine sand, and slag consists mostly of coarse rock fragments. Two tailings ponds are mapped along Dry Canyon and slag is present nearby along the margins of Pine Creek. These deposits are associated with operations of the International Smelting and Refining Company and its successor, the Anaconda Copper Company. International operated copper and lead smelters, a lead/zinc flotation mill, and a slag treatment plant from 1910 through 1971, and Anaconda worked the Carr Fork copper mine and concentrator in Pine Canyon from 1973 to 1981 (Hansen, 1963; Braxton and Buck, 1989).

SUMMARY AND CONCLUSIONS

The Oquirrh fault zone is exposed as a west-dipping normal fault that extends discontinuously for 19 miles (31 km) on the west side of the northern Oquirrh Mountains. Surficial geologic units in the fault zone are from Pliocene to Holocene in age, but are dominantly deposits of latest Pleistocene Lake Bonneville. Prominent shorelines of the lake are cut into underlying units and are useful datums for determining the paleoseismic history of the fault zone. The Oquirrh fault zone consists of three geographic sections characterized by unique topographic and geologic features. The sections do not necessarily imply either segmentation of the fault zone or independent surface rupture of each section.

The northern section of the fault zone trends slightly northwest and includes a series of scarps in a near-linear zone in unconsolidated material. The scarps are all below the level of the Provo shoreline of Lake Bonneville, but are both above and below the level of the Stansbury shoreline. Post-Lake Bonneville alluvial fans of latest Pleistocene to Holocene age are common in this section of the fault zone and locally obscure fault traces, including the fault trace where it is projected to intersect the Stansbury shoreline. The compound scarp in the northern section of the fault zone is as much as 10.8 meters (35.4 ft) high (Barnhard and Dodge, 1988). Results from trench mapping and radiocarbon dating along this section near Big Canyon indicate that the MRE occurred between 4,300 and 6,900 ^{14}C years ago (4,800 and 7,900 cal B.P.), with an associated NVD of 2.2 meters (7.2 ft) (Olig and others, 1994, this volume).

The central section of the fault zone includes scarps in unconsolidated material on the margin of an elevated spur, the Erda salient, extending westward from the range front. The salient is typically overlain by Lake Bonneville deposits, and younger alluvial fans are less common here than farther north. The scarps on the salient are all below the level of the Bonneville shoreline, but the Provo shoreline intersects the scarps and is offset. This indicates an MRE younger than the 14,000 years B.P. minimum age of the Provo shoreline. Previous studies of scarp morphology along this section of the fault suggested that the MRE occurred close to, but not more than, 13,500 years ago (Barnhard and Dodge, 1988). More recent results from detailed mapping and trench excavations along this section near Pole Canyon found stratigraphic evidence to support the younger age for the MRE determined at Big Canyon, although no datable material was found to confirm this interpretation (Olig and others, 1994, this volume). Results from Pole Canyon also indicate that the PE occurred between 20,300 and 26,400 ^{14}C years ago, and the APE occurred sometime before 32,800 ^{14}C years ago (Olig and others, 1994, this volume). At Pole Canyon, 2.7 meters (8.9 ft) of NVD is associated with the MRE and 2.3 meters (7.5 ft) of NVD is associated with the PE.

The southern section of the fault zone is commonly a range-front scarp at the bedrock-alluvium contact along the Pine Canyon reentrant, although two short fault scarps are in alluvium. All scarps are above the level of the Bonneville shoreline. The reentrant is typically underlain by alluvial fans that predate Lake Bonneville and may be as old as Pliocene. Because of the absence of shorelines and deposits of appropriate age, no paleoseismic investigations were conducted in this section of the fault zone to determine the timing of surface-faulting events.

Previous investigators have postulated faults that cut valley fill west of the Oquirrh fault zone. These faults include the Mill Pond, Erda, and Occidental faults and several smaller, unnamed faults. Solomon (1993) found no evidence that these faults offset surficial deposits, but they may displace older Quaternary deposits in the subsurface. Their relation to the Oquirrh fault zone is unknown.

Farmin (1933) and Thomas (1946) proposed that the Occidental fault, exposed in bedrock of the Oquirrh Mountains, extends northwestward as the bedrock-alluvium scarp along the north limb of the southern section of the Oquirrh fault zone. Gates (1962) proposed a further extension of the range-front fault into Tooele Valley. If these extensions are correct, they imply that this north limb might be a reactivation of an older cross fault.

Because the proposed valley extensions of the Occidental fault do not offset surficial Lake Bonneville deposits, the Occidental fault and perhaps the southern section of the Oquirrh fault zone may not have been active in the Holocene. However, the range-front scarp on the north limb of the southern section is colinear with scarps on the south margin of the Erda salient that offset post-Bonneville alluvial fans; this supports the possibility of Holocene activity on the range-front scarp. Olig and others (1994, this volume) suggest that the range-front scarp in the southern section is part of the same rupture segment as scarps further north, and that this part of the fault zone must have been active in the Holocene. A conclusion that the Oquirrh fault zone is a single rupture segment is consistent with the observation by Helm (1994) that regional transverse crustal structures mark the ends of this fault zone and single segments of other fault zones. The contradictory evidence suggests that further work is needed to determine the age of most recent activity of the range-front scarp along the Pine Valley reentrant, and to resolve the question of segmentation along the Oquirrh fault zone.

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PALEOSEISMOLOGY OF UTAH, VOLUME 6

PALEOSEISMIC INVESTIGATION OF THE OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH

by
Susan S. Olig, William R. Lund, Bill D. Black, and Bea H. Mayes

Pole Canyon trench. View is to the east toward the Oquirrh fault scarp. Vehicle is at the base of the scarp. A minor Lake Bonneville transgressive shoreline lies just beyond the east end of the bench.

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PALEOSEISMIC INVESTIGATION OF THE OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH

by
Susan S. Olig, William R. Lund, Bill D. Black, and Bea H. Mayes

ABSTRACT

The Oquirrh fault zone is a range-front normal fault bounding the east side of Tooele Valley. It has long been recognized as a potential source for large earthquakes that pose a threat to population centers along the central Wasatch Front in Utah. Scarps of the Oquirrh fault zone offset the Provo shoreline of Lake Bonneville and previous studies of scarp morphology suggested that the most-recent surface faulting on the fault zone occurred between 9,000 and 13,000 years ago. Based on a potential rupture length of 12 to 21 kilometers, moment magnitude (M_w) estimates for this event range from 6.3 to 6.8. In contrast, our results from detailed mapping and trench excavations at two sites indicate that the most-recent earthquake actually occurred between 4,300 - 6,900 ^{14}C yr B.P. (4,800 and 7,900 cal B.P.) with net vertical tectonic displacements of 2.2 to 2.7 meters, much larger than expected considering the estimated rupture length for this event. Empirical relations between magnitude and displacement yield moment magnitude estimates of M_w 7.0 to 7.2.

At both the Big Canyon and Pole Canyon sites, trenches exposed faulted Lake Bonneville sediments and thick wedges of scarp-derived colluvium associated with the most-recent surface-faulting earthquake. Bulk sediment samples from a faulted debris-flow deposit at the Big Canyon site yielded radiocarbon age estimates of 7,650 ± 90 yr B.P. and 6,840 ± 100 yr B.P. A bulk sediment sample from unfaulted fluvial deposits that bury the fault scarp gave a radiocarbon age estimate of 4,340 ± 60 yr B.P. Stratigraphic and structural evidence for a pre-Bonneville lake cycle penultimate earthquake was exposed at the Pole Canyon site. Charcoal from a marsh deposit, overlying the penultimate-event colluvium and deposited during the Lake Bonneville transgression, produced a radiocarbon age estimate of 20,370 ± 120 yr B.P. A sample consisting of multiple charcoal fragments from a fluvial deposit faulted during the penultimate event yielded a radiocarbon age estimate of 26,200 ± 200 yr B.P. Indirect stratigraphic evidence for an antepenultimate event was also exposed at Pole Canyon. Charcoal from fluvial sediments burying the eroded free-face for this event gave a radiocarbon age estimate of 33,950 ± 1,160 yr B.P., providing a minimum-limiting age for the antepenultimate event.

Ages for the past two surface-faulting earthquakes on the Oquirrh fault zone yield a recurrence interval of 13,300 to 22,100 ^{14}C years and estimated slip rates of 0.1 to 0.2 mm/yr. Temporal clustering of earthquakes in the late Holocene on the nearby Wasatch fault zone does not appear to have influenced activity on the Oquirrh fault zone. However, consistent with findings on the Wasatch fault zone and with some other Quaternary faults within the Bonneville basin, we found no evidence of surface

faulting during the time Lake Bonneville was at or near its highest level, suggesting a possible causal relation between rates of strain release along faults and changes in loads imposed by the lake. However, our data are only complete for one deep-lake cycle (past 30,000 years), and whether this pattern persisted during the previous Cutler Dam and Little Valley lake cycles is unknown.

The Oquirrh fault zone should be considered seismogenic and capable of producing M 7 or larger earthquakes. Critical facilities constructed in Tooele Valley should be designed to withstand the effects of a large earthquake (M 7+) whose epicenter is at most a few kilometers away rather than the 30 or 40 kilometers expected for earthquakes on the Wasatch fault zone.

INTRODUCTION

Purpose and Scope

The Oquirrh fault zone lies near the eastern boundary of the Basin and Range Province in west-central Utah (figure 1). It has long been recognized (Gilbert, 1890) as a potential source of large earthquakes and, as such, presents a significant earthquake hazard to the central Wasatch Front region (population over 1,000,000). For example, using Campbell's (1987) empirical attenuation relation for Utah, ground-motion estimates for a surface-faulting earthquake on the Oquirrh fault zone exceed 0.2 g in downtown Salt Lake City roughly 30 kilometers east of the fault trace. These ground motions could induce liquefaction and could seriously damage older buildings and bridges in the Salt Lake City area. Additionally, the city of Tooele (population 14,500) and the Tooele Army Depot, which routinely handles and stockpiles large quantities of high-explosive and chemical munitions, are only 6 and 10 kilometers, respectively, from the closest fault scarps on unconsolidated alluvium at the northern end of the Oquirrh fault zone, and are much closer to the sharp bedrock-alluvium contact along the mountain front that marks the southward extension of the fault zone (Bucknam, 1977; Barnhard and Dodge, 1988; Solomon, this report).

The purpose of this cooperative project between the Utah Geological Survey and the U.S. Geological Survey (National Earthquake Hazard Reduction Program contract no. 1434-92-G-2218) is to determine the seismic-source potential of the Oquirrh fault zone and to evaluate the earthquake hazard the fault zone presents to the Wasatch Front and Tooele Valley. The study focuses on the northern part of the fault zone where fault scarps are developed on unconsolidated Quaternary basin-fill deposits, and includes interpreting aerial photographs, detailed geologic mapping of surficial deposits at trench sites, profiling fault scarps, excavating and mapping trenches at two sites, and radiocarbon dating key stratigraphic units. Paleoseismic parameters determined include net vertical tectonic displacement per event, timing of past surface-faulting earthquakes, the recurrence interval between the most-recent and penultimate surface-faulting earthquakes, fault slip rate, and estimated paleoearthquake magnitudes.

Previous Work

Previous studies of the Oquirrh fault zone concentrated on the surficial expression of the fault. Gilbert (1890, p. 352) was the first to identify west-facing fault scarps on Lake Bonneville deposits along the west side of the northern Oquirrh Mountains. Much later, the Oquirrh fault zone was mapped at a scale of 1:250,000 by Bucknam (1977) and by Barnhard and Dodge (1988). Both maps show the location and extent of fault scarps formed on unconsolidated sediments on the Tooele 1°x 2° quadrangle. Everitt and Kaliser (1980) mapped the surficial geology of Tooele Valley, including the Oquirrh fault zone, at a scale of 1:50,000. Their map is not of sufficient detail for use in detailed paleoseismic studies. Both Everitt and Kaliser (1980) and Barnhard and Dodge (1988) recognized two sections of the fault: a northern section that included fault scarps on Quaternary basin-fill sediments, and a southern section that included a fault contact between bedrock and alluvium along the range front. Tooker and Roberts (1971a, 1971b, 1988, 1992) and Tooker (1980) mapping bedrock in the Oquirrh Mountains at a scale of 1:24,000, show scarps of the Oquirrh fault zone along the west side of the mountain range. Solomon (1993; this volume) prepared a detailed map (1:24,000 scale) of the surficial geology of Tooele Valley including scarps of the Oquirrh fault zone. His map was used as the basis for this paleoseismic study.

Barnhard and Dodge (1988) measured topographic profiles of the Oquirrh fault zone to characterize scarp morphology and help constrain fault behavior. Scarp heights ranged between 2.9 and 10.8 meters and surface offsets between 1.3 and 7.3 meters. Most scarps were compound, representing displacement during more than one surface-faulting earthquake. They compared plots of scarp heights versus maximum slope angle for the Oquirrh fault zone with similar plots for other scarps of known age in the Bonneville basin. Based on this and crosscutting relations with the Provo shoreline of Pleistocene Lake Bonneville (see discussion in Geologic Setting section), they suggested that the latest faulting on the Oquirrh fault zone occurred between 9,000 and 13,500 years ago, and probably was closer to the 13,500 year age.

Youngs and others (1987), in a detailed probabilistic analysis of earthquake ground-shaking hazard along the Wasatch Front, identified the Oquirrh fault zone as a potential source of large earthquakes that could significantly affect the Wasatch Front (Salt Lake City metropolitan area). However, they stated that for purposes of their analysis, there were ". . . insufficient paleoseismic data on the amount of displacement . . ." to assess paleoearthquake magnitudes, and therefore, they were forced to rely on magnitude estimates based on poorly defined rupture-length and rupture-area relationships. They determined that the Oquirrh fault zone is capable of generating an earthquake in the magnitude 7 to 7¼ range. Similarly, they found that ". . . available data do not tightly constrain the time since the most-recent surface-faulting event or the recurrence interval between events . . . ."

Arabasz and others (1989), evaluating seismic risk relevant to the siting of a superconducting supercollider in Tooele County, relied on a personal communication (1987) from Ted Barnhard of the U.S. Geological Survey and a reconnaissance

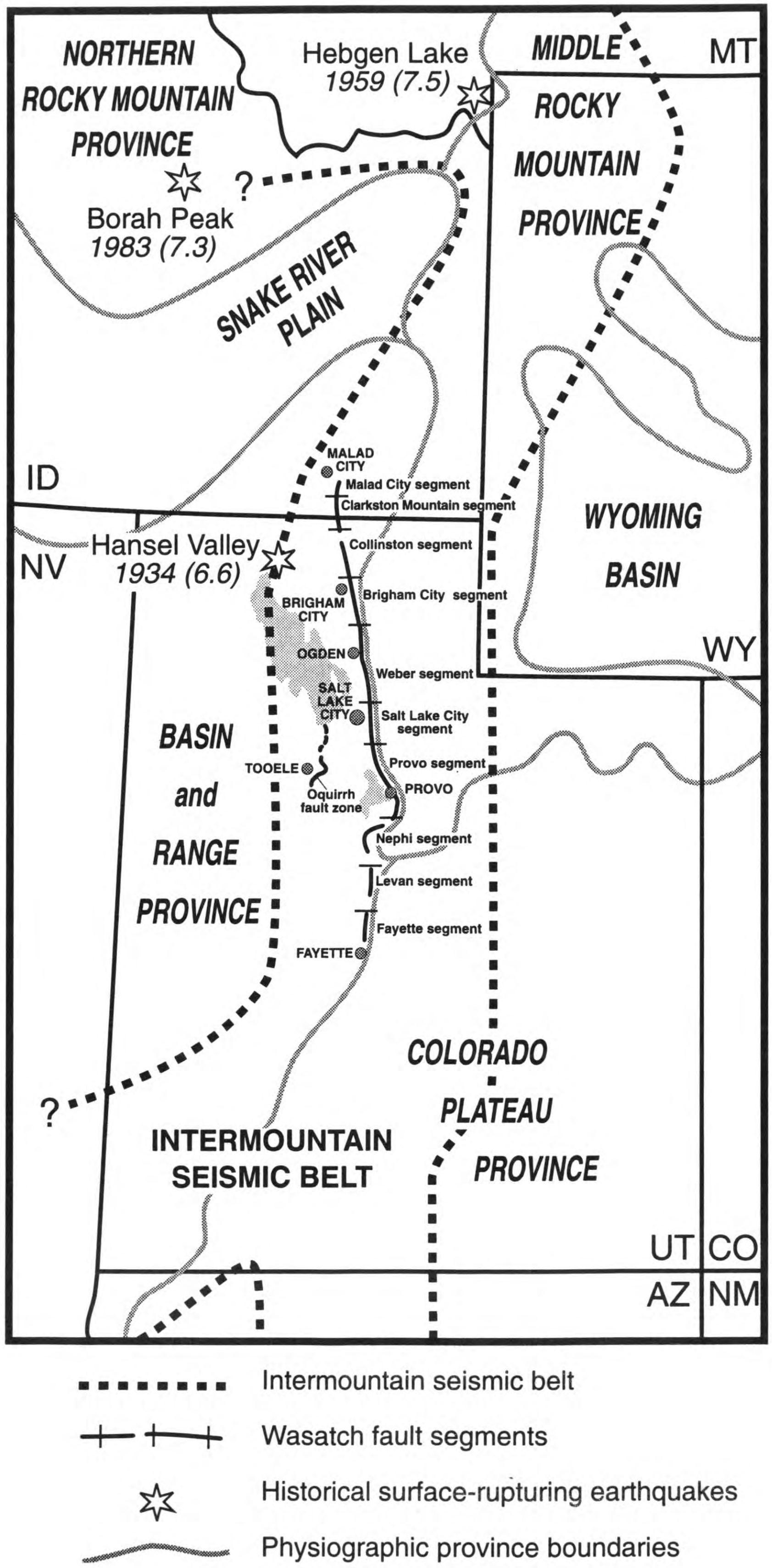


Figure 1. *Index map showing the relation of the Oquirrh fault zone to regional physiographic features, the Intermountain seismic belt (ISB), and the segments of the Wasatch fault zone.*

report by Woodward-Clyde Consultants (1982; in Youngs and others, 1987) to assign an age of 8,000 to 13,500 years for the time of most-recent movement on the Oquirrh fault zone. That age estimate was based on the relation of fault scarps to shorelines of Lake Bonneville and on fault-scarp profile data. Arabasz and others (1989) estimated a maximum magnitude of 7.3 for an event on the Oquirrh fault zone using a displacement of 4.08 meters determined from fault-scarp profiles measured across single-event Oquirrh fault zone scarps (Barnhard, personal communication, 1987; in Arabasz and others, 1989). For comparison, a net vertical tectonic displacement of 4 meters approaches the largest net vertical displacement measured on the Wasatch fault zone (4.5 - 4.75 meters on the Salt Lake City segment [figure 1]; Lund and Schwartz, 1987). Lacking paleoseismic data, Arabasz and others (1989) used an inferred slip rate of 0.1-0.2 mm/yr from Youngs and others (1987) to arrive at an estimated recurrence interval for the Oquirrh fault zone of greater than 10,000 years.

GEOLOGIC SETTING

The Oquirrh fault zone extends for about 30 kilometers from Lake Point to south of Tooele along the east side of Tooele Valley at the base of the Oquirrh Mountains (figure 2). It is a west-dipping normal fault that varies in strike from north-northwest to northeast. A variety of different names have been used for the fault zone including: the Oquirrh marginal fault (Everitt and Kaliser, 1980); the northern Oquirrh fault zone (Barnhard and Dodge, 1988; Hecker, 1993); and the Oquirrh fault zone (Barnhard, 1988; Olig and others, 1993). The latter name is retained here for simplicity and because "northern Oquirrh Mountains" is not a formal place name.

During much of Quaternary and Tertiary time, the eastern Basin and Range Province, within which the Oquirrh fault zone lies, has been characterized by roughly east-west extension, as indicated by the numerous, dominantly normal-slip, generally north-striking faults that characterize the region (figure 3; Zoback, 1983; Hecker, 1993). The Oquirrh fault zone is one of those faults and lies about 35 kilometers west of the Salt Lake City segment of the Wasatch fault zone (figure 1). The Wasatch fault zone is the most active Quaternary fault in Utah (Hecker, 1993) and it marks the eastern boundary of the Basin and Range Province (Machette and others, 1991). The study area is also within the central part of the Intermountain seismic belt (figure 1), a north-trending zone of shallow, diffuse intraplate seismicity that extends from Montana, through central Utah, to northern Arizona (Smith and Sbar, 1974; Smith and Arabasz, 1991). Non-surface-faulting earthquakes in the Intermountain seismic belt (usually less than magnitude 6.5) are difficult to associate with individual Quaternary faults (Youngs and others, 1987; Arabasz and others, 1992), and no historical earthquakes (since 1847) can be directly associated with the Oquirrh fault zone. However, seismicity and well-bore breakouts along the Wasatch Front show that extension is still occurring in a west-northwest to west direction (Zoback, 1983, 1989; Eddington and others, 1987; Bjornadottir and Pechmann, 1989) indicating that future large earthquakes in west-central Utah are a certainty.

Major west-dipping, range-bounding Quaternary faults generally lying along strike with the Oquirrh fault zone include the East Great Salt Lake fault zone beneath Great Salt Lake to the north (Vivieros, 1986; Pechmann and others, 1987) and the Mercur and Topliff Hills fault zones and faults along the East Tintic Mountains to the south (Bucknam and Anderson, 1979a; Everitt and Kaliser, 1980; Barnhard and Dodge, 1988; Wu and Bruhn, 1994). Because these faults have a similar sense of displacement and form a north-south-trending, albeit somewhat discontinuous, zone of faults through central Utah, they could be considered individual segments of a large fault zone that extends for 205 kilometers from Rozel Bay in Great Salt Lake south to Furner Pass (figure 3). In their hazard evaluation for the Wasatch Front, Youngs and others (1987) combined these faults into one zone they called the Oquirrh Mountains fault zone. However, neither Anderson and Miller (1979) nor Hecker (1993) chose to group these faults together in their statewide fault compilations and we have followed that practice here.

Late Quaternary sedimentation along the western base of the Oquirrh Mountains has been dominated by alluvial-fan sediments shed from the mountains and deposition of lacustrine sediments (Solomon and others, 1992). Tooele Valley lies within the Bonneville basin, which was repeatedly inundated by paleolakes during the late Quaternary. Figure 4 depicts the altitude through time of the three most-recent deep-lake cycles: the Bonneville, Cutler Dam (or Hansel Valley), and the Little Valley (Currey, 1982; Scott and others, 1983; Currey and Oviatt, 1985; McCoy, 1987; Oviatt and others, 1987, 1992; Machette, 1988; McCalpin and Forman, 1991; McCalpin and others, 1992). Lacustrine sediments of Lake Bonneville dominate the surficial geology along the northern section of the Oquirrh fault zone. They form a generally thin mantle over older alluvial deposits and are in turn locally buried by post-lake alluvium and colluvium. No geologic deposits related to the Cutler Dam or Little Valley lake cycles were encountered during this study.

Three Lake Bonneville shorelines (Stansbury, Bonneville, and Provo in order of decreasing age; figure 4) form regional geomorphic datums in the Bonneville basin and are well developed in Tooele Valley. Because the time of their formation is well constrained (Oviatt and others, 1992), these shorelines can be used to help determine the timing of faulting events in the basin. The Stansbury shoreline formed about 22,000 years ago as the lake paused briefly in its transgression to its highest stand at the Bonneville shoreline. The lake reached the Bonneville level about 15,000 years ago (Oviatt and others, 1992) and intermittently overflowed its basin until about 14,500 years ago. The lake level then catastrophically dropped about 100 meters to the Provo shoreline during the Bonneville flood. Lake Bonneville again overflowed its basin until about 14,200 years ago when a more arid climate caused the lake to regress rapidly under closed-basin conditions. By 12,000 years ago the lake had reached a level below present day Great Salt Lake. The Gilbert shoreline (figure 4) represents a brief rise in Great Salt Lake in latest Pleistocene time. The northern section of the Oquirrh fault zone lies entirely below the Bonneville shoreline and mostly below the Provo shoreline. However, in at least three locations

Base Map from U.S. Geological Survey Tooele, AMS
1° x 2° topographic quadrangle

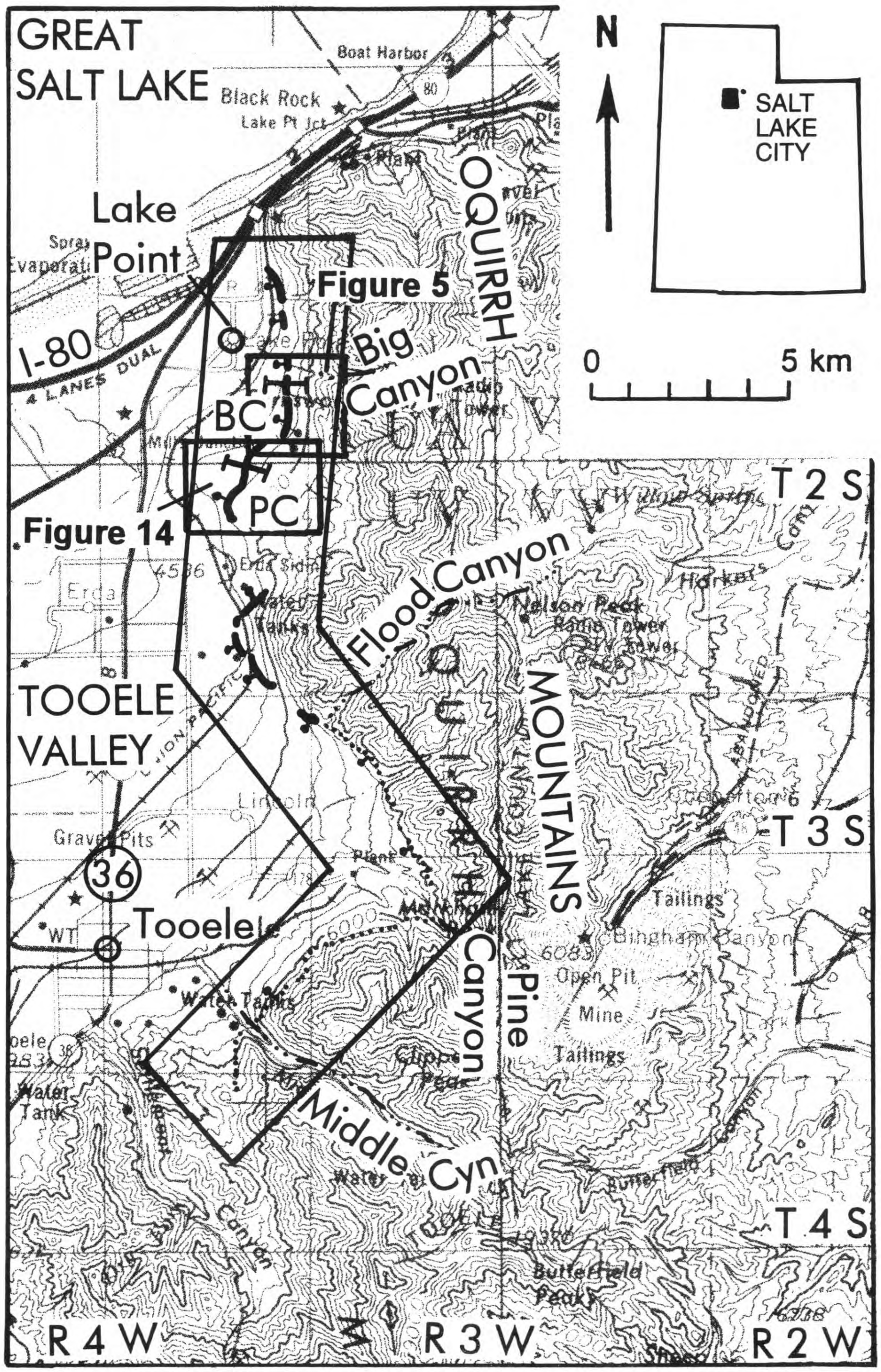


Figure 2. Map of the Oquirrh fault zone (after Barnhard and Dodge, 1988) showing trench site locations: PC-Pole Canyon; BC-Big Canyon. Heavy lines represent fault scarps on alluvium with bars and balls on downthrown side. Dotted line represents sharp bedrock-alluvium contact along mountain front without scarps in alluvium.

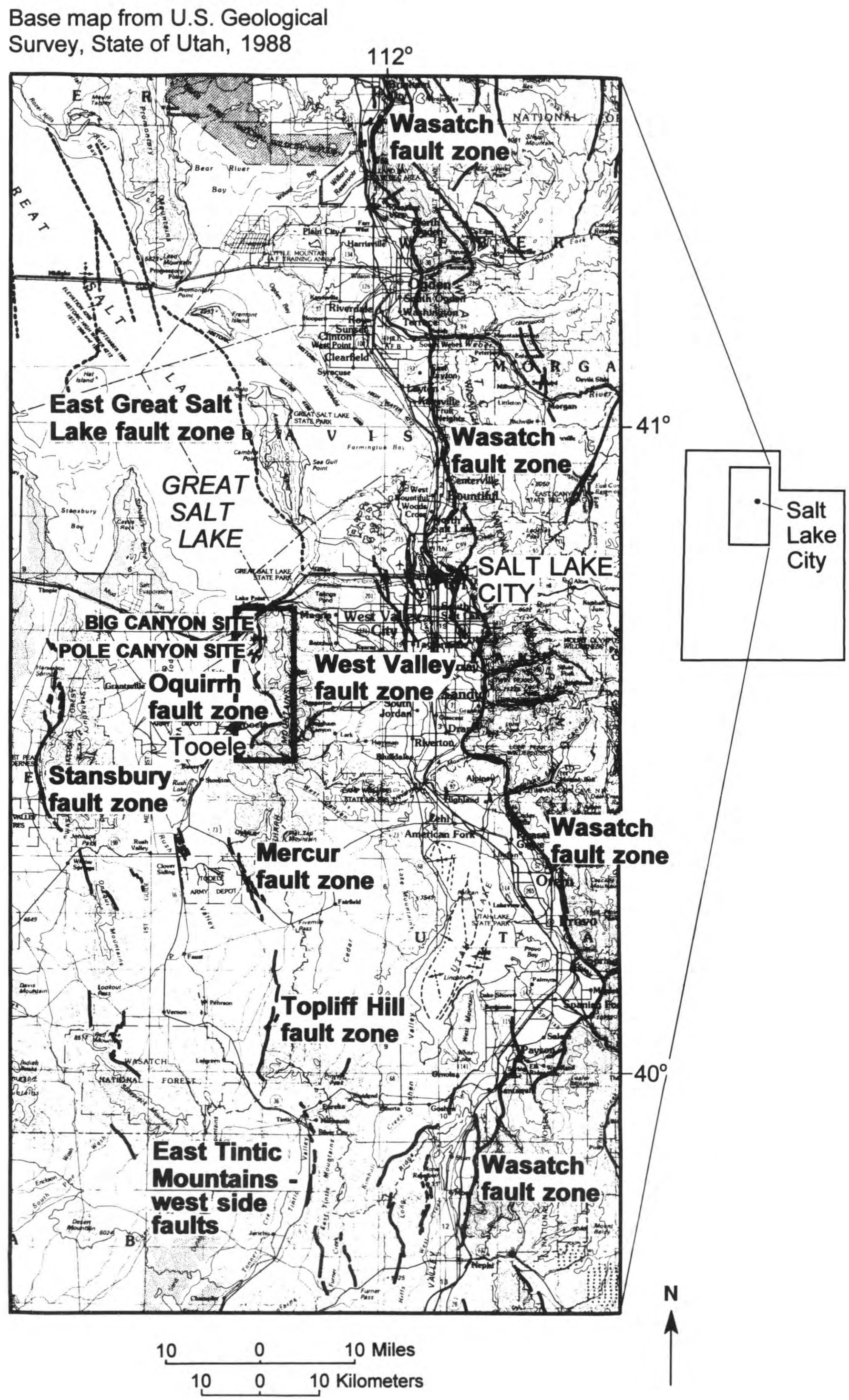


Figure 3. *Regional Quaternary fault map of central Utah showing location of the Oquirrh and other nearby fault zones (modified from Hecker, 1993).*

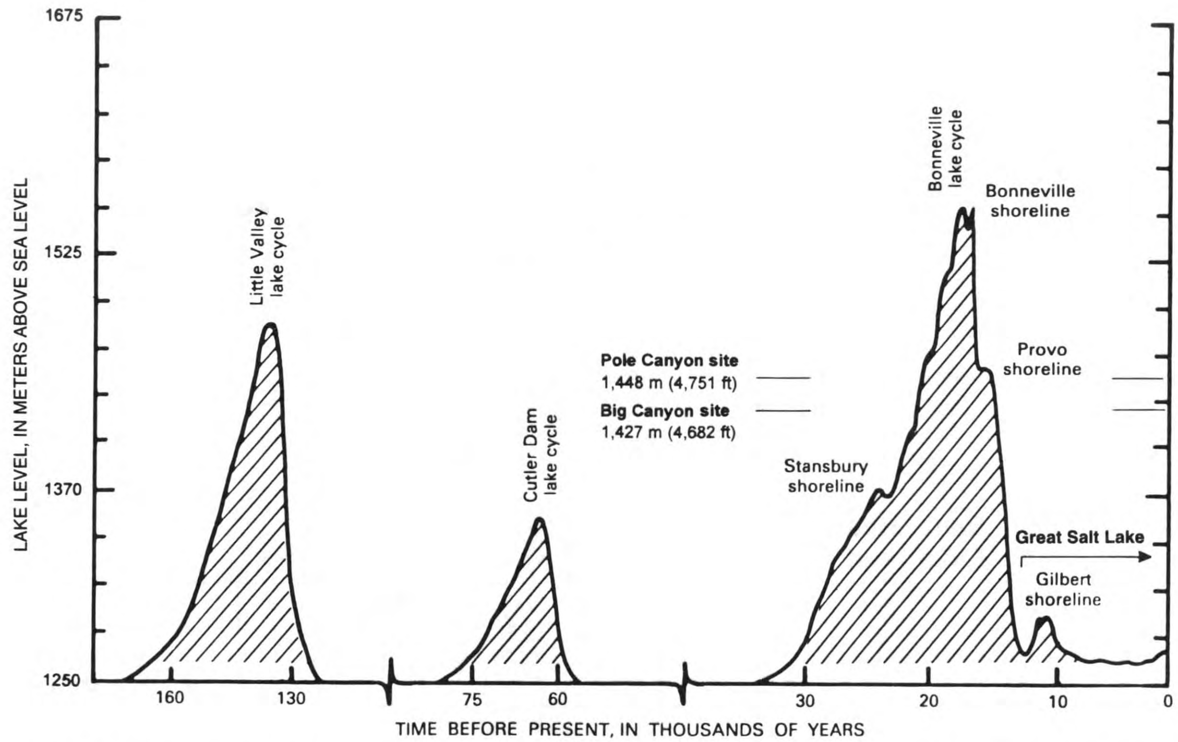


Figure 4. *Time-altitude diagram of deep-lake cycles in the Bonneville basin during the past 170,000 years (modified from Machette and others, 1992; originally modified from Currey and Oviatt, 1985).*

(Barnhard and Dodge, 1988), the fault zone displaces the Provo shoreline, demonstrating that the most-recent surface faulting on the fault zone is younger than Provo time (<14,200 years).

The southern section of the Oquirrh fault zone is characterized by a sharp contact between bedrock and alluvium (shown as a dotted line on figure 2), extending for 8 kilometers from Flood Canyon south to Pine Canyon, where the fault makes a near right-angle bend and continues southwest for an additional 10 kilometers to a canyon south of Middle Canyon. It is more difficult to constrain the time of most-recent faulting on this section of the fault because it lies entirely above the Bonneville shoreline and only very young and very old deposits are preserved along the range front. Solomon (1993; this report) mapped some short fault scarps preserved on older Quaternary gravels, but he found no scarps offsetting younger alluvial fans at canyon mouths along the southern section of the fault.

FAULT TRENCHING

Big Canyon Site

Surficial Geology

The Big Canyon site is roughly 2 kilometers southeast of Lake Point and 0.3 kilometers west of the mouth of Big Canyon (figure 2). There, a west-facing main scarp and a smaller east-facing antithetic scarp form a graben 50 to 150 meters wide (figures 5 and 6). The elevation near the base of the main fault scarp is about 1,427 meters; roughly 60 meters below the Provo shoreline (figures 5 and 6). The time-altitude diagram for the Bonneville lake cycle (figure 4) shows that the lake transgressed across the site between 20,000 to 21,000 years ago, and regressed from the site about 13,000 to 14,000 years ago (Scott and others, 1983; Currey and Oviatt, 1985; Oviatt and others, 1992). Since the lake's regression, deposition near the Big Canyon site has been dominated by construction of alluvial fans at the mouths of drainages and the reworking of lacustrine and alluvial deposits elsewhere along the mountain front (figure 5), with some areas such as the graben receiving significant amounts of eolian sediment. At the trench site, both the main and antithetic fault scarps offset reworked lacustrine deposits, and are buried to the north by younger alluvial-fan deposits from Big Canyon. Thus, the timing of latest faulting on these scarps is younger than 13,000 to 14,000 years, but older than the youngest fan alluvium.

Profiles of fault scarps on reworked lacustrine deposits at the Big Canyon site yield scarp heights ranging from 12 to 18 meters, maximum slope angles of 24 to 32 degrees, and surface offsets of 4.0 to 6.8 meters (figure 7). Complex profiles with a break-in-slope between the crest and base, together with large surface offsets, indicate that the main scarp is probably compound and represents cumulative displacements from more than one surface-faulting event. Although scarp measurements suggest 4.0 to 6.8 meters of net vertical tectonic displacement in the past 13,000 to 14,000 years, highly eroded scarp crests and the concentration of boulders along the scarp suggest that a pre-existing scarp was modified by Lake Bonneville's transgression, with the boulders probably representing a beach lag deposit. Thus, the surface offset measured from the scarp profiles may not accurately represent the net vertical tectonic displacement during the past 13,000 to 14,000 years.

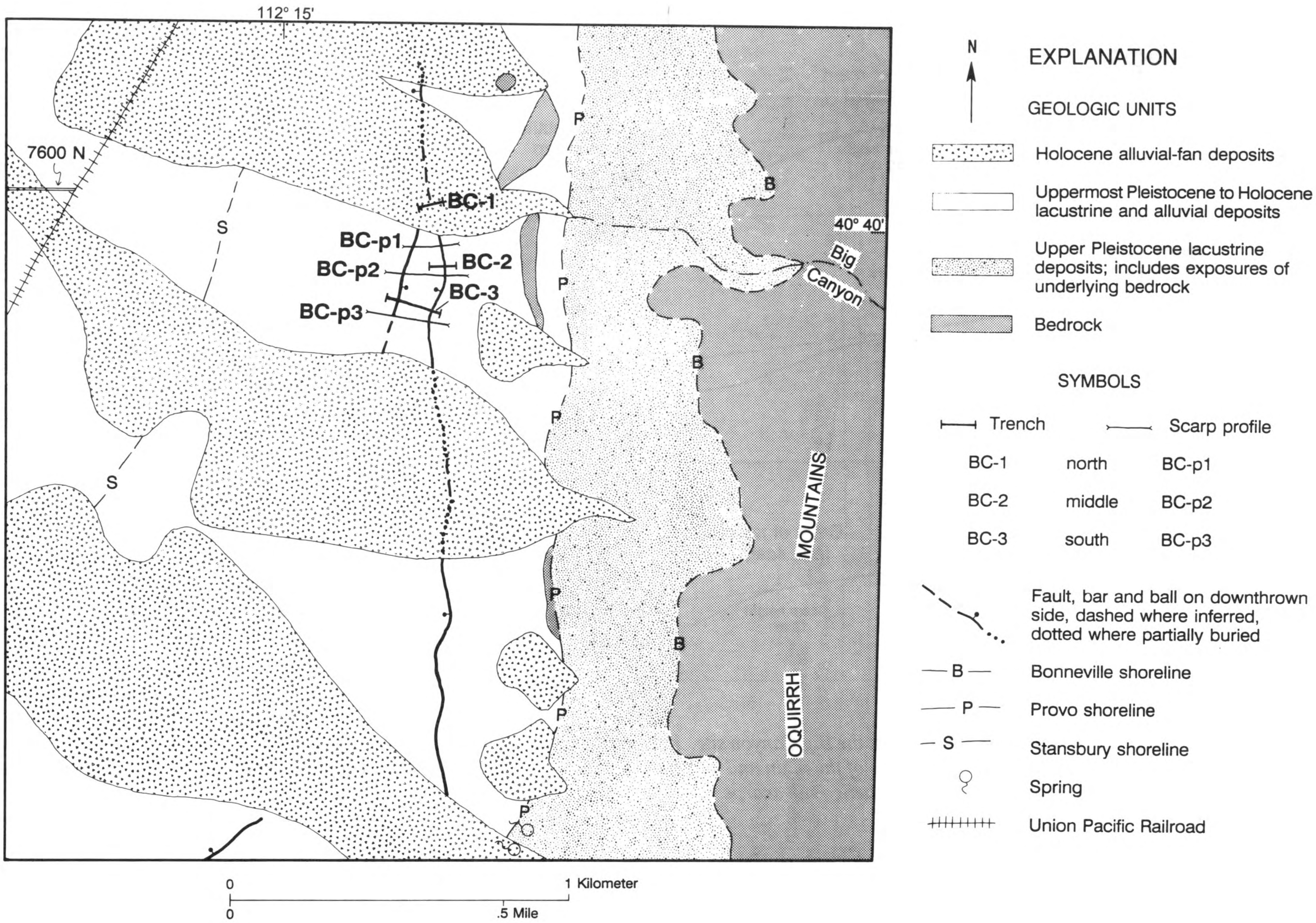


Figure 5. *Generalized geologic map of the Big Canyon site (modified from Solomon, 1993; this volume).*

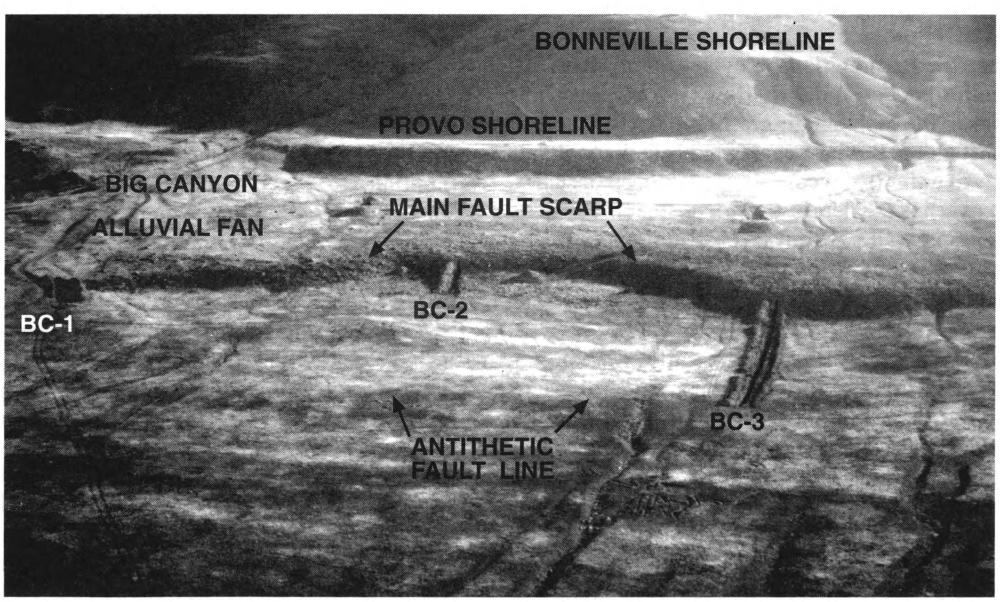


Figure 6. *Oblique aerial view of the Big Canyon site (looking east) showing locations of trenches (BC-1, BC-2, and BC-3) relative to key geomorphic features.*

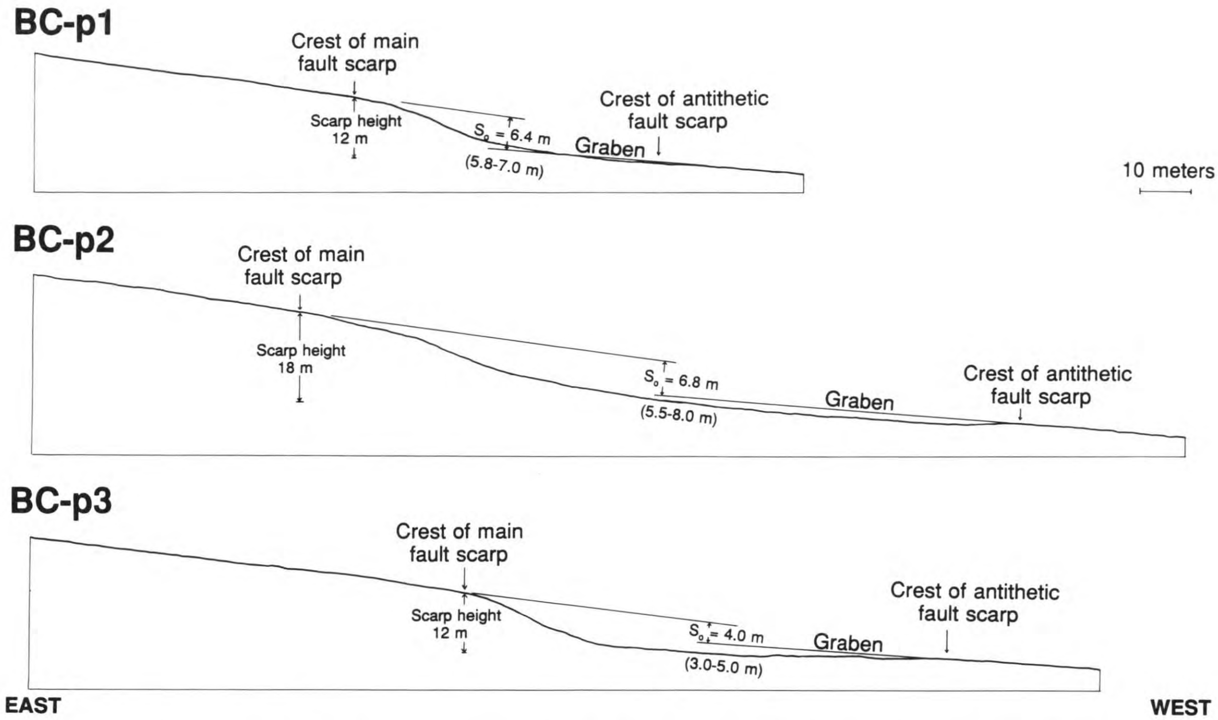


Figure 7. Topographic scarp profiles measured at the Big Canyon site. Preferred estimates of surface offset (S_o) are based on a surface reconstruction using a break in slope halfway between the crests of the main and antithetic fault scarps. Range of values (in parentheses) is the S_o at 1/3 to 2/3 the distance between the crests of the main and antithetic fault scarps.

Trench Exposures

Three trenches were excavated at the Big Canyon site: trench BC-1 was in unfaulted Big Canyon fan alluvium that buried the main fault scarp; trench BC-2 crossed only the main fault scarp; and trench BC-3 crossed the main fault scarp, the graben, and the antithetic fault (figures 5 and 6).

Stratigraphy: Similar stratigraphy and structural relations in trenches BC-2 and BC-3 provide evidence for one surface-faulting earthquake since the Bonneville lake cycle (figures 8, 9, 10, 11, and 12). In both trenches, a debris-flow deposit overlying lacustrine sediments in the fault hanging wall is displaced across the fault zone against older alluvial-fan sediments in the footwall (figures 9 and 12). An unfaulted wedge-shaped deposit of scarp-derived colluvium overlies the debris-flow deposit at the base of the scarp in the hanging wall. A thin layer of unfaulted colluvium and alluvium drapes the entire scarp. Detailed descriptions for all of the geologic units exposed in the trenches are included in the appendix.

The older alluvial-fan sediments in the footwall (units 1 through 7, figure 9; unit 1-7 undifferentiated, figure 12) are interpreted to be older than the Lake Bonneville transgression (>20,000 years ago) and younger than the Little Valley lake cycle (<120,000 years ago) (figure 4) based on their geomorphic and stratigraphic position, development of carbonate cementation, oxidation and weathering of clasts, and degree of soil development. The deposits of loess (units 2, 4, and 6) interbedded with the alluvium indicate periodic changes in deposition along the range front, possibly related to drier paleoclimates during interpluvial periods of oxygen-isotope stages 3 or 5 (Oviatt and others, 1987). It should be noted that stratigraphic and geomorphic relations do not preclude the possibility that these older footwall sediments are pre-Little Valley in age and that deposits of the Little Valley lake cycle were eroded from the site. However, there is no evidence to support this interpretation.

Lacustrine sediments exposed near the fault in the hanging wall (units 8-10, figures 9 and 12) are interpreted as a nearly complete package of Lake Bonneville sediments based on their geomorphic and stratigraphic position, lithologic characteristics, the presence of ostracodes in unit 10, and the presence of gastropods in unit 9. In both trenches, unit 10 contains a thin, nearly continuous sand horizon (figures 9 and 12). Horizons such as this, with medium to coarse particles of sand or ostracodes, are common at this stratigraphic position throughout the Bonneville basin and probably were deposited during the Bonneville flood (D.R. Currey, verbal communication, 1992).

Unconformably overlying units 9 and 10 are well-rounded, tufa-cemented gravels (unit 11, figure 10) that could be traced almost the entire length of trench BC-3 (figures 8 and 10). Unit 11 is interpreted as a regressive Lake Bonneville beach deposit. It is the youngest unit in the west end of trench BC-3 that is offset by the antithetic fault zone (figure 11), and was probably deposited 13,000 to 14,000 years ago (figure 4). A buried, weakly developed soil Bk to Bt horizon is present on parts of units 10 and 11, indicating that these deposits were subaerially exposed for some time before unit 10 was buried by a later debris-flow

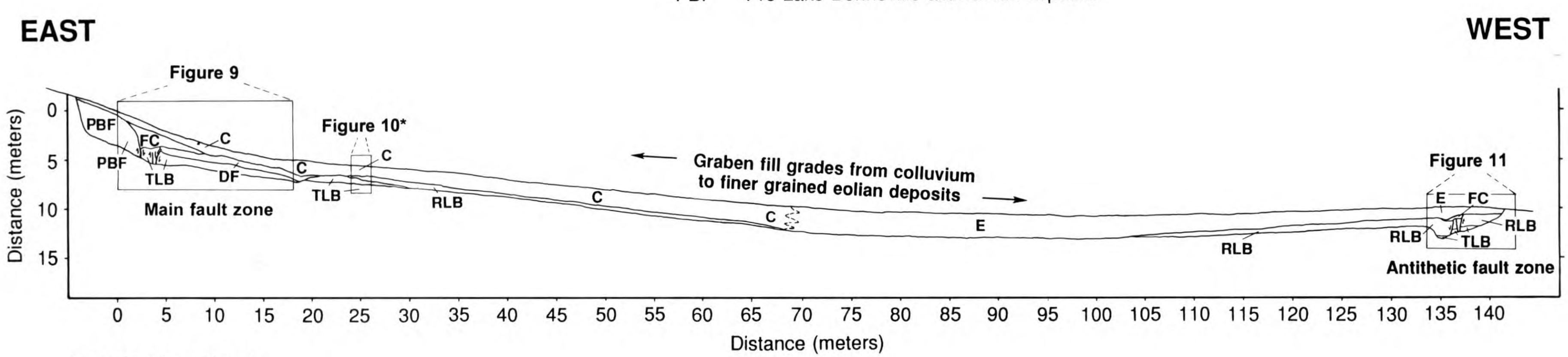
UNIT DESCRIPTIONS

Post-faulting deposits

E	Eolian and colluvial deposits
C	Colluvium
FC	Fault-scarp colluvium

Pre-faulting deposits

DF	Debris-flow deposit
RLB	Regressive Lake Bonneville beach deposits
TLB	Transgressive Lake Bonneville deposits
PBF	Pre-Lake Bonneville alluvial-fan deposits



*Actual log is north wall.

Figure 8. *Diagram of trench BC-3 at the Big Canyon site.*

Mapped by Susan S. Olig, Bill D. Black, and William R. Lund
May 1992
Planimetric base constructed on a 1 m x 1 m grid
Drafted by Bea H. Mayes

EXPLANATION

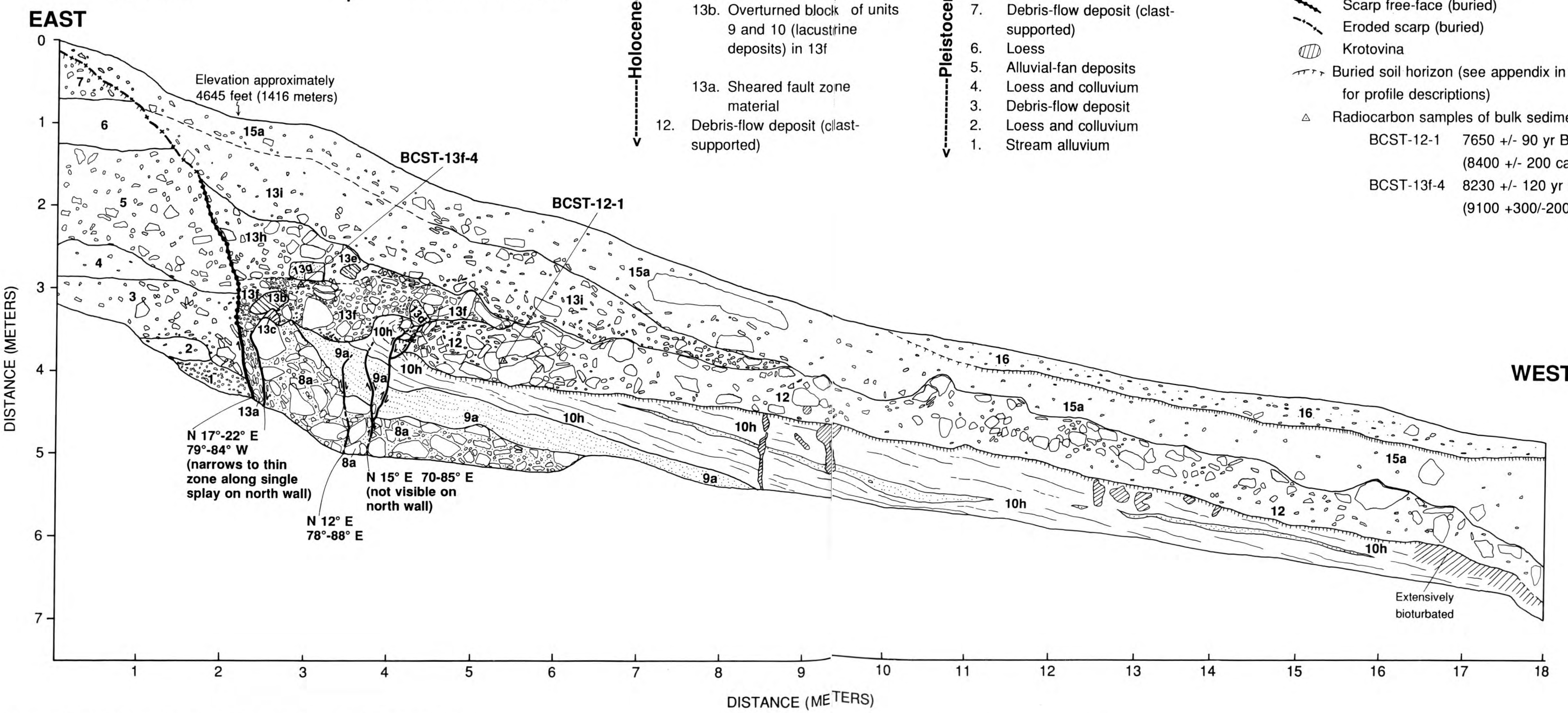
UNIT DESCRIPTIONS[1]
(See appendix in text for detailed descriptions)

--Holocene--->
- 16. Slope wash
- 15a. Colluvium
- 13. Main fault zone and fault-scarp colluvium[2]
  - 13i. Wash-element association of colluvium
  - 13h. Upper debris-element association of colluvium
  - 13g. Block of units 9 and 10 (lacustrine deposits) in 13h
  - 13f. Lower debris-element association of colluvium
  - 13e. Block of unit 10 (lacustrine deposit) in 13h
  - 13d. Overturned block of units 9 and 10 (lacustrine deposits) in 13f
  - 13c. Block of unit 10 in 13f
  - 13b. Overturned block of units 9 and 10 (lacustrine deposits) in 13f
  - 13a. Sheared fault zone material
- 12. Debris-flow deposit (clast-supported)

<---Pleistocene--->
- 10h. Shallow- to deep-water lacustrine deposits[3]
- 9a. Shallow-water lacustrine deposits[3]
- 8a. Transgressive beach deposits[3]
- 7. Debris-flow deposit (clast-supported)
- 6. Loess
- 5. Alluvial-fan deposits
- 4. Loess and colluvium
- 3. Debris-flow deposit
- 2. Loess and colluvium
- 1. Stream alluvium

SYMBOLS

- Rock
- Laminations in silts and clays
- Bedding in sands
- Contact, dashed where indistinct
- Fault, dashed where indistinct
- Scarp free-face (buried)
- Eroded scarp (buried)
- Krotovina
- Buried soil horizon (see appendix in text for profile descriptions)
- Radiocarbon samples of bulk sediment
  - BCST-12-1 7650 +/- 90 yr B.P.[4] (8400 +/- 200 cal B.P.)[5]
  - BCST-13f-4 8230 +/- 120 yr B.P.[4] (9100 +300/-200 cal B.P.)[6]



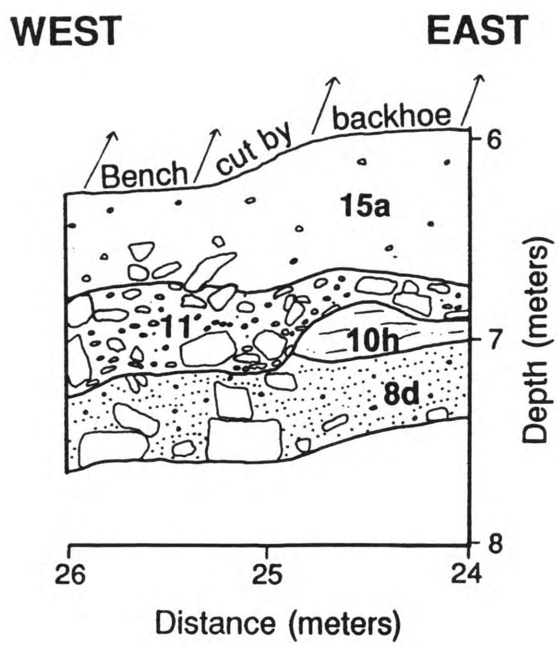
[1]Descriptions do not necessarily include all of units 1 through 21; only units exposed in this part of this trench are included.
[2]Following the terminology of Nelson, 1992.
[3]Deposited during the Bonneville lake cycle. Lake Bonneville occupied part of the eastern Great Basin from about 30 kya to 12 kya (Scott and others, 1983; Oviatt and others, 1992). Lake Bonneville first transgressed across the Big Canyon site about 20 kya and regressed across the site about 13-14 kya.

Figure 9. *Log of the main fault zone in trench BC-3 at the Big Canyon site.*

[4]Ages in radiocarbon years before 1950 A.D. Correction was not made for isotope fractionation in nature.
[5]Calendar-corrected age using the method of Stuiver and others (1993), with a lab error multiplier of 2, and an age span of 300 years. Doesn't include correction for mean residence time.
[6]Calendar-corrected age using curves of Stuiver and others (1993) and a lab error multiplier of 2. Doesn't include correction for mean residence time.

Figure 9 (continued)

Mapped by Susan S. Olig and Bill D. Black
June 1992
Planimetric base constructed on a 1 m X 1 m grid
Drafted by Bea H. Mayes



EXPLANATION

UNIT DESCRIPTIONS[1]
(See appendix in text for detailed descriptions)

Holocene	15a.	Colluvium
Pleistocene	11.	Regressive beach deposits[2]
	10h.	Shallow- to deep-water lacustrine deposits[2]
	8d.	Transgressive beach deposits[2]

SYMBOLS

Rock
Laminations in sandy clayey silts
Bedding in sands

Footnotes:

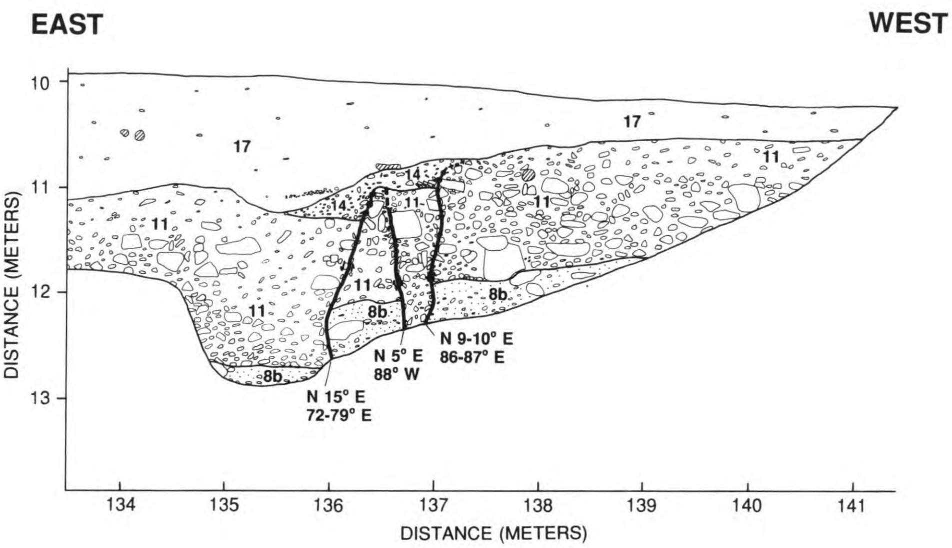
[1] *Descriptions do not necessarily include all of units 1 through 21; only units exposed in this part of this trench are included.*

[2] *Deposited during the Bonneville lake cycle. Lake Bonneville occupied part of the eastern Great Basin from about 30 kya to 12 kya (Scott and others, 1983; Oviatt and others, 1992). Lake Bonneville first transgressed across the Big Canyon site about 20 kya and regressed across the site about 13-14 kya.*

Figure 10. *Log of north wall of trench BC-3 between stations 24 and 26 at the Big Canyon site.*

Mapped by Susan S. Olig, Bea H. Mayes,
Bill D. Black, and William R. Lund
June 1992

Planimetric base constructed on a 1 m x 1 m grid
Drafted by Bea H. Mayes



EXPLANATION

UNIT DESCRIPTIONS[1]
(See appendix in text for detailed descriptions)

Holocene

17. Colluvium and colluviated loess
14. Antithetic-fault-scarp colluvium

Pleistocene

11. Regressive beach deposits[2]
8b. Transgressive beach deposits[2]

SYMBOLS

- Rock
- Bedding in sands
- Contact
- Fault, dashed where indistinct
- Scarp free-face (buried)
- Eroded scarp (buried)
- Krotovina

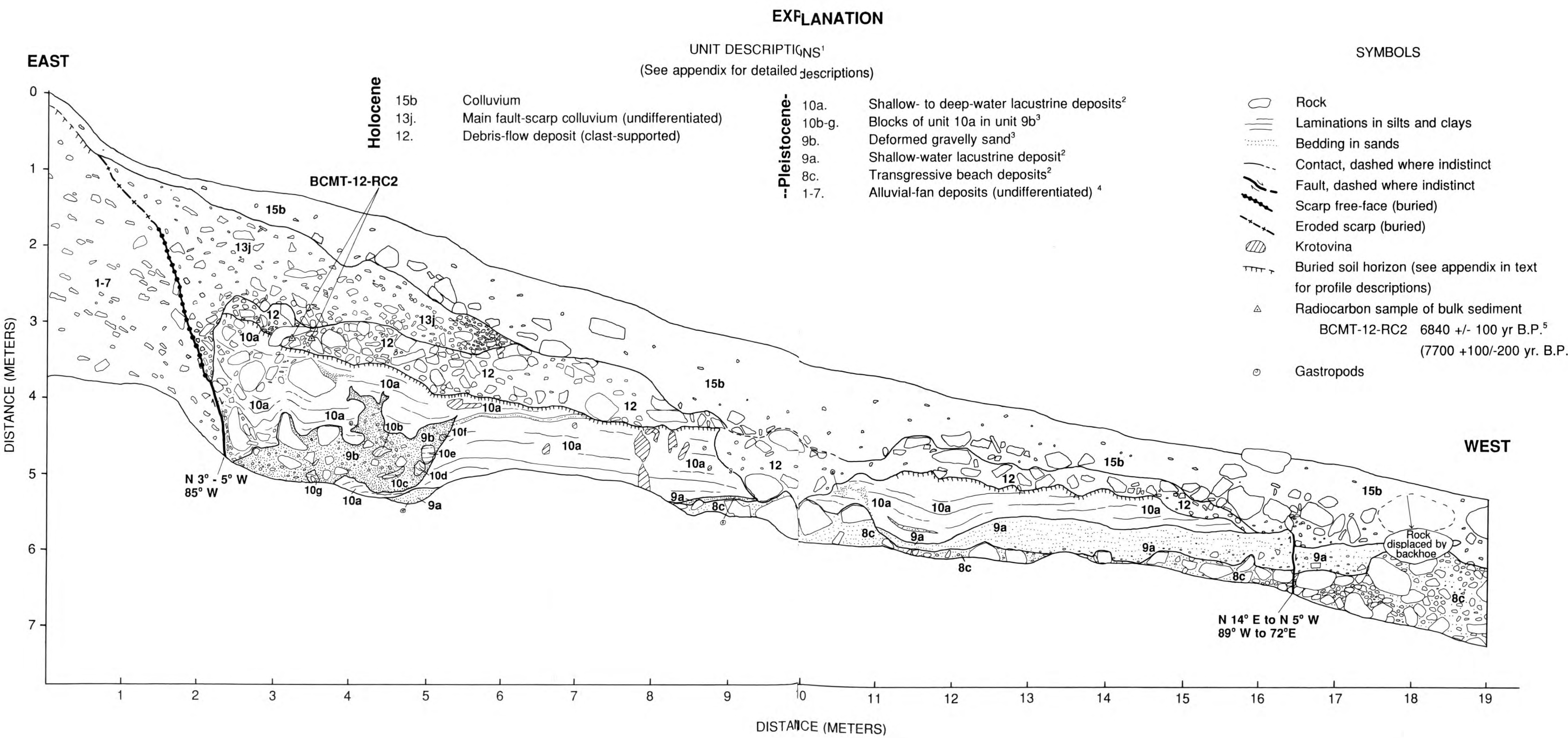
Footnotes:

[1]*Descriptions do not necessarily include all of units 1 through 21; only units exposed in this part of this trench are included.*

[2]*Deposited during the Bonneville lake cycle. Lake Bonneville occupied part of the eastern Great Basin from about 30 kya to 12 kya (Scott and others, 1983; Oviatt and others, 1992). Lake Bonneville first transgressed across the Big Canyon site about 20 kya and regressed across the site about 13-14 kya.*

Figure 11. *Log of the antithetic fault zone in trench BC-3 at the Big Canyon site.*

Mapped by Susan S. Olig, Bill D. Black, and William R. Lund
May 1992
Planimetric base constructed on a 1 m x 1 m grid
Drafted by Bea H. Mayes



[1]Descriptions do not necessarily include all of units 1 through 21; only units exposed in this part of this trench are included.

[2]Deposited during the Bonneville lake cycle. Lake Bonneville occupied part of the eastern Great Basin from about 30 kya to 12 kya (Scott and others, 1983; Oviatt and others, 1992). Lake Bonneville first transgressed across the Big Canyon site about 20 kya and regressed across the site about 13-14 kya.

[3]The origin of unit 9b is unclear, but it clearly is disturbed and the unit has, at least in part, been injected into unit 10a.

Figure 12. *Log of the main fault zone in trench BC-2 at the Big Canyon site.*

[4]This unit is stratigraphically equivalent to units 1 through 7 exposed in the footwall of trench BC-3. It contains interbedded debris-flow deposits and stream alluvium similar to unit 1, 3, 5, and 7 in trench BC-3, but interbedded loess deposits (units 2, 4, and 6 in trench BC-3) are missing, and so the unit was left undifferentiated.

[5]Age in radiocarbon years before 1950 A.D. Correction was not made for isotope fractionation in nature.

[6]Calendar-corrected age using the method of Stuiver and others (1993), with a lab error multiplier of 2, and an age span of 300 years. Doesn't inclue correction for mean residence time.

Figure 12 (continued)

Table 1.
Radiocarbon ages for samples collected from trenches across the Oquirrh fault zone.

Location (Site and trench)[1]	Field and laboratory numbers	Sample material[2] and unit sampled	Radiocarbon age[3] and laboratory error (yr B.P.)	Calibrated age[4] and range of 1σ (cal B.P.)	Remarks
BIG CANYON					
Trench BC-1	BCNN-19-1 BETA 60645	Bulk sediment, matrix of unfaulted stream alluvium, unit 19	4,340 ± 60	4,900 (4,800 - 5,000)	Minimum limiting age for the most recent event
Trench BC-2	BCMT-12-RC2 BETA 55559	Bulk sediment, matrix of faulted debris-flow deposit, unit 12	6,840 ± 100	7,600 (7,500 - 7,900)	Best maximum limiting age for the most recent event
Trench BC-3	BCST-12-1 BETA 55560	Bulk sediment, matrix of faulted debris-flow deposit, unit 12	7,650 ± 90	8,400 (8,200 - 8,600)	Maximum limiting age for the most recent event
	BCST-13f-4 BETA 55561	Bulk sediment, matrix of fault-scarp colluvium, debris facies, unit 13f	8,230 ± 120	9,200 (8,900 - 9,400)	Probably contains older detrital carbon
POLE CANYON					
Trecnch PC	OFPC-RC2 BETA 63545	Charcoal, Lake Bonneville transgressive marsh deposit, unit D1a	20,370 ± 120	Too old	Minimum limiting age for the penultimate event
Trench PC	OFPC-RC3 BETA 63546	Multiple small flecks of charcoal, fine-grained stream alluvium, unit B2	26,200 ± 220	Too old	Best maximum limiting age for the penultimate event. Average age for charcoal in stream deposit
Trench PC	OFPC-RC5 BETA 65456	Single fleck of charcoal, fine-grained stream alluvium, unit B2	33,950 ± 1,160	Too old	Best minimum limiting age for the antepenultimate event. Shows range in age of charcoal in unit B2

[1]Samples from the Big Canyon site were analyzed using the conventional gas-proportional method and all samples from the Pole Canyon site were analyzed using an accelerator mass spectrometer.

[2] Bulk sediment samples are the fine (<125μ) organic fraction concentrated using methods after Kihl (1975) by the Sedimentology Laboratory at INSTAAR, University of Colorado.

[3]Radiocarbon years before A.D. 1950 with a half-life of 5568 years and 95% of activity of the National Bureau of Standards oxalic acid used as modern standard. Lab errors represent 1σ. Ages for charcoal samples were corrected for fractionation to a base of $\delta^{13}C$ = -25%. Ages for bulk sediment samples not corrected for isotope fractionation.

[4]All ages for bulk sediment samples were rounded to the nearest century. Calibration procedure after Stuiver and Reimer (1993) using lab error multiplier of 2, the 20-year atmospheric record (data set 1), a carbon age span of 300 years (the maximum permissible), and the intercept method. Actual size spans for bulk sediment samples are probably closer to 1000 years, so σ may be larger than the stated values.

deposit (unit 12, figures 9 and 12). The soil profile is variably truncated, with the A horizon and part, to all, of the B horizon eroded away.

Trench BC-2 exposed evidence for soft-sediment deformation in unit 10. Sand and pea-size gravel, injected at high angles to bedding, formed extremely irregular and convoluted injection features within the unit (figure 12, between stations 2 and 6). Clasts larger than 50 centimeters were also incorporated into unit 10. The deformation clearly postdates deposition of the sand horizon in unit 10 and probably predates the subaerial exposure of the unit. The characteristics of the deformation and its localized distribution (not observed in trench BC-2) suggests it was caused by a debris flow entering Lake Bonneville, probably while the lake was at the Provo level. Alternatively, the deformation may be related to liquefaction induced by an earthquake that did not cause surface rupture on the Oquirrh fault zone. Although liquefaction of material as coarse as gravel is rare, it has happened, such as in the 1983 M_S 7.3 Borah Peak, Idaho, earthquake (Andrus and Youd, 1987; figure 1).

Unit 12 is an organic-rich debris flow and the youngest unit displaced by the main fault in trenches BC-2 and BC-3 (figures 9 and 12). In both trenches, unit 12 and underlying Bonneville sediments were deformed upward in a drag fold against the main fault during the most-recent surface-faulting earthquake. Although the matrix of unit 12 contains disseminated charcoal flecks and other organic material, a soil A horizon was not observed on this unit. We believe the unit's characteristic mottled texture and the disseminated charcoal resulted from a soil that was incorporated into the flow as it mobilized. If this is true, the organic material could possess a significant inherited age and is likely much older (possibly hundreds of years) than the debris flow. Bulk sediment samples from unit 12 yield radiocarbon age estimates of 6,840 ± 100 yr B.P. (trench BC-2) and 7,650 ± 90 yr B.P.(trench BC-3) (table 1). We believe that the roughly 800 ^{14}C years difference between the age estimates reflects the age span of the organic material from the incorporated soil rather than providing evidence for two debris-flow events. Studies of modern soil profiles on alluvial-fan sediments along the Wasatch Front suggest that the mean residence time of carbon can be as long as 800 years for A horizons and 2,000 years for C horizons (Stafford and Forman, 1993). Thus, an age span of 800 years appears reasonable for carbon incorporated into unit 12 from a pre-existing soil.

Because the radiocarbon age estimates from unit 12 are older than the debris-flow event, the youngest age provides the best constraint on the maximum age for most-recent faulting on the Oquirrh fault zone. The calendar-calibrated age, corrected for variations of ^{14}C production in the atmosphere (Stuiver and Quay, 1979) and rounded to the nearest century, is 7,600 -100, +300 cal B.P. See the footnotes for table 1 for details on the calibration method used and a caveat on standard deviation.

After the most-recent event, a thick wedge (2.6 to 2.8 m) of colluvium accumulated at the base of the main fault scarp and partially buried the scarp free face (figures 9 and 12). A smaller colluvial wedge (<0.5 m thick) was deposited at the base of the antithetic fault scarp (figure 11). Stratigraphic and geomorphic relations strongly suggest that the most-recent earthquake on the antithetic fault zone is contemporaneous with the most-recent earthquake on the main fault zone at the Big Canyon site. Fault-scarp-derived colluvium exposed in trench BC-3 included distinct upper and lower debris-element associations (units 13b through 13h) and a wash-element association (unit 13i), exhibiting many characteristics typical of deposits derived from normal fault scarps (Nelson, 1992). Unit 13j in trench BC-2 was more homogeneous and lacked distinctive slope and debris facies. It did have a 1.1-meter-long "heel," interpreted as a filled fissure at the base of the scarp free face.

A bulk sediment sample from an organic-rich section of unit 13f in trench BC-3 (figure 9) yielded a radiocarbon age estimate of 8,230 ± 120 yr B.P. (table 1). However, unit 13f contains reworked components of many older deposits (for example units 13b through 13e). Because this age estimate is older than the ages for the underlying unit (12), we believe that this sample contained older detrital carbon reworked into the wedge colluvium, possibly from unit 12, and therefore does not provide a best limiting age for the most-recent faulting.

Trench BC-1 exposed a 4-meter-thick package of unfaulted, interbedded debris-flow deposits and alluvium (figure 13) that buries the main fault scarp (figure 6). A bulk sediment sample from unit 19 yielded a radiocarbon age estimate of 4,340 ± 60 yr B.P. and a calendar-calibrated age of 4,900 ± 100 cal B.P. (table 1). Similar to the other bulk sediment samples, this age estimate provides a maximum limiting estimate for the age of the deposit due to the age span of the detrital carbon in the sample. However, there is at least a half a meter of older, unfaulted deposits underlying unit 19; therefore, we believe that the age estimate from unit 19 provides a reasonable minimum age limit for the most-recent surface faulting on the Oquirrh fault zone even though the actual age of unit 19 might be slightly younger than 4,900 years.

Structure: In trench BC-2, the main fault consists of a single splay, striking N. 3-5° W. and dipping 85° W. (figure 12), characterized by well-developed shear fabric. In trench BC-3, the main fault is about 2 meters wide with a 20-centimeter-wide zone of intense shearing. Four smaller faults are present in the hanging wall (figure 8). The shear zone strikes N. 17-22° E. and dips 79-82° W. Drag folding of hanging-wall sediments is present in both trenches, but is particularly pronounced in trench BC-3. The antithetic fault zone in trench BC-3 consists of three, near-vertical splays oriented from N. 5° E. to N. 15° E., forming a zone about 1 meter wide.

Earthquake Timing

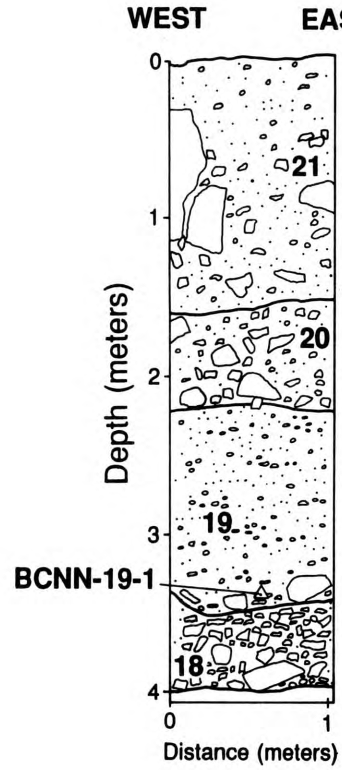
Evidence from surficial geologic mapping, scarp profiling, and three trenches at the Big Canyon site indicates that the most-recent surface-faulting earthquake on the Oquirrh fault zone occurred between 4,300 and 6,900 ^{14}C years ago (4,800 and 7,900 cal B.P.). Additionally, Lake Bonneville sediments are offset by only the most-recent event, indicating that no surface-faulting events took place on the fault zone between 8,000 and 20,000 years ago. Localized deformation of Lake Bonneville sediments seen in the trenches probably occurred between 14,500 and 13,000 years ago, and could have been caused by a non-surface-faulting earthquake, but more likely is related to a debris flow entering the near-shore zone of the lake and causing soft-sediment deformation.

Mapped by Susan S. Olig, Bill D. Black, and William R. Lund

October 1992

Planimetric base constructed on a 1 m X 1 m grid

Drafted by Bea H. Mayes



EXPLANATION

UNIT DESCRIPTIONS[1,2]

(See appendix for detailed descriptions)

Holocene
- 21. Alluvial-fan deposits
- 20. Debris-flow deposit
- 19. Stream-channel deposit
- 18. Stream alluvium

SYMBOLS

Rocks

Contacts

Radiocarbon sample of bulk sediment

BCNN-19-1 4340 +/- 60 yr B.P.[3] (4,900 ±100 cal B.P.)[4]

Figure 13. *Log of part of trench BC-1 showing stratigraphic relations of unfaulted Big Canyon alluvial-fan deposits.*

Displacement

Net vertical tectonic displacement is a measure of vertical slip across a fault zone produced by a surface-faulting earthquake (Schwartz, 1988). It consists of apparent slip minus the effects of backtilting, antithetic faulting, and other near-field deformation. Determining the net vertical tectonic displacement per event provides an estimate of individual earthquake size and allows a comparison between successive surface-faulting earthquakes on a fault zone. A scarp profile can be used to estimate net vertical tectonic displacement if the same undeformed surface can be identified on both sides of the fault zone (Bucknam and Anderson, 1979b).

Unfortunately, net vertical tectonic displacement for the most-recent event at the Big Canyon site cannot be directly measured from trench exposures or scarp profiles. However, by making some assumptions about scarp height, net slip can be estimated from trench exposure and scarp-profile data. Models of normal-fault scarp formation and degradation suggest that scarp heights are typically twice the wedge thickness as long as the slopes of offset surfaces are not too steep and recurrence intervals are not too short (Ostenaa, 1984). Thicknesses of most-recent-event colluvial wedges range from 2.6 meters (including the "heel" of the wedge, trench BC-3) to 2.8 meters (trench BC-2) at the Big Canyon site. Assuming that associated scarp heights for this event were twice the wedge thickness yields a height range of 5.2 to 5.6 meters. Antithetic faulting and backtilting in the hanging wall along with offset of a sloping ground surface accentuated the scarp height, whereas drag folding has decreased scarp height in relation to the net vertical tectonic displacement at the Big Canyon site.

We calculate that for an 80 degree dipping fault and 6 degree dipping surface slope, scarp height is about 0.1 meters greater than surface offset. We measured 0.8 meters of total vertical separation at the base of unit 11 across the antithetic fault zone in trench BC-3. The base of unit 11 can also be used to estimate backtilting. This contact dips 3 degrees west in pit exposures about 100 meters east of the main fault scarp. In trench BC-3, this contact dips 0 degrees within the graben east of the antithetic fault, suggesting about 3 degrees of backtilting to the east. Using an inflection point between stations 75 and 80 (figure 8) to remove 3 degrees of backtilting for the base of unit 11 yields 3.0 to 3.2 meters of backtilting at the fault. Finally, we measured 0.9 to 1.0 meters of drag folding on the tops of units 8 and 10.

Thus, starting with an estimated scarp height of 5.2 to 5.6 meters, and then: (1) subtracting 0.1 meters to account for the difference between surface offset and scarp height on a sloping surface, (2) subtracting 0.8 meters of antithetic faulting, (3) subtracting 3.0 to 3.2 meters of backtilting, and (4) finally adding 0.9 to 1.0 meters of drag folding produces an estimated net vertical tectonic displacement of 2.0 to 2.7 meters for the most-recent event at the Big Canyon site. Our "best estimate" for net vertical tectonic displacement at Big Canyon is 2.2 meters. We arrived at that estimate by (1) assuming that 5.2 meters is the best estimate for scarp height at Big Canyon because the wedge in trench BC-2 did not have a heel or fissure fill, (2) subtracting 0.1 meters to account for the difference between surface offset and scarp height on a sloping surface, (3) subtracting 0.8 meters of antithetic faulting, (4) subtracting 3.1 meters of backtilting, and (4) adding 1.0 meter of drag folding.

Pole Canyon Site

Surficial Geology

The Pole Canyon site lies on a broad, wave-cut surface at the base of the Oquirrh Mountains 2.7 kilometers southwest of the Big Canyon trench site, and 1.7 kilometers northwest of the mouth of Pole Canyon (figure 2). Surficial geologic deposits in the area consist of coarse-grained Lake Bonneville sediments, post-Bonneville alluvial fans, and areas of undifferentiated lacustrine and older, reworked alluvial deposits (Solomon, 1993; figure 14).

The Oquirrh fault zone at the Pole Canyon site consists of a single, sinuous, west-facing, multiple-event scarp nearly 14 meters high. Neither east-facing antithetic scarps nor a graben are evident at the ground surface. The elevation at the base of the fault scarp at the trench site is about 1,448 meters, placing it roughly 40 meters below the Provo shoreline of Lake Bonneville. Numerous other minor shorelines of Lake Bonneville parallel topographic contours at elevations both above and below the trench site. The fault scarp is distinguishable from the shorelines because it usually does not parallel topographic contours and it offsets several shorelines, including the Provo shoreline just south of the trench site (figure 14). Currey and Burr's (1988) linear model of threshold-controlled shorelines of Lake Bonneville indicates that the lake regressed from the Pole Canyon site shortly after 14,200 years ago, providing a maximum limiting age for the most-recent faulting.

The fault scarp at the Pole Canyon trench site is geomorphically, tectonically, and stratigraphically complex. Both the scarp profile (figure 15) and the trenching (discussed in later sections) showed that the scarp represents multiple surface-faulting earthquakes. Stratigraphic relations in the trench show that material was eroded from the scarp as Lake Bonneville transgressed across the site. East of the trench site both the Bonneville and Provo shorelines are retrograde features (Currey, 1982) marked by prominent erosional escarpments (figure 16). A topographic profile extending from the Oquirrh Mountains through the Pole Canyon site (figure 17) indicates that more than 20 meters of pre-Bonneville alluvial-fan material was eroded by Lake Bonneville from the surface on which the trench is located. The eroded material was transported by longshore currents along the mountain front and probably deposited in Stockton Bar, a large Lake Bonneville depositional feature south of Tooele (Gilbert, 1890; Burr and Currey, 1988).

After eroding the pre-lake land surface, Lake Bonneville deposited a veneer of mostly coarse-grained sediment on the wave-cut surface as it transgressed to and then regressed from its highstand. Before regressing from the site, Lake Bonneville etched a small (1.5 meter high) shoreline into the fault scarp a few meters east of the trench (figure 15). Following the Bonneville lake cycle, the degraded and sediment-draped scarp was

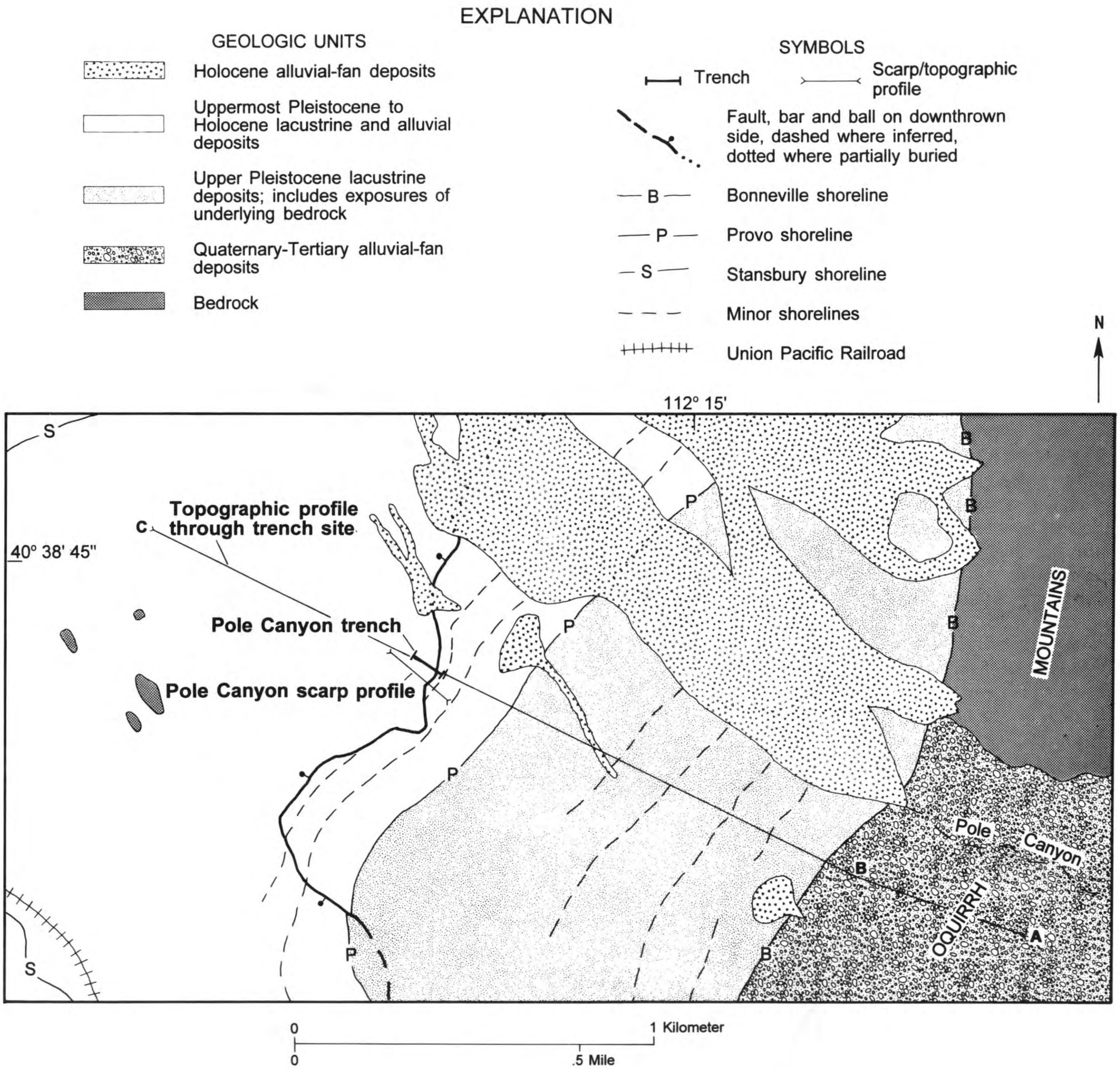


Figure 14. Generalized geologic map of the Pole Canyon site (modified from Solomon, 1993; this volume).

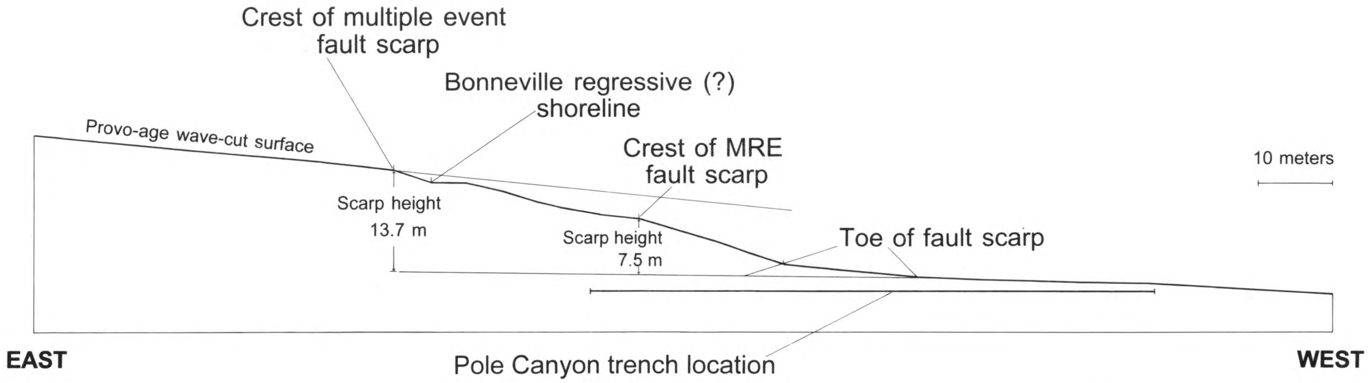


Figure 15. *Topographic scarp profile at the Pole Canyon trench site. Because the scarp was eroded and later draped with lacustrine sediment by Lake Bonneville, the profile could not be used to estimate net vertical tectonic displacement across the fault zone.*

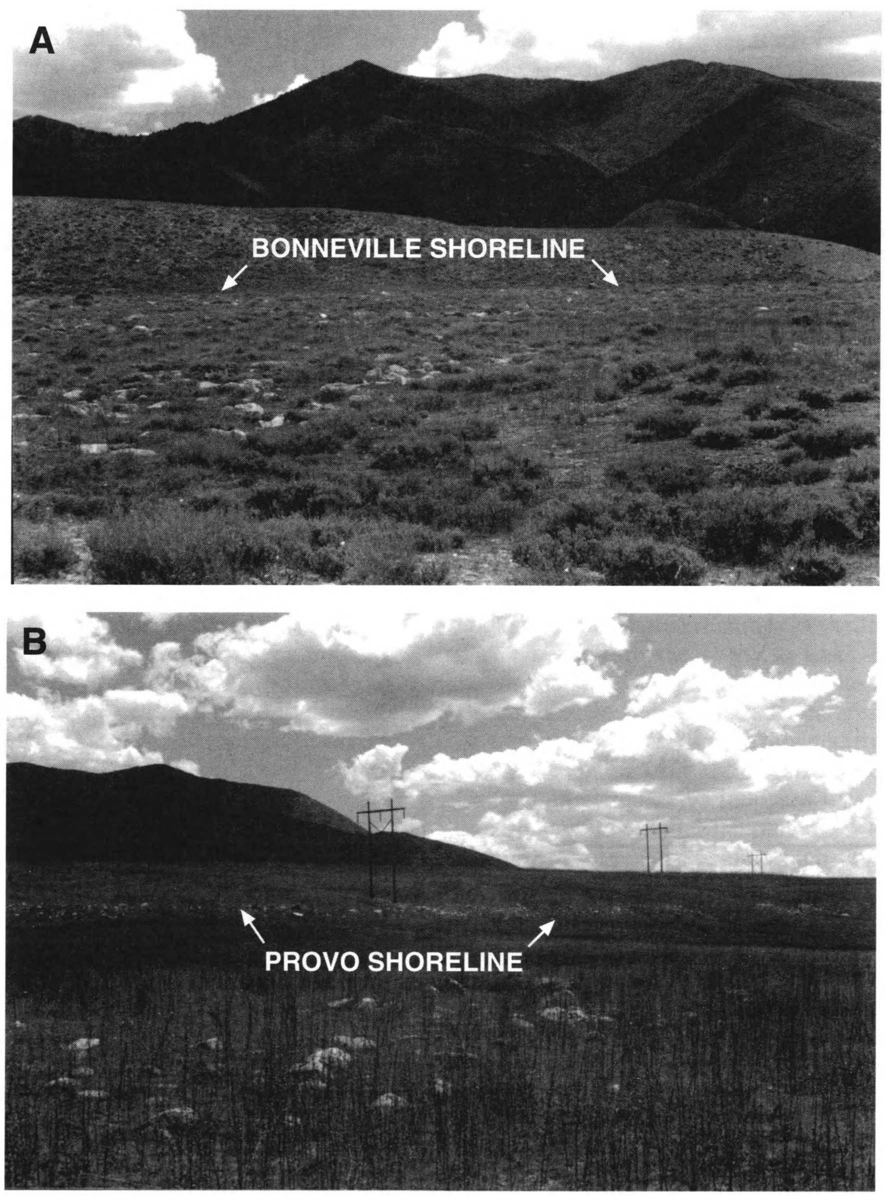


Figure 16. *Photographs of the (A) Bonneville and (B) Provo shoreline escarpments east of the Pole Canyon trench site.*

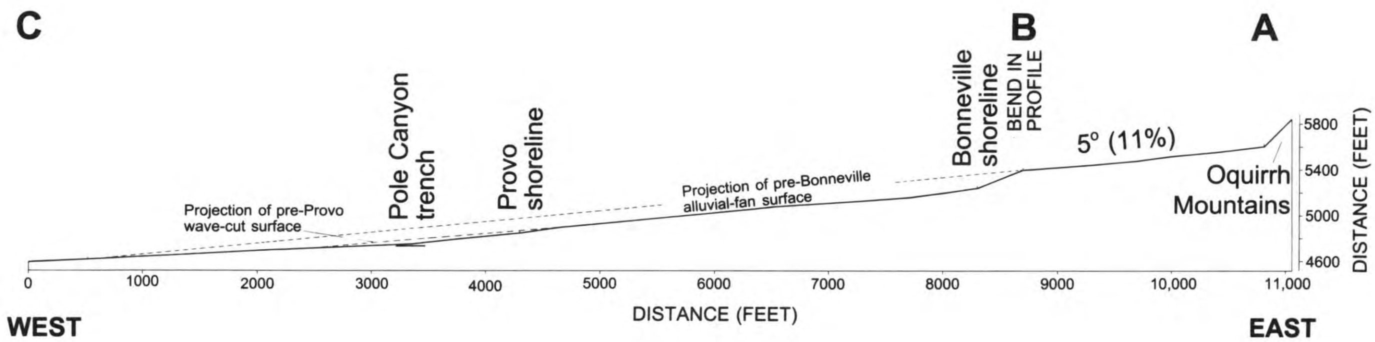


Figure 17. *Topographic profile measured from the Oquirrh Mountains through the Pole Canyon trench site.*

further modified by the most-recent surface-faulting earthquake and by subsequent erosion and mantling of the most-recent-event scarp by slope-wash colluvium.

Trench Exposure

A single 76-m-long, 11-m-deep trench was excavated at the Pole Canyon site. It exposed direct stratigraphic and structural evidence for the two youngest surface-faulting earthquakes on the fault zone , and indirect stratigraphic evidence for a third, older surface-faulting event. We extended the trench from the top of the steep (20°) lower portion of the scarp westward onto the downthrown side of the fault zone (figure 15) to detect any antithetic faults, a buried graben, or stratal backtilting; none were encountered (plate 1).

Stratigraphy: Deposits in the Pole Canyon trench were grouped into seven stratigraphic packages, A through G (see appendix and plate 1), each package representing either a unique depositional environment during late Pleistocene or Holocene time, or providing stratigraphic evidence for a surface-faulting earthquake. Some stratigraphic packages consist of a single geologic deposit (for example, stratigraphic package G), whereas others could be subdivided into units (for example B1, B2, B3) that exhibit similar generic, textural, or stratigraphic characteristics. Some of those units could be further divided into subunits based chiefly on textural characteristics (for example, B1a, B1b, B1c).

Stratigraphic package A includes the oldest geologic deposits in the trench. They lie at the base of the east end of the trench (plate 1, stations 1 to 9.5). Unit A1 consists of horizontally bedded alluvial and eolian deposits truncated by a buried paleoslope. The paleoslope is draped by colluvial and eolian deposits of unit A2. Fluvial deposits of unit A3 either incise unit A2 or mantle the paleoslope. Two paleosols (S1 and S2) developed on stratigraphic package A at different locations in the trench. The paleosols are probably equivalent in age, but can not be correlated within the trench exposure. Both paleosols exhibit weakly developed, clay-enriched Bt horizons, indicating that the unconformity separating stratigraphic package A from overlying deposits represents a former land surface that remained stable for considerable time.

A short distance further west and stratigraphically higher in the trench (plate 1, stations 13 to 21), a similar relation exists between stratigraphic packages B and G. There, colluvium of stratigraphic package G mantles the most-recent surface-faulting earthquake's degraded scarp free face which is eroded across horizontally bedded deposits of stratigraphic package B. The similarity between the stratigraphic relations in the two parts of the trench is striking. Based on that similarity, stratigraphic package A is interpreted as representing an eroded and colluvium-mantled scarp free face formed following a surface-faulting earthquake. The event occurred before stratigraphic package B was deposited and therefore predates the penultimate (second oldest) event which displaced unit B down to the west (see later discussion of penultimate-event faulting). The fault and colluvial wedge associated with this third oldest (antepenultimate) surface-faulting earthquake are buried beneath the floor of the trench.

Stratigraphic package B unconformably overlies stratigraphic package A. It consists of pre-Bonneville interbedded, coarse- and fine-grained fluvial deposits that postdate the antepenultimate event and predate the penultimate event. Unit B1 consists of several, interbedded, well-sorted and washed, coarse-grained gravel beds (subunits B1a through B1j, plate 1). All of the gravel beds are either stratigraphically below, interbedded with, or truncated by unit B2, a fine-grained deposit of laminated silt and clay occupying a paleostream channel incised into unit B1. Detrital charcoal collected from unit B2 yield radiocarbon age estimates of 26,200 ± 220 yr B.P. and 33,950 ± 1160 yr B.P. (plate 1 and table 1). Unit B3 is a coarse-grained fluvial unit interbedded with unit B2. Unit B4 is a "sliver" of stratigraphic package B downfaulted to the west along with the penultimate-event colluvial wedge by the most-recent surface-faulting earthquake. Unit B5 is a fine-grained silty and clayey deposit underlying the penultimate-event colluvial wedge. It is likely a continuation of unit B2 on the downthrown side of the fault zone but the exposure was too small to permit a definitive correlation. Based on the radiocarbon age estimates from unit B2, stratigraphic package B is late Pleistocene in age. This fluvial sequence is stratigraphicly below and therefore older than the Lake Bonneville deposits in the trench.

Stratigraphic package C is the penultimate-event colluvial wedge. It formed as material was eroded from the top and then deposited at the base of the penultimate-event scarp. Stratigraphic package C contains considerable sand and gravel (see appendix), but it also includes a high percentage of silt and clay, giving the wedge a generally fine-grained appearance. The source of the silt and clay is believed to be unit B2, which was exposed in the scarp free face following the penultimate event. The colluvial wedge rests unconformably on unit B5, a probable continuation of unit B2 on the downthrown side of the fault zone (plate 1).

A buried soil (paleosol S3) at the top of stratigraphic package C (plate 1) consists of a weak, clay-enriched Bt horizon overlying a Bk horizon. No A horizon was present, indicating that the original soil profile has likely been truncated by erosion. The Bt horizon exhibits thin clay skins and prismatic soil structure; the Bk horizon shows stage II $CaCO_3$ accumulation. The paleosol is evidence that the penultimate-event colluvial wedge was exposed at the ground surface for considerable time before being buried by stratigraphic package D.

Stratigraphic package D consists of Lake Bonneville deposits. Nearshore transgressive sediments deposited on the downthrown side of the fault zone comprise unit D1. Subunit D1a, a pale-yellow silty clay layer a few tens of centimeters thick, rests directly on stratigraphic package C (the penultimate-event colluvial wedge). The clay layer is thought to be the "green clay," a lake-marginal marsh deposit commonly found at the base of Bonneville lake-cycle sediments (D.R. Currey, verbal communication, 1993). Charcoal from subunit D1a yielded a radiocarbon age estimate of 20,370 ± 120 yr B.P. (table 1), which constrains the timing of Lake Bonneville's transgression across the site.

Subunits D1b and D1c consist of coarse-grained sand, gravel, and cobbles deposited in a high-energy, nearshore environment. Subunit D1b exhibits crude bedding that dips steeply (50-60°) toward the fault zone near the bottom of the deposit, but becomes progressively less steep near the top of the deposit (plate 1). The change in dip is a primary depositional feature, suggesting that subunit D1b was a prograding bar that formed as Lake Bonneville transgressed toward and eventually crossed the fault scarp. A few meters west of the scarp, subunit D1a splits into two parts (plate 1, station 31). Most of it continues beneath unit D1b; however, a thin stringer extends westward and upward into unit D1b parallel to bedding at an angle of about 35 degrees. The split is interpreted to represent a pause in Lake Bonneville's transgression, during which fine-grained sediment was deposited in a pond that existed between the temporarily stable prograding bar and the fault scarp. Once Lake Bonneville resumed its transgression, the pond quickly filled with coarse-grained sediment burying the fine-grained layer.

As it crossed the penultimate-event scarp, Lake Bonneville encountered and began to erode the fine-grained sediment of unit B2 on the upthrown side of the fault. Stratigraphic relations in the trench (plate 1, stations 5 to 20) show that a minimum of 1.5 meters of unit B2 was removed by the lake before coarse-grained unit D2 was deposited disconformably on the wave-cut surface. Unit D3, a layer of lacustrine, brown silty clay, was then deposited conformably on the nearshore sands and gravels of unit D2. Unit D3 may represent deep-water deposition as Lake Bonneville neared the Bonneville shoreline. When the lake reached its highstand, the Pole Canyon site was under more than 135 meters of water (figure 4). Alternatively, unit D3 may represent deposition in the calm water of a lagoon or other protected environment prior to the lake reaching its highest elevation. This alternative is suggested because unit D3 is only locally present in the trench (upthrown block) and it pinches out to the west against unit D2.

The waning phase of Lake Bonneville is represented by unit D4, a very coarse-grained, regressive beach deposit. Numerous large boulders and areas of extremely strong (concrete-like) tufa cementation (especially on the upthrown side of the fault zone) make unit D4 a distinctive and easily recognized unit in the Pole Canyon trench (plate 1). It is the only geologic deposit that can be conclusively identified on both sides of the fault zone. Unit D4 was deposited across whatever remained of the eroded and sediment-draped penultimate-event scarp shortly after 14,200 years ago as Lake Bonneville regressed from the Provo shoreline under closed-basin conditions. No evidence of soil development, representing prolonged post-Bonneville exposure at the ground surface, was found on unit D4.

Stratigraphic package E is a poorly sorted, post-Bonneville, subaerial deposit consisting of brown, clayey, sandy gravel. The deposit's genesis is uncertain, but it is probably the remnant of a debris flow from the Oquirrh Mountains that flowed across part of the site. Stratigraphic package E is only present in a small area of the trench on the upthrown side of the fault zone. It rests directly on the Lake Bonneville regressive beach deposit (unit D4) and is truncated on the west by the eroded free face of the most-recent-event scarp. Because of its probable genesis and geomorphic position, we believe that stratigraphic package E's absence on the downthrown side of the fault zone is due to non-deposition rather than erosion.

Stratigraphic relations in the trench clearly show that stratigraphic package E postdates Lake Bonneville. The unit's relation to the most-recent-event eroded scarp free face implies a pre-most-recent-event age, although it is possible that the unit was deposited after the most-recent event but before the scarp free face was substantially eroded. Later erosion then truncated the unit creating the geomorphic relations observed in the trench. Either interpretation is possible and neither possibility affects the interpretation of the size and timing of surface faulting on the fault zone.

Stratigraphic package F is the most-recent surface-faulting earthquake colluvial wedge. It formed as material from the upper part of the most-recent-event scarp was eroded and then deposited at the base of the scarp. This colluvial wedge is much coarser grained then the penultimate-event wedge because the geologic deposits exposed in the most-recent-event scarp were mostly coarse-grained units of stratigraphic packages B and D. The most-recent-event wedge rests unconformably on the regressive beach deposits of unit D4. There is no evidence of soil formation on the wedge.

Stratigraphic package G consists of post-most-recent-event colluvium mantling the fault scarp. It was deposited after scarp erosion and colluvial-wedge deposition had created a degraded (less steep) scarp surface across which slope wash could flow. Other than the most-recent-event colluvial wedge, stratigraphic package G is the only geologic deposit in the trench that postdates all surface faulting at the site.

Structure: The Oquirrh fault zone is exposed in the Pole Canyon trench as a roughly north-south-trending (N. 18-32° E.), high-angle (66-77°), predominantly normal-slip fault displacing unconsolidated deposits of stratigraphic packages B, C, and D down to the west (plate 1). No evidence of antithetic faulting stratal backtilting, or other secondary (minor) deformation was exposed in the trench.

The fault zone and related tectonic colluvial-wedge deposits provide direct evidence for two surface-faulting earthquakes on the Oquirrh fault zone. One event predates Lake Bonneville's transgression across the site, and the other occurred in post-Bonneville time. Faults F1 and F2 (plate 1) are related to the most-recent and penultimate surface-faulting earthquakes, respectively. During the most-recent surface-faulting earthquake, a small remnant of stratigraphic package B (unit B4) was displaced down to the west on fault F1 along with the penultimate-event colluvial wedge (stratigraphic package C), thus preserving part of the penultimate-event scarp free face on the downthrown side of the fault.

Limitations on the depth of the trench constrained what could be deduced regarding displacement on fault F2 during the penultimate event. Unit B5 beneath the penultimate-event colluvial wedge is textually similar to unit B2 on the upthrown side of the fault zone. However, even with additional hand excavation in the fault zone, a definitive correlation could not be made with confidence between the two units.

Although structural evidence for a third, older surface-faulting earthquake was not exposed in the trench, there is strong indirect stratigraphic evidence (see discussion of stratigraphic package A) for an antepenultimate surface-faulting earthquake on the fault zone. The position of the antepenultimate event's eroded scarp free face in the trench wall indicates that the fault on which that earthquake occurred is probably located several meters east of faults F1 and F2. No evidence was found in the trench to indicate why faulting migrated westward during the past two surface-faulting earthquakes.

Earthquake Timing

Radiocarbon Age Estimates: Five samples (OFPC-RC1 through OFPC-RC5) were collected from the Pole Canyon trench for radiocarbon dating. Radiocarbon age estimates were obtained for three of the samples (OFPC-RC2, OFPC-RC3, and OFPC-RC5; table 1) using the accelerator-mass-spectrometer technique. All three age estimates are from detrital charcoal. Sample OFPC-RC1 was also detrital charcoal, but it was in poor condition (oxidized) and not a good candidate for radiocarbon analysis (Beta Analytic, Inc., written communication, 1993). Sample OFPC-RC4 proved to be nonorganic (possibly manganese) and could not be analyzed. All three radiocarbon age estimates from the Pole Canyon trench are too old to calendar calibrate.

Two of the age estimates (OFPC-RC3 and OFPC-RC4) came from unit B2 on the upthrown side of the fault zone (plate 1). Sample OFPC-RC3 consisted of several small flecks of charcoal collected from an approximately two-square-meter area of unit B2. The flecks were combined to create a single sample which provided an "average" radiocarbon age estimate of 26,200 ± 120 yr B.P. Sample OFPC-RC4 consisted of a single, larger piece of charcoal from the same area of unit B2. It yielded a ^{13}C adjusted radiocarbon age estimate of 33,950 ± 1160 yr B.P. The two age estimates show that the detrital charcoal in unit B2 extends across an age range of several thousand years. This is not unexpected since unit B2 is a channel-fill deposit of a paleostream that likely drained from the Oquirrh Mountains. Charcoal in the unit was undoubtedly derived from a variety of sources of different ages in the stream's drainage basin. However, the generally close correspondence of the two age estimates (within in a few thousand years) shows that unit B2 is a late Pleistocene deposit, although the unit must be somewhat younger than the detrital charcoal contained within it.

The third age estimate (OFPC-RC2) is from unit D1a, the lake-marginal marsh deposit at the bottom of the Bonneville sediments on the downthrown side of the fault zone. The unit directly overlies the penultimate-event colluvial wedge (plate 1), showing that it is younger than the penultimate event. Sample OFPC-RC2 consisted of a single dime-size piece of charcoal (probably a remnant of marsh vegetation) and yielded a radiocarbon age estimate of 20,370 ± 120 yr B.P.

Most-Recent-Event Timing: The Pole Canyon trench provided neither stratigraphic relations nor dateable organic material that allowed the timing of the most-recent surface-faulting earthquake on the Oquirrh fault zone to be constrained more closely than was possible at the Big Canyon trench site (see discussion of Big Canyon trench site). The most-recent-event colluvial wedge in the Pole Canyon trench rests directly on Lake Bonneville regressive beach deposits (unit D4), demonstrating that the earthquake is post-Bonneville in age. The contact between the two units showed no evidence of soil development on the beach deposit, eliminating the possibility of dating bulk soil organics to obtain a maximum limiting age for the event. The lack of soil development and the absence of subaerial deposits between the beach deposit and the colluvial wedge implies that the most-recent event occurred soon after Lake Bonneville regressed from the site. However, evidence from the Big Canyon site shows that the most-recent surface-faulting earthquake actually occurred several thousand years after the Lake Bonneville regression. The lack of soil development on unit D4 might be related to the strong tufa cementation of the unit, which may have retarded the downward translocation of silt and clay and thus slowed the pedogenic process.

The top of the most-recent-event colluvial wedge was also examined for soil development. None was identified, indicating that the wedge was buried by colluvium (stratigraphic package G) before sufficient time passed for a soil to form. The wedge has an organic matrix that might have provided enough bulk carbon for a radiocarbon age estimate. However, because carbon in colluvial wedges can come from a variety of sources of different ages, the significance of an age estimate on the matrix would be difficult to interpret (Forman, 1989), especially in the absence of constraining dates above and below the wedge. For that reason, the wedge matrix was not dated, and all that can be confidently stated about the timing of the most-recent surface-faulting earthquake on the Oquirrh fault zone based on evidence from the Pole Canyon trench is that it occurred after Lake Bonneville regressed from the site.

Penultimate-Event Timing: The three radiocarbon age estimates from the Pole Canyon trench help constrain the timing of the penultimate event on the Oquirrh fault zone. Age estimates OFPC-RC3 and OFPC-RC5 from unit B2 predate the penultimate event and provide an upper limit for the time of faulting. Because OFPC-RC3 gives an average age for unit B2 (see section on Radiocarbon Age Estimates), 26,200 ± 220 yr B.P. is the preferred maximum limiting age for the penultimate event. The third date, OFPC-RC2, postdates the penultimate event and provides a minimum limiting age for the faulting. Therefore, the penultimate event occurred sometime within the approximate 6,200 ^{14}C year window between 26,440 and 20,250 yr B.P. (one-sigma laboratory error limits added to OFPC-RC3 and subtracted from OFPC-RC2 to give the maximum time window).

Stratigraphic and pedologic relations that might otherwise help locate the penultimate event more closely within the radiocarbon time window proved contradictory and were of no use in constraining the time of faulting. Paleosol S3 on the penultimate-event colluvial wedge (stratigraphic package C) exhibits a weak, clay-enriched Bt horizon. That degree of pedogenic development implies that the penultimate-event wedge was exposed at the ground surface for considerable time (possibly thousands of years) before being buried by Lake Bonneville deposits, and argues for placing the penultimate event toward the distal part of the radiocarbon time window. Conversely, the penultimate-event colluvial wedge lacks the colluvial mantle that frequently develops as a fault scarp erodes to a more stable configuration (note stratigraphic package G's relation to the most-recent-event colluvial wedge). Instead, the penultimate-event wedge is directly overlain by Lake Bonneville deposits, implying that the lake transgressed across the wedge before a colluvial cover could accumulate. That relation argues for placing the penultimate event toward the proximal part of the radiocarbon time window closer to Lake Bonneville's transgression. It is possible that the transgressing lake eroded the colluvium overlying the penultimate-event wedge; however, that explanation fails to account for the presence of paleosol S3 and the apparent long period of soil formation that followed the penultimate event. Because the evidence is contradictory, it is not possible to select a "best estimate" for the timing of the penultimate event other than to place it in the middle of the radiocarbon time window at 23,350 ^{14}C years ago. Assigning this timing to the penultimate event is arbitrary, but it minimizes the error between a "best estimate" and the actual time of faulting.

Antepenultimate-Event Timing: There is little evidence to constrain the timing of the antepenultimate earthquake. Unit B2 unconformably overlies stratigraphic package A, which contains indirect stratigraphic evidence for an antepenultimate event. Charcoal from unit B2 yielded a radiocarbon age estimate of 33,950 ± 1160 yr B.P., so the antepenultimate event is older than that age estimate. The unconformity between stratigraphic packages A and B is marked by paleosols S1 and S2, which exhibit weakly developed, clay-enriched Bt horizons (see Stratigraphy section). The paleosols indicate that a long soil-forming interval followed the antepenultimate event and preceded stratigraphic package A's burial. Therefore, the antepenultimate event is certainly older than 33,950 ± 1160 yr B.P., but how much older depends on the amount of time represented by the unconformity between stratigraphic packages A and B, and the time required for a colluvium-mantled scarp free face to develop following the antepenultimate event. That interval could be thousands or even tens of thousands of years long.

Displacement

Because the fault scarp at the Pole Canyon site has been modified by Lake Bonneville (first eroded and later draped with lacustrine sediments), net vertical tectonic displacement across the scarp cannot be determined from a scarp profile. However, net slip can be estimated for the most-recent and penultimate events using stratigraphic relations in the trench and the size of the colluvial wedges associated with those earthquakes.

Most-Recent-Event Net Slip: Net vertical tectonic displacement can be estimated for the most-recent surface-faulting earthquake using the tufa-cemented, regressive beach deposit (unit D4), which predates the event and provides a distinctive marker horizon on both sides of the fault zone. We measured 3.3 meters of down-to-the-west vertical stratigraphic separation across the fault zone at the base of unit D4. However, some of the offset results from unit D4 being draped across the pre-Lake Bonneville fault scarp. Reconstruction of stratigraphic package D, on both sides of the fault zone prior to the most-recent event indicates a 0.6 meter difference in elevation (down to the west) across the fault at the base of unit D4. That difference represents the pre-event drape of unit D4 across the scarp and must be subtracted from the total stratigraphic separation to arrive at a best estimate of net slip for the most-recent event of 2.7 meters. The thickness of the most-recent event colluvial wedge is 2.2 meters, which is a minimum estimate of displacement for the most-recent event. The 3.3 meters of vertical stratigraphic separation at the base of unit D4 is considered a maximum estimate for most-recent-event net slip. The absence of antithetic faulting and stratal backtilting made adjustments for those features unnecessary when calculating the net vertical tectonic displacement across the fault zone at the Pole Canyon site.

Penultimate-Event Net Slip: Stratigraphic relations necessary to directly measure the net vertical tectonic displacement produced by the penultimate event were not exposed in the Pole Canyon trench. However, a rough estimate of net slip can be obtained by comparing the thicknesses of the penultimate- and most-recent-event colluvial wedges and the calculated net slip for the most-recent event. The most-recent-event colluvial wedge is 2.2 meters thick, which is 82 percent of the "best estimate" of the net vertical tectonic displacement for the most-recent-event net slip (2.7 m), and 67 percent of the maximum estimated slip (3.3 m). By comparison, the penultimate-event colluvial wedge is 1.9 meters thick. If it is assumed that the thickness of the penultimate-event wedge is also roughly 82 percent of the net vertical tectonic displacement produced by that event, a "best estimate" for penultimate-event net slip is 2.3 meters. The thickness of the colluvial wedge, 1.9 meters, provides a minimum estimate of net vertical tectonic displacement. Assuming that the penultimate-event wedge thickness represents 67 percent of the net slip yields a maximum estimate of 2.9 meters for net vertical tectonic displacement during the penultimate event.

Evidence for the antepenultimate earthquake in the Pole Canyon trench does not provide enough information to estimate net vertical tectonic displacement for that event.

PALEOSEISMIC CHARACTERISTICS OF THE OQUIRRH FAULT ZONE

Earthquake Timing, Recurrence, and Slip Rate

Figure 18 summarizes timing information for the most-recent, penultimate, and antepenultimate surface-faulting earthquakes on the Oquirrh fault zone. The age ranges for the events are: (1) 4,300 to 6,900 ^{14}C years ago for the most-recent event, (2) 20,300 to 26,400 ^{14}C years ago for the penultimate event, and (3) >32,800 ^{14}C years ago for the antepenultimate event. Radiocarbon (^{14}C) years are reported for the most-recent event so that a direct comparison can be made with the age ranges for the older events, which are based on radiocarbon age estimates that were too old to calendar calibrate. Comparison of the estimated times of faulting yields a minimum recurrence interval of 13,300 ^{14}C years and a maximum interval of 22,100 ^{14}C years between the penultimate and most-recent surface-faulting earthquakes on the Oquirrh fault zone. Existing data are insufficient to calculate a recurrence interval between the penultimate and antepenultimate events.

Temporal clustering of earthquakes on the central segments of the Wasatch fault zone during the late Holocene (between 400 and 1,500 years ago; Machette and others, 1991, 1992) does not appear to have influenced activity on the Oquirrh fault zone. Of the past four events (Lund, 1993) on the Salt Lake City segment (figure 1), only the antepenultimate event (5,400 ± 300 cal B.P.; Machette and others, 1991, 1992) may have been contemporaneous with an event (the most recent; 4,800 - 7,900 cal B.P.) on the Oquirrh fault zone.

Using our best estimates for net vertical tectonic displacement from the Pole Canyon and Big Canyon sites, slip rates ranging from 0.1 mm/yr (2.2 m/22,100 yr) to 0.2 mm/yr (2.7 m/13,300 yr) were calculated for the interval between the most-recent and penultimate events. For comparison, average Holocene slip rates for the central segments of the Wasatch fault zone are 1 to 2 mm/yr (Machette and others, 1991), whereas slip rates for other Quaternary faults in Utah usually range between 0.01 and 0.5 mm/yr (Hecker, 1993).

Slip rates for faults in the Basin and Range Province are often based on scarp-profile data alone. It is interesting to note that, if all of the observed surface offset at the Big Canyon site was assumed to have occurred after the regression of Lake Bonneville, it would be possible to mistakenly estimate a post-Lake Bonneville slip rate of over 0.5 mm/yr. The resulting gross overestimation of the actual vertical slip rate (0.16 - 0.17 mm/yr; 2.2 m/13,000 - 14,000 yr) provides an example of how unrecognized pre-existing topography can produce a significant overestimation of slip rates from scarp-profile data alone.

Paleomagnitude Estimates

Since Tocher (1958) first developed an empirical relation between earthquake size and surface-rupture length, many relations have been developed to estimate magnitude from fault parameters (see dePolo and Slemmons, 1990 for discussion). Table 2 compares magnitude estimates based on fault length, displacement per event, and a combination of length and displacement for the Oquirrh fault zone.

Table 2.
Magnitutde estimates for surface-faulting earthquakes on the Oquirrh fault zone.

	Moment Magnitude (M_W)		**Surface-Wave Magnitude (M_S)**	
	Wells and Coppersmith (1994)[1]	**Hanks and Kanamori (1979)[2]**	**Bonilla and others (1984)[3]**	**Mason and Smith (1993)[4]**
Based on Length[5]	**6.3** (L_S = 12 km)		**6.5 - 6.6** (L_S = 12 km; L_t = 15 km)	
	6.6 (L_S = 21 km)		**6.8 - 7.0** (L_S = 21 km; L_t = 28 km)	
	6.8 L_S = 32 km)		**7.0 - 7.2** (L_S = 32 km, L_t = 40 km)	
Based on Displacement[6]	**7.2** (d = 2.4 m)			
	7.0 D = 2.7 m)		**7.3** (D = 2.7 m)	
	7.2 (D = 4.8 m)		**7.5** (D = 4.8 m)	
Based on Length and Displacement		**6.8** (L_S = 21 km, d = 2.4 m)		**6.9** (L_S = 21 km, D = 2.7 m)
		6.9 (L_S = 32 km, d = 2.4 m)		7.2 (L_t = 40 km, D = 4.8 m)

[1]*Relations for all types of slip: $M_w = 5.08 + 1.16 \log L_s$ (s = 0.28); $M_w = 6.93 + 0.82 \log d$ (s = 0.39); $M_w = 6.69 + 0.74 \log D$ (s = 0.04)*

[2]*$M_W = 0.66 \log M_O - 10.7$; where M_O is seismic moment and $M_O = \mu dA$; μ is the shear modulus, d is average displacement, and A is the rupture plane area; we assume $\mu = 3.3 \times 10^{11}$ dynes/cm^2, a fault dip of 55°, and the seismogenic depth is 15 km*

[3]*Ordinary least-squares relations for western North America: $M_S = 5.17 + 1.237 \log L$ (s = 0.324); $Ms = 6.98 + 0.742 \log D$ (s = 0.367)*

[4] *$M_S = 6.1 + 0.47 \log (D*L_S)$*

[5]*All lengths measured from Barnhard and Dodge (1988) and Solomon (1993), L_S is straight line distance and L_t is along trace distance. The minimum L_s (12 km) is for the northern section, scarps on alluvium from Lake Point to Flood Canyon. The intermediate L_s (21 km) also includes the southern section, the fault contact between bedrock and alluvium from Flood Canyon to south of Middle Canyon. The maximum L_s (32 km) and L_t (40 km) was measured from Black Rock to Stockton to include a short scarp mapped by Solomon (1993) on Lake Bonneville sediments near Stockton not previously recognized as part of the Oquirrh fault zone.*

[6]*d is average displacement determined from an average of three observations of NVTD at the Big Cottonwood and Pole Canyon sites (2.2, 2.3, and 2.7 m); D is maximum displacement taken as twice the average displacement (4.8 m) as per observations of Wells and Coppersmith 1994 or as the maximum observed NVTD (2.7 m).*

Estimates of M_w (moment magnitude) based on displacements range from 7.0 to 7.2 and are consistently higher than M_w estimates based on length (6.3 to 6.8) for the Oquirrh fault zone (see table 2 footnotes for details on relations and input parame-

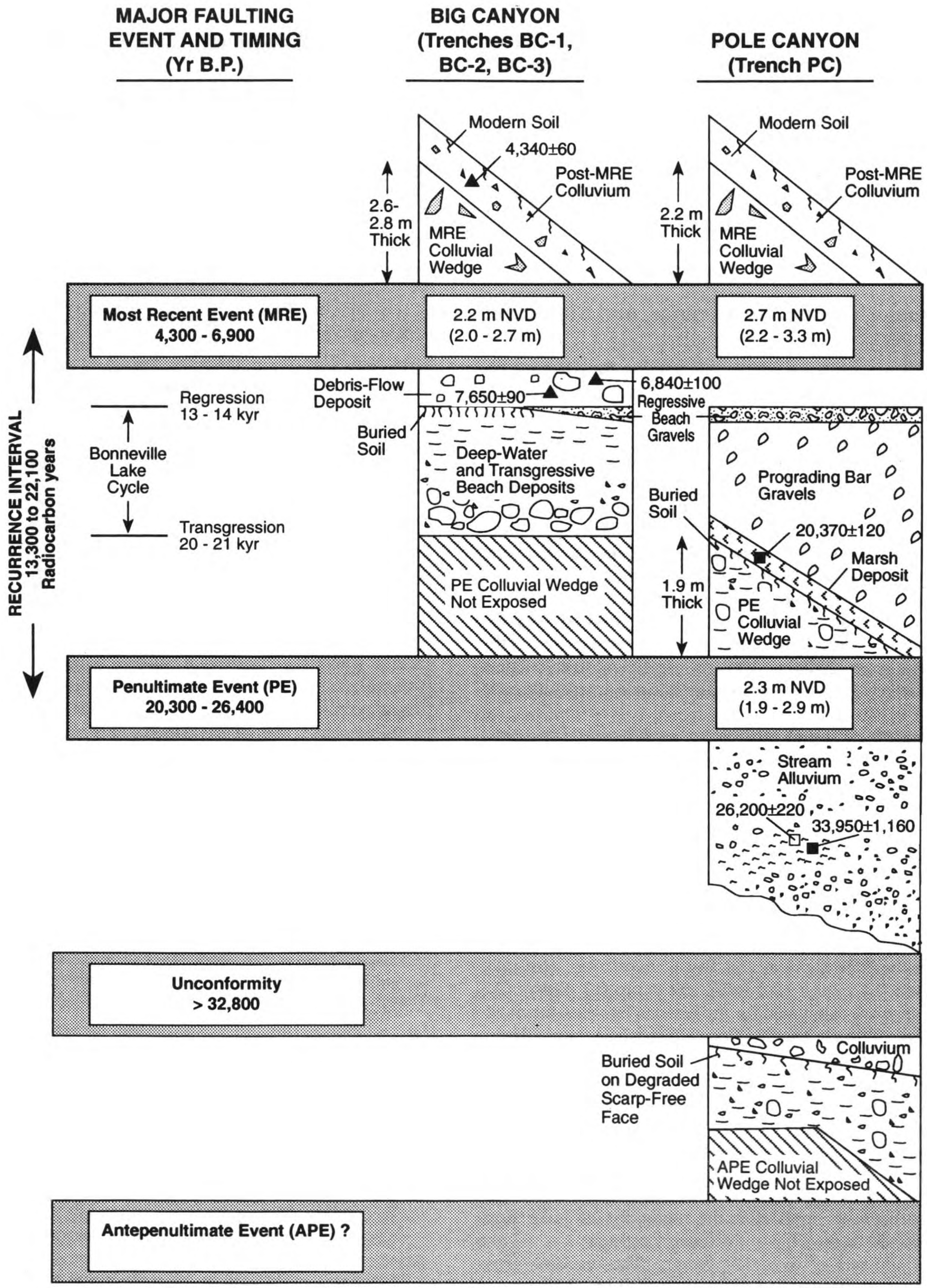


Figure 18. Schematic representation of Holocene and latest Pleistocene faulting chronology for the Oquirrh fault zone based on evidence at the Big and Pole Canyon trench sites. Timing and recurrence are based on stratigraphic and geomorphic relations, and radiocarbon ages. Symbols representing radiocarbon samples include triangles for bulk sediment samples, solid boxes for single-fragment charcoal samples, and an open box for a sample of several charcoal fragments. All ages are reported in ^{14}C years.

ters). In comparison, magnitude estimates based on length and displacement are slightly larger than length-based estimates and are within the range of one standard deviation (typically 0.3 to 0.4 for the relations used). The variability of displacement along a rupture (Crone and others, 1987) typically makes estimates of paleomagnitudes based on displacements difficult and often undesirable because of the limited number of observations (dePolo and Slemmons, 1990). It is worthwhile to note that even though we only have a limited number of observations, our values for net vertical tectonic displacement from two trench sites are similar, suggesting that they are closer to an average than to an extreme. However, even if our maximum observed net vertical tectonic displacement is taken as a maximum displacement for the entire fault, which is unlikely, the estimated M_W is still 7.0, about one standard deviation larger than length-based estimates. The Oquirrh fault zone does not appear unique in this regard. Mason and Smith (1993) found that paleomagnitudes based on displacement were typically 20 percent larger than paleomagnitudes based on length for Quaternary normal faults in the Intermountain seismic belt.

The discrepancy between the length- and displacement-based estimates is even more evident when either Bonilla and other's (1984) or Wells and Coppersmith's (1994) relations are used to estimate surface-rupture length from displacement. Length estimates vary from 48 kilometers (for D = 2.7 m) to 71 kilometers (for d = 2.4 m), which are four to almost six times the measured straight-line distance of the northern section of the Oquirrh fault zone, and two to three times the measured straight-line distance for the entire fault.

There are three possible reasons for the discrepancy between fault length and displacement on the Oquirrh fault zone: (1) we overestimated displacement, (2) we underestimated rupture length, or (3) the Oquirrh fault zone does not fit available empirical models, possibly because of differences in shear modulus, stress drop, or rupture surface associated with this fault zone. In making comparisons, we were careful to use fault measurements appropriate for the specific relation being used (for example using maximum [D] versus average [d] displacement), and we allowed for the possibility that the 2.7 meters of net vertical tectonic displacement observed at Pole Canyon was actually the maximum displacement for the fault. Therefore, we believe our displacement values are reasonable and not overestimated.

It is possible that fault rupture may extend farther north beneath Great Salt Lake or farther south beyond Middle Canyon. Mason (1992) suggested that underestimation of fault length could be a common cause for the difference between displacement- and length-based paleomagnitude estimates. If fault rupture does extend to the south, any associated scarps have either been eroded or buried, because few, if any, scarps are evident there today. On his surficial geologic map, Solomon (1993; this volume) shows a short discontinuous fault scarp on older alluvial-fan deposits near Silcox Canyon, roughly 5 kilometers southwest of the southernmost extent of the bedrock-alluvium fault trace, and a very short fault scarp on Lake Bonneville sediments near the town of Stockton. Tooker and Roberts (1992) identified many additional faults in alluvium in the Stockton area, but Solomon (1993) interpreted those features as either shorelines associated with Lake Bonneville or as stream terraces. To the north, well-developed scarps of the Oquirrh fault zone trend directly toward Great Salt Lake and show no indication that displacement is diminishing to the north. It is possible that faulting on the northern section of the fault zone extends beneath the lake.

Assessing the third possibility, that the Oquirrh fault zone does not fit available empirical fault models, is beyond the scope of this study. However, previous seismological and theoretical studies have suggested a dependency of earthquake size on the tectonic environment and the rate of earthquake activity (for example, Kanamori and Allen, 1986; Scholz and others, 1986). Recently, Anderson and others (1995) developed a preliminary regression relation to estimate M_W from fault length and slip rate. They found that regressions that ignore fault slip rates appear to underestimate earthquake magnitudes for slow slipping faults. For example, for a fault with a slip rate of 0.1 mm/yr, moment magnitude estimates are 70 percent larger than for a fault with a slip rate of 34 mm/yr. Using their relation ($M_w = 5.01 \pm 1.24 \log L_S - 0.23 \log S$; where S is slip rate in mm/yr) yields an expected M_S of 7.1 for a 32-kilometer-long fault and a slip rate of 0.15 mm/yr. This length-based estimate agrees well with displacement-based estimates for the Oquirrh fault zone. Thus, it is possible that the Oquirrh fault zone generates slightly larger earthquakes for fault ruptures of comparable length than do faults with higher slip rates.

Fault Segmentation

Although our results only pertain to the northern and central sections of the Oquirrh fault zone, they do have implications for rupture segmentation. Estimates of fault length based on observed displacements are 4 to 6 times the length of the northern section and 2 to 3 times the length of all three sections combined. This suggests that the northern, central, and southern sections of the fault zone are part of the same rupture segment and that the isolated, discontinuous fault scarps as far south as Stockton (Solomon, 1993; this volume) could also be part of the Oquirrh fault zone. However, further work is needed along the southern section of the fault to test this preliminary hypothesis.

Comparing our results with available information on the Mercur fault zone (called the South Oquirrh Mountains fault zone by Wu and Bruhn, 1994) to the south suggests that the Mercur and Oquirrh fault zones have behaved as independent rupture segments, at least since the Bonneville lake cycle (table 3). Barnhard and Dodge (1988) reinterpreted Everitt and Kaliser's (1980) trench log for an excavation across the Mercur fault zone and concluded that the most-recent faulting occurred prior to the Bonneville lake cycle. In addition, both Everitt and Kaliser (1980) and Wu and Bruhn (1994) found geomorphic evidence indicating that the latest faulting along the southern Oquirrh Mountains predates the highstand of Lake Bonneville. South of Mercur Canyon, crosscutting relations between a fault scarp and the Bonneville shoreline indicate that the fault was partially eroded by the lake and was then buried by lacustrine sediments (Everitt and Kaliser, 1980). In their mapping, Wu and Bruhn (1994) found that faults offset pre-Bonneville alluvial fans, but are buried by post-Bonneville alluvial fans.

Table 3.
Ages[1] of surface-faulting earthquakes on the Oquirrh fault zone and adjacent faults.

FAULT	HOLOCENE	LATE PLEISTOCENE
East Great Salt Lake fault	<6,800[2]	?[3]
Oquirrh fault zone	4,300 - 6,900[4]	20,300 - 26,400[4] >>33,000[4]
Mercur fault		>17,000 - 18,000[5]

[1]*Reported in radiocarbon years before present*
[2]*From D.R. Currey, written communication, 1994*
[3]*Ages for events prior to the most-recent faulting are unknown*
[4]*From this study*
[5]*From Barnhard and Dodge, 1988*

Available paleoseismic information is inconclusive regarding a possible rupture segment boundary between the Oquirrh fault zone and the East Great Salt Lake fault zone to the north (table 3). Timing of the most-recent activity along the East Great Salt Lake fault zone is not well constrained, but geomorphic and indirect stratigraphic evidence suggests that faulting has occurred in post-Bonneville time, perhaps as recently as 6,800 years ago (D.R. Currey, written communication, 1994). That faulting could have been contemporaneous with the most-recent surface faulting on the Oquirrh fault zone. However, Pechmann and others (1987) estimated Quaternary slip rates of 0.4 to 0.7 mm/yr for the East Great Salt Lake fault zone based on vertical subsidence rates determined from seismic and drill-hole data, suggesting a much greater rate of activity for the East Great Salt Lake fault zone than for the Oquirrh fault zone.

Possible Effect of Lake Bonneville on Earthquake Timing

The past three surface-faulting earthquakes on the Oquirrh fault zone all occurred during interpluvial periods spanning the Bonneville lake cycle. However, we do not know if this pattern of no faulting during pluvial intervals persisted through the older Cutler Dam and Little Valley lake cycles as well. Trench exposures along the Granger fault of the West Valley fault zone in Salt Lake Valley (figure 3) indicated a similar pattern of activity, with post-Lake Bonneville faulting (during the past 12,000-13,000 years) and no faulting during Bonneville time (Olig and others, 1986; Keaton and others, 1993). Machette and others (1992) found higher post-Bonneville slip rates along the central segments of the Wasatch fault zone (figure 1) (0.4-1.8 mm/yr) compared to lower rates recorded in pre-Bonneville lake-cycle alluvium (0.1-0.3 mm/yr); however, the pre-Bonneville data are limited. They speculated that Lake Bonneville may have decreased seismic activity and slip along the Wasatch fault zone probably due to increased confining pressures associated with water loads and the thick sediment packages deposited by the lake. Accelerated rates of faulting during the regressive phase of Lake Bonneville and the subsequent interpluvial period were attributed to a decrease in confining pressure and resulting isostatic uplift in the Bonneville basin. If true, their theory may have far-reaching implications regarding fault dips and mechanics of normal-slip faults.

In his analysis using a simple elastic model of loads imposed by ice sheets on the earth's crust, Johnston (1989) pointed out that in an extensional tectonic regime, the effect of the load on fault stability varies with the dip of the fault. The load decreases fault stability for dips greater than 45 degrees and increases stability for dips less than 45 degrees. Thus, if this simple elastic model is applicable, decreased fault activity during the Bonneville lake cycle might imply overall low-angle fault dips (<45°) for the Wasatch and other basin-and-range faults in the Bonneville basin. Alternatively, isostatic rebound from the loads imposed by Lake Bonneville has long been recognized (Gilbert, 1890) and is well documented (Crittenden, 1963; Currey, 1982), suggesting that a visco-elastic model, where the load depresses a brittle crust into an underlying ductile medium, might be a more appropriate model. In his analysis for this model, Johnston (1989) showed that if isostasy is assumed, the load not only increases vertical stresses, but also increases horizontal stresses. Depending on the boundary conditions, the change in vertical stresses will be greater than or equal to the change in horizontal stress. Therefore, the effect of the load on fault stability would still depend on fault dip in a visco-elastic model, and decreased faulting during the Bonneville lake cycle would still imply fault dips of less than 45 degrees.

Many researchers have discussed both the mechanical paradox for failure on low-angle normal faults (assuming Mohr-Coulomb failure criteria) and the lack of observations of such failures in the historical seismic record (for example, Smith and Bruhn, 1984; Doser and Smith, 1989; West, 1992). We do not mean to imply here that the absence of faulting on the Oquirrh fault zone during the Bonneville lake cycle is evidence for low-angle dips on seismogenic faults, rather we point out possible implications as a stimulus for developing a better understanding of faulting patterns relative to Lake Bonneville chronology. Obviously, more paleoseismic data are needed, particularly for the period during and prior to the Bonneville lake cycle, in order to determine if a causal relation exists. If it does, a better understanding of this relation might provide insight into the mechanics of normal faulting.

SUMMARY AND CONCLUSIONS

Direct stratigraphic and geomorphic evidence along the northern section of the Oquirrh fault zone shows: (1) the most-recent surface-faulting earthquake occurred between 4,300 and 6,900 ^{14}C years ago (4,800 and 7,900 cal B.P.), (2) the penultimate event occurred between 20,300 and 26,400 ^{14}C years ago, (3) the antepenultimate event occurred sometime before 32,800 ^{14}C years ago, (4) estimates of net vertical tectonic displacement range between 2.0 and 3.3 meters with best estimates of 2.2 and 2.7 meters for the most-recent and penultimate events respectively, (5) the recurrence interval between the two youngest events on the fault zone is 13,300 to 22,100 ^{14}C years, (6) calculated slip rates are 0.1 to 0.2 mm/yr for this interval, and (7) paleomagnitude estimates of M_w based on displacements range from 7.0 to 7.2 and are consistently higher than M_w estimates based on length alone (6.3 to 6.8).

Although conclusions that can be drawn about the long-term behavior of a fault zone based on the timing of only the past two surface-faulting earthquakes and the recurrence interval between them are limited, there are a few notable observations that can be made: (1) the most-recent event was actually 2,000 to 9,000 years younger than previous age estimates based on scarp morphology alone, (2) no surface faulting occurred on the Oquirrh fault zone during the Bonneville lake cycle, and (3) the elapsed time since the most-recent surface-faulting earthquake is thousands of years less than even the most conservative estimate of fault recurrence.

Paleomagnitude estimates for surface faulting on the Oquirrh fault zone vary considerably depending on the empirical relation used, but estimates based on displacement are consistently larger than estimates based on length. As might be expected, estimates based on both length and displacement fall between the length-based and displacement-based values (table 2). Therefore, we conclude that until further investigation can clarify this discrepancy, it is prudent not to use magnitude estimates based on rupture length alone to characterize paleomagnitudes of earthquakes on the Oquirrh fault zone.

The large displacements documented for surface-faulting earthquakes on the northern section of the Oquirrh fault zone implies that a much longer rupture length than 12 kilometers is likely for the fault zone. Thus, we infer that the northern and southern sections together probably form a single rupture segment, and that it is possible that prehistoric ruptures of the Oquirrh fault zone extended as far south as Stockton and northward beneath Great Salt Lake.

Temporal clustering of earthquakes on the nearby Wasatch fault zone in the late Holocene does not appear to have influenced activity on the Oquirrh fault zone. However, consistent with findings on the Wasatch fault zone and with some other Quaternary faults within the Bonneville basin, we found no evidence of surface faulting during the time Lake Bonneville was at or near its highest level, suggesting a possible causal relation between rates of strain release along faults and changes in loads imposed by the lake. However, our data are only complete for one deep-lake cycle (the past 30,000 years), and whether this pattern persisted during the previous Cutler Dam and Little Valley lake cycles is unknown.

Results of this study show that the Oquirrh fault zone has produced multiple, large-magnitude, surface-faulting earthquakes in Tooele Valley during late Pleistocene and Holocene time. For purposes of earthquake-hazard evaluations along the central Wasatch Front and in west-central Utah, the fault zone should be considered seismogenic and capable of producing magnitude 7 or larger earthquakes. Elapsed time since the most-recent surface-faulting earthquake is less by several thousand years than the minimum recurrence interval for the past two large earthquakes on the fault zone. However, predicting time-dependent fault behavior based on one recurrence interval is not prudent, and even though it appears that another large earthquake is not likely on the Oquirrh fault zone for some time, critical facilities constructed in Tooele Valley should be designed to withstand the effects of a large earthquake whose epicenter is at most a few kilometers away rather than 30 or 40 kilometers away along the Wasatch fault zone.

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APPENDIX

APPENDIX

DESCRIPTION OF GEOLOGIC UNITS, BIG CANYON TRENCH SITE, OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH

UNITS 1-7

These are the oldest units exposed in trenches BC-2 and BC-3. They consist of interbedded alluvial-fan, loess, and colluviated loess deposits that lie within the fault footwall and predate the most-recent surface-faulting earthquake. The loess and colluviated loess deposits are not exposed in trench BC-2 and so the deposits of this age were left undifferentiated in that trench.

Unit 1 - Sandy, silty gravel[1] (stream alluvium): Light yellowish brown (10YR 6/4) when dry, brown (10YR 5/3) when wet[2]; 70% gravel[3] 15% sand, and 15% fines (mostly silt); maximum clast size 7 cm; subangular to subrounded; low plasticity[4], moderately sorted, clast supported, clasts imbricated N. 5° E., 4° E; clasts 70% limestone and 30% quartzite; carbonate stringers in matrix and coatings on clasts (stage I+ $CaCO_3$); upper contact abrupt and planar.

Unit 2 - Silt with sand and gravel (colluviated loess): Pale brown (10YR 6/3) when dry, brown (10YR 5/3) when wet; 15% gravel, 15% sand, and 70% fines; maximum clast size 5 cm; subangular to subrounded; low plasticity; moderately cemented, some carbonate nodules and stringers (stage I+ $CaCO_3$); no bedding or stratification; moderately sorted; root pores; abrupt upper contact; deposit is variable in thickness and discontinuous.

Unit 3 - Silty gravel with sand (stream alluvium?): Very pale brown (10YR 7/3) when dry; brown (10YR 5/3) when wet; trace of boulders, 20% cobbles, 55% gravel, 10% sand, and 15% fines (mostly silt); cobbles subrounded, gravel and sand subangular; low plasticity; no bedding or stratification, poorly sorted, generally clast supported; clasts 80% limestone; 20% quartzite; some flecks of carbonate in matrix and in pores; upper contact abrupt and planar.

Unit 4 - Sandy, gravelly silt (colluviated loess and colluvium): Color varies from pale brown (10YR 6/3) to yellowish brown (10YR 5/4) when dry, and from brown-dark brown (10YR 4/3) to pale brown (10YR 6/3) when wet; trace of cobbles, 20% gravel, 15% sand, and 65% fines (mostly silt); maximum clast size 9 cm; subangular to subrounded; low plasticity; poorly cemented; moderately sorted and contains discontinuous, thin lenses of gravel; unit is laterally discontinuous and thickness varies from 0 to over 1 m; upper contact abrupt.

[1] Unified Soil Classification System used to classify unit texture and grain size.

[2] Munsell color chart used to describe unit color.

[3] Percentages reported for clast size fractions are field estimates.

[4] Plasticity estimated in the field; for coarse-grained units plasticity is reported for the matrix (fines portion) of the deposit.

Unit 5 - Silty gravel with sand (interbedded stream alluvium and debris-flow deposit): Pale brown (10YR 5/3) when wet; 30% cobbles, 45% gravel, 10% sand, and 15% fines; maximum clast size 22 cm; gravel and cobbles subrounded, sand subangular; low plasticity; moderately cemented, carbonate coating on clasts and stringers in matrix (stage II $CaCO_3$); moderately to poorly sorted; stratified (25-cm-thick debris-flow deposit interbedded within stream deposits); imbrication of clasts in stream alluvium dips 6° W.; clasts 60% limestone, 40% quartzite; root tubes; upper contact abrupt.

Unit 6 - Silt with sand (loess and colluviated loess): Pale brown (10YR 6/3) when dry, brown (10YR 5/3) when wet; trace of cobbles, 5% gravel, 10% sand, 85% fines (mostly silt); maximum clast size 10 cm; subrounded; weakly to moderately cemented, carbonate stringers (stage I+ $CaCO_3$); moderately to well sorted; no bedding or stratification; root tubes; many krotovina; upper contact abrupt and planar.

Unit 7 - Sandy, cobbly, silty gravel (debris-flow deposit): Light gray (2.5Y 7/2) when dry, light olive brown (2.5Y 5/3) when wet; trace of boulders, 15% cobbles, 50% gravel, 15% sand, 20% fines; maximum clast size 30 cm; subangular to subrounded; low plasticity; well cemented, carbonate coating on clasts (varies from stage II to III+ $CaCO_3$); clast-supported, clasts randomly oriented, poorly sorted, no stratification; clasts 85% limestone, 15% quartzite; upper contact abrupt and disconformable near fault; root tubes.

Unit 1-7 (undifferentiated) - Sandy, cobbly gravel with silt (interbedded stream alluvium and debris-flow deposits): Very pale brown (10YR 7/4) when dry, light yellowish brown (10YR 6/4) when wet; 5% boulders, 25% cobbles, 40% gravel, 20% sand, and 10% fines; maximum clast size 75 cm; angular to rounded; low plasticity; noncemented to weakly cemented; crudely stratified, poorly sorted; clasts 85% limestone, 15% quartzite; upper contact disconformable.

UNITS 8-11

These sediments include a nearly complete package of transgressive, deep-water, and regressive Lake Bonneville deposits that lie on the downthrown side of the fault and predate the most-recent faulting event. Units 8 and 9 include transgressive beach deposits exposed in trenches BC-2 and BC-3. Also in trench BC-2, near the main fault, was a sandy gravel deposit (unit 9b) that appears to be a part of unit 9 that was deformed by liquefaction or soft-sediment deformation. Unit 10 is a fine-grained, shallow to deep-water lacustrine deposit only present close to the fault, but found in both trenches BC-2 and BC-3. Unit 11 is a tufa-cemented regressive beach deposit at the west end of trench BC-2. An erosion-truncated paleosol is developed on the top of the Lake Bonneville deposits.

Unit 8a - Sandy, cobbly, bouldery gravel (transgressive beach deposits): Grayish brown (2.5Y 5/2) when dry, very dark grayish brown to dark grayish brown (2.5Y 3/2 to 4/2) when wet; 35% boulders, 25% cobbles, 25% gravel, 15% sand, and trace of fines; subrounded to rounded; nonplastic; poorly cemented; moderately to well sorted; well stratified; becomes finer grained upward; bedding dips variably to the west and unit is warped up along the main fault zone; upper contact distinct but gradational; carbonate rinds on the bottoms of some clasts but carbonate is highly variable and appears partially dissolved.

Unit 8b - Cobbly, gravelly sand (transgressive beach deposits): Light brownish gray (2.5Y 6/2) when dry, olive brown (2.5Y 4/3) when wet; 5% boulders, 15% cobbles, 25% gravel, and 55% sand; maximum clast size 35 cm; sand subangular to rounded, larger clasts are rounded; nonplastic; noncemented; well sorted; coarse horizontal bedding; upper contact abrupt and irregular; some cobbles and gravels variably coated with tufa-cemented sand; this unit is exposed near the antithetic fault zone and grades into unit 8d to the east within the graben.

Unit 8c - Sandy, cobbly, bouldery gravel (transgressive beach deposits): Light yellowish brown (2.5Y 6/3) when dry, olive brown (2.5Y 4/3) when wet; 30% boulders, 25% cobbles, 25% gravel, and 20% sand; maximum clast size 80 cm; subrounded to rounded; nonplastic; moderately cemented; moderate to well sorted; stratified; upper contact with unit 15 abrupt and irregular, upper contact with unit 9 distinct but more gradational; many clasts variably coated with tufa-cemented sand.

Unit 8d - Gravelly sand with boulders and cobbles (transgressive beach deposit): Light yellowish brown (2.5Y 6/3) when dry, brown (10YR 5/3) when wet; 10% boulders, 5% cobbles, 25% gravel, 55% sand, 5% fines; subrounded to rounded; nonplastic; cementation varies from weak to very strong; well sorted; well stratified; fines upward; horizontal bedding; this unit underlies unit 11 west of station 25 in trench BC-3 and unit 10 east of station 25; the contact with unit 11 is abrupt, irregular, and angular; the contact with unit 10 is gradational; this unit grades into units 8a and 9a to the east and grades into unit 8b to the west.

Unit 9a - Sand to gravelly sand (transgressive beach deposits): Light yellowish brown to light gray (2.5Y 6/3 to 7/2) when dry, brown to grayish brown (10YR 5/3 to 2.5Y 5/2) when wet; 0-20% gravel, 80-100% sand, and trace of fines; maximum clast size 10 cm; subangular to well rounded; nonplastic; poorly to moderately cemented; well sorted; thinly bedded, bedding horizontal except near main fault where beds are warped 20° to the west; becomes finer grained upward; upper contact gradational; contains abundant gastropods.

Unit 9b - Gravelly sand with cobbles (injected into unit 10): Light brownish gray (2.5Y 6/2) when dry, grayish brown (2.5Y 5/2) when wet; 10% cobbles, 25% gravel, 55% sand, and 10% fines; maximum clast size 18 cm; subangular to rounded; nonplastic; noncemented to weak cemented; unit is only exposed between stations 2 and 6 in trench BC-2; upper contact varies from gradational to abrupt and is very irregular and convoluted, upper section lacks bedding and appears to have been injected into unit 10 although material is unusually coarse (includes gravel as coarse as 2 cm), lower section contains pockets of thinly bedded very fine sand and allochthonous blocks of unit 10 (10b through 10g) distributed in random orientations.

Unit 10a - Sandy clay to sandy silt to gravelly, bouldery silt with sand (shallow- to deeper-water deposits deformed between stations 2 and 6 in trench BC-2): Light gray (10YR 7/2 to 2.5Y 7/2) when dry, brown to light olive brown (10YR 5/3 to 2.5Y 5/3) when wet; 0-25% boulders, 0-5% cobbles, 0-15% gravel, 10-30% sand, and 45-80% fines; maximum clast size 60 cm in deformed section and 1.5 cm elsewhere; subrounded to rounded; medium to high plasticity; moderately to well cemented; poorly sorted where deformed, well sorted elsewhere; laminations with very fine sand partings and ostracodes; bedding highly contorted, tilted, and folded into v-shaped folds between stations 2 and 6, elsewhere bedding dips gently to the west; contains prominent laterally continuous sand horizon, unit fines upward below this horizon and coarsens upward above this horizon; upper section contains abundant rootlets, root pores, and krotovina; upper contact abrupt and eroded.

Units 10b to 10g - Sandy silt (allochthonous blocks of unit 10a in unit 9b): Light gray (2.5Y 7/2) when dry, light olive brown (2.5Y 5/3) when wet; 30% sand, 70% fines; blocks are as large as 15 cm; bedding shows random orientations of blocks; blocks are distributed throughout lower section of unit 9b.

Unit 10h - Silty clay to clayey silt (shallow- to deep-water deposits): Pale yellow (2.5Y 7/3) when dry, light yellowish brown (2.5Y 6/3) when wet; 5% sand and gravel, 95% fines; maximum clast size 3 cm; well rounded; low to medium plasticity; moderately cemented; well sorted; laminations with very fine sand partings and ostracods; bedding dips gently to the west and is warped up along main fault zone in trench BC-3; contains prominent laterally continuous sand horizon; unit fines upward below this horizon and coarsens upward above this horizon; upper section contains abundant rootlets, root pores, and krotovina; upper contact abrupt and eroded.

Unit 11 - Sandy, cobbly gravel with boulders (regressive beach deposits): Pale brown (10YR 6/3) when dry, olive brown (2.5Y 4/3) when wet; 5-10% boulders, 25-45% cobbles, 30-40% gravel, 15-30% sand, and trace of fines; maximum clast size 45 cm; well rounded; tufa cementation varies laterally from weak to strong; illuviation of fines into this unit is greatest where cementation is weakest; well sorted; stratified, horizontally bedded; upper contact generally distinct.

Buried soil on units 10 and 11: This soil consists of a truncated and buried B horizon overlying the Cu horizon. The B horizon varies laterally depending on parent material, slope position, and degree of truncation. On unit 10 close to the fault, the soil consists of a Bk to Bkm horizon, locally as thick as 40 cm (for example near station 10 in trench BC-3), with high plasticity, a platy to prismatic to massive structure, carbonate stringers and nodules, and carbonate coatings and fillings of root pores. On unit 11 this horizon consists of a Btj-Blj horizon, with clay and silt caps in areas with moderate to strong tufa cementation of the parent material (for example, near station 25 in trench BC-2), and clay films on grains and some weak bridges between grains in areas with less cementation (for example near the antithetic fault zone in trench BC-3).

UNIT 12

This debris-flow deposit overlies Lake Bonneville sediments on the downthrown side of the fault in trenches BC-2 and BC-3. It predates the most-recent surface-faulting event.

Unit 12 - Silty, sandy, cobbly, bouldery gravel (debris-flow deposit): Dark grayish brown (10YR 4/2) when dry, very dark grayish brown (10YR 3/2) when wet; 20% boulders, 15-20% cobbles, 30-35% gravels, 15% sand, and 15% fines; maximum clast size 64 cm; subangular to rounded; low plasticity, low dry strength, low toughness; poorly to well cemented with carbonate; very poorly sorted; nonstratified, clast supported, clasts randomly oriented; unit is warped up near main fault; abundant but variable amount of organics in matrix and intraclasts of soil result in a mottled appearance in places; abundant roots and root pores, some krotovina; upper contact abrupt with unit 13 but gradational with unit 15.

UNITS 13-14

These deposits are related to the most-recent surface-faulting earthquake. They include material in the main fault zone (unit 13a in trench BC-3), and fault-scarp colluvium of the main (unit 13) and antithetic (unit 14) fault zones. Units 13a-13i and unit 14 are in trench BC-3. Unit 13j is in trench BC-2.

Unit 13a - Sandy, cobbly, clayey gravel (sheared fault zone material): Pale yellow (2.5Y 7/3) when dry, light yellowish brown (2.5Y 6/3) when wet; 20% cobbles, 35% gravels, 20% sand, and 25% fines; maximum particle size 15 cm; subangular to rounded; poorly cemented; medium plasticity; very poorly sorted; very well developed shear fabric defines a 10 to 20 centimeter-wide zone that strikes N. 17-22° E. and dips 79-84° W.

Unit 13b - Sand and sandy silt (allochthonous block of units 9a and 10h in unit 13f): Bedding is overturned and dips 35° W.

Unit 13c - Clayey silt (allochthonous block of unit 10h in unit 13f): Block under unit 13b, bedding dips to the east.

Unit 13d - Sand and sandy silt (allochthonous block of units 9a and 10h in unit 13f): Bedding is overturned and dips 25° W.

Unit 13e - Sandy silt (allochthonous block of unit 10h in unit 13h): Bedding dips 40° W.

Unit 13f - Cobbly, sandy gravel with silt and boulders (lower debris-element association of fault-scarp colluvium): Dark grayish brown (10YR 4/2) when dry, very dark brown (10YR 2/2) when wet; 10% boulders, 15% cobbles, 40% gravel, 25% sand, 10% fines; maximum clast size 45 cm; angular to rounded; low plasticity; no cementation; clast supported; very poorly sorted and heterogeneous, contains allochthonous blocks of lacustrine sediments and pockets of organic-rich material throughout; upper contact distinct to gradational with unit 13h.

Unit 13g - Sand and silty sand (allochthonous block of units 9a and 10h in unit 13h)

Unit 13h - Cobbly, gravelly sand with silt (upper debris-element association of fault-scarp colluvium): Grayish brown to brown (10YR 5/2-5/3) when dry, dark grayish brown (10YR 4/2) when wet; 15% cobbles, 35% gravel, 40% sand, 10% fines; maximum clast size 27 cm; angular to subrounded; low plasticity; poorly cemented; varies from clast- to matrix-supported; very poorly sorted to heterogeneous with some local stratification; contains allochthonous blocks of lacustrine sediments only at the base and has much less organic material in matrix than unit 13f; upper contact distinct but gradational.

Unit 13i - Sandy gravel with cobbles and silt (wash-element association of fault-scarp colluvium): Brown (10YR 5/3) when dry, dark grayish brown (10YR 4/5) when wet; trace of boulders, 10% cobbles, 50% gravel, 30% sand, and 10% fines; maximum clast 50 cm; subangular to rounded; low plasticity; poorly cemented; generally matrix supported; moderately to poorly sorted; slightly stratified; some slope-parallel imbrication of clasts especially in distal portion of deposit; upper contact gradational and indistinct in places.

Unit 13j - Silty gravel with sand and cobbles (undifferentiated fault scarp colluvium): Light gray (10YR 7/2) when dry, grayish brown (10YR 5/2) when wet; trace of boulders, 15% cobbles, 45% gravel, 25% sand, and 15% fines; maximum clast size 25 cm; subangular to well rounded; very low plasticity; noncemented to weakly cemented; generally matrix supported except near base and at distal portion of deposit; poorly to very poorly sorted; crudely stratified, weak slope-parallel imbrication of clasts; includes fissure fill or "heal" at base of buried free-face, roughly 1 meter deep; upper contact distinct but gradational.

Unit 14 - Sandy gravel with cobbles (antithetic fault-scarp colluvium): Light brownish gray (10YR 6/2) when dry, dark grayish brown to very dark grayish brown (10YR 4/2-3/2) when wet; 10% cobbles, 50% gravel, 35% sand, 5% fines; maximum clast size 9 cm; subrounded to rounded; nonplastic; poorly to moderately cemented, many clasts are coated with carbonate or tufa-cemented sand, some carbonate in matrix (stage I $CaCO_3$); poorly sorted; clasts are imbricated, dipping to the east.

UNITS 15-21

These deposits consist of alluvium and colluvium that postdate faulting at the Big Canyon site. Units 15a and 16 overlie the most-recent earthquake colluvial wedge at the main fault in trench BC-3, unit 15b overlies the most-recent event colluvial wedge in trench BC-2, and unit 17 overlies fault-scarp colluvium associated with the antithetic fault zone in trench BC-3. Units 18 through 21 are in trench BC-2 and are alluvial-fan sediments from Big Canyon that bury the main fault scarp.

Unit 15a - Sandy, gravelly silt (colluvium): Dark grayish brown (10YR 4/2) when dry, very dark grayish brown (10YR 3/2) when wet; trace of boulders and cobbles, 35% gravel, 30% sand, 35% fines; maximum clast size 170 cm; subangular to rounded; medium plasticity, low to medium toughness, low dry strength; non- to moderately cemented; some weak stratification, weak slope-parallel imbrication of clasts, poorly sorted; matrix-supported; unit is thinnest on main scarp and thickest at station 20, grades finer to the west into unit 17; upper contact with unit 16 gradational; modern soil is developed on this unit.

Unit 15b - Gravelly, sandy silt (colluvium): Grayish brown (2.5Y 5/2) when dry, very dark gray (10YR 3/1) when wet; 5% boulders, 5% cobbles, 15% gravel, 25% sand, and 50% fines; maximum clast size 90 cm; subangular to rounded; medium plasticity, medium toughness, low dry strength; non- to poorly cemented; some weak stratification, weak slope-parallel imbrication of clasts; poorly sorted; matrix supported; unit is thinnest on main scarp; modern soil is developed on this unit.

Unit 16 - Sandy gravel with cobbles (slope wash and alluvium): Grayish brown (10YR 5/2) when dry, very dark grayish brown (10YR 3/2) when wet; trace of boulders, 10% cobbles, 40% gravel, 35% sand, and 15% fines; maximum clast size 26 cm; subangular to rounded; low plasticity; noncemented; moderately sorted; clast supported; stratified, clasts strongly imbricated; unit only present at the base of the scarp in trench BC-3.

Unit 17 - Gravelly, sandy, clayey silt (colluvium and colluviated loess): Brown (10YR 5/3) when dry, dark grayish brown (10YR 4/2) when wet; 15% gravel, 20% sand, and 65% fines; maximum clast size 5 cm; subangular to subrounded; medium plasticity, moderate toughness and dry strength; poorly to moderately cemented; moderately sorted; nonstratified; highly bioturbated, many roots; modern soil is developed on this unit; grades into unit 15a in the graben.

Modern soil on units 15 and 17: This soil consists of a thin soil A horizon, 0 to 10 cm thick, overlying a Bw to Bkj horizon, 10 to 100 cm thick. The soil is thickest on unit 17 in the deepest part of the graben, where a cumulative profile has developed. The A horizon is dark grayish brown (2.5Y 4/2) when dry, and black (5Y 2.5/1) when wet. The Bw horizon is dark grayish brown (10YR 4/2) when dry and dark brown (10YR 3/3) when wet. The Cu horizon is grayish brown (2.5Y 5/2) when dry and very dark gray (10YR 3/1) when wet. The Bkj horizon is more cemented and reacts more vigorously to HCl than the underlying Cu horizon and has some thin carbonate coatings on clasts.

Unit 18 - Sandy gravel with cobbles (stream alluvium): Brown (10YR 5/3) when dry, dark brown (10YR 4/3) when wet; trace of boulders, 10% cobbles, 60% gravel, 20-25% sand, 5-10% fines; maximum clast size 38 cm; poorly cemented; well sorted; well stratified with interfingering lenses of coarser and finer material, some finer-grained lenses contain hackberry seeds (*Celtis reticulata*[?]; D.B. Madsen, personal communication, 1992); horizons of discontinuous carbonate coatings on clasts (stage I $CaCO_3$); upper contact abrupt and eroded by overlying channel deposit (unit 19).

Unit 19 - Sandy, silty gravel (channel deposit): Dark grayish brown (10YR 4/2) when dry, very dark grayish brown (10YR 3/2) when wet; 0-10% cobbles, 55-60% gravel, 20% sand, and 20-25% fines; maximum clast size 20 cm; subangular; poorly cemented; unit is channel shaped, has a basal lag deposit, and becomes finer grained upward; clast-supported at base but generally matrix supported elsewhere; mottled texture with pockets of organic-rich matrix; upper contact distinct and abrupt.

Unit 20 - Silty, cobbly gravel with sand (debris-flow deposit): Dark grayish brown (10YR 4/2) when dry, very dark brown (10YR 2/2) when wet; trace of boulders, 25% cobbles, 40% gravel, 10-15% sand, and 20-25% fines; maximum clast size 60 cm; subangular; low plasticity; poorly cemented; poorly sorted; nonstratified, clasts randomly oriented; upper contact varies from gradational to abrupt.

Unit 21 - Silty, cobbly gravel with sand (interbedded stream alluvium and debris-flow deposits): Dark grayish brown (10YR 4/2) when dry, very dark grayish brown (10YR 3/2); 5% boulders, 30-40% cobbles, 20-30% gravel, 10% sand, and 25% fines; maximum clast size 2 m; angular to subrounded; noncemented; low plasticity; unit consists of lenses of well-sorted, well-stratified, clast-supported stream alluvium at the base, and interbedded and overlying very poorly sorted, heterogeneous, non-stratified, debris-flow sediments.

DESCRIPTION OF GEOLOGIC UNITS, POLE CANYON TRENCH, OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH

STRATIGRAPHIC PACKAGE A

The oldest geologic deposits exposed in the trench. They predate and immediately postdate the antepenultimate surface-faulting earthquake and lie below an unconformity with younger fluvial and lacustrine units of stratigraphic packages B and D. Two paleosols are developed on this stratigraphic package.

Paleosol S1 Buried soil on units A2b, A2c, and A3a: Buried soil consisting of a weak clay-enriched Bt horizon overlying a strong K horizon (stage III+ $CaCO_3$). The Bt horizon averages 14 cm thick (probably partially eroded), is light yellowish brown (10YR 6/4)[1], and exhibits weakly developed blocky soil structure with poorly developed clay skins on some ped surfaces. The K horizon is light gray (10YR 7/4) and is plugged with $CaCO_3$. Thickness of the K horizon varies, ranging from about 15 cm on units A2b and A2c to 35 cm on unit A3a.

Paleosol S2 Buried soil on units A2b and A3b: Buried soil consisting of a weak clay-enriched Bt horizon overlying a Bk horizon. The Bt horizon averages 12 cm thick, is pale brown (10YR 6/3), and exhibits weakly developed angular blocky soil structure. The Bk horizon contains filaments and stringers of $CaCO_3$ and weak carbonate coatings on the bottom of gravel clasts (stage I+ $CaCO_3$).

Paleosols S1 and S2 may be equivalent, but they do not connect within the trench wall exposure. The strong K horizon associated with paleosol S1 argues for an older age than paleosol S2.

Unit A3

Fluvial deposits that incise or mantle the antepenultimate earthquake scarp and associated colluvial units

A3b Gravelly, clayey sand[2] (debris-flood deposit?): Mottled light yellowish brown (10YR 6/4) to yellowish brown (10YR 5/6) with streaks of reddish yellow (7.5YR 7/8) iron staining; <5% boulders and cobbles, 35% gravel, 50% sand, 15% clayey fines[3,4], maximum clast size 30 cm; subangular to subrounded; moderately plastic[5]; crudely stratified; weakly to moderately cemented (stage I+ $CaCO_3$); upper contact abrupt and unconformable; paleosol at top of unit (Bt and Bk horizons).

A3a Sandy gravel (cut-and-fill stream deposit): Color variable due to strong carbonate cementation (white, 10YR 8/2), locally iron stained (reddish yellow, 5YR 7/8); 65% gravel, 30% sand, 5% fines, maximum clast size 9 cm; subangular to subrounded; none to very low plasticity; well stratified with alternating layers of coarse and fine gravel up to 20 cm thick; moderately to strongly cemented (stage III+ $CaCO_3$); upper contact abrupt and unconformable; paleosol at top of unit (Bt and K horizons).

Units A3a and A3b may be equivalent, however, they do not connect within the trench wall exposure.

[1]Munsell color chart used to describe unit colors.
[2]Unified Soil Classification System used to classify unit texture and grain size.
[3]Percentages reported for clast size fractions are field estimates.
[4]Clast composition is predominantly limestone and quartzite unless otherwise noted.
[5]Plasticity estimated in the field; for coarse-grained units plasticity is reported for the matrix (fines portion) of the deposit.

Unit A2

Colluvial and eolian deposits mantling the antepenultimate earthquake-degraded scarp free face

A2c Sandy silt (loess): Very pale brown (10YR 7/3), locally mottled with yellow (10YR 7/5) iron staining; 5% coarse sand, 45% fine sand, 50% silty fines, maximum clast size 3 mm; subangular to subrounded; low plasticity; weakly stratified; moderately cemented in upper part (stage II- $CaCO_3$, K horizon), porous with low dry strength; upper contact abrupt and unconformable with overlying cut-and-fill fluvial unit; interbedded with unit A2b.

A2b Cobbly, sandy gravel with silt (colluvium): Light gray (10YR 7/2); <5% boulders, 10% cobbles, 50% gravel, 30% sand, 10% fines, maximum clast size 30 cm; subangular to subrounded; very low plasticity; indistinct bedding; moderately to strongly cemented (stage III grading to stage II+ $CaCO_3$ with depth); upper contact abrupt and unconformable; paleosol at top of unit (Bt and K horizons); interbedded with unit A2c.

A2a Sandy silt (loess): Very pale brown (10YR 7/3); 5% gravel, 25% mostly fine sand, 70% fines, maximum clast size 13 cm; gravel and sand subrounded; low plasticity; indistinctly bedded; weakly cemented (stage I $CaCO_3$), porous with low dry strength; upper contact abrupt.

Unit A1

Pre-antepenultimate event alluvial and eolian deposits

A1c Sandy gravel (debris-flood deposit?): Pale brown (10YR 6/3) with yellow (10YR 7/6) iron staining along upper contact; <5% cobbles and boulders, 60% gravel, 35% sand, 5% fines, maximum clast size 57 cm; cobbles and boulders subrounded, gravel and sand subangular to subrounded; very low plasticity; crudely stratified (alternating layers of coarse and finer grained sandy gravel); weakly to moderately cemented (stage I+ $CaCO_3$); upper contact abrupt.

A1b Sandy silt (loess): Pale brown (10YR 6/3); 5% gravel, 35% very fine sand, 60% fines, maximum clast size 12 cm (very rare); gravel subangular to subrounded, sand angular to subangular; low plasticity; nonstratified; weakly cemented (stage I $CaCO_3$), porous with low dry strength; upper contact abrupt.

A1a Sandy gravel with silt and cobbles (alluvial-fan deposit): Very pale brown (10YR 7/4); <5% cobbles, 60% gravel, 30-35% sand, 5-10% fines, maximum clast size 25 cm; subangular to subrounded; very low plasticity; crudely bedded; moderately cemented (stage II+ $CaCO_3$); upper contact abrupt; matrix appears to be reworked loess.

STRATIGRAPHIC PACKAGE B

Fluvial sediments unconformably overlying stratigraphic package A. They postdate the antepenultimate earthquake and predate the penultimate earthquake. Paleosols S1 and S2 at the contact between stratigraphic packages A and B show that a period of soil formation followed the antepenultimate earthquake prior to deposition of stratigraphic package B.

Unit B5

Stratigraphic package B sediments beneath the penultimate-earthquake colluvial wedge

B5 Sandy, clayey silt: Very pale brown (10YR 7/3); <5% gravel, 25% very fine sand, 75% fines, maximum clast size 7 cm; gravel subrounded, sand subangular to subrounded; low plasticity; nonstratified; very weakly cemented; upper contact abrupt and unconformable; the matrix material in the overlying penultimate-earthquake colluvial wedge is similar in color and texture to this unit as is unit B2 on the upthrown side of the fault zone.

Unit B4

Remnant of stratigraphic package B down-faulted with the penultimate-earthquake colluvial wedge during the most recent surface-faulting earthquake

B4 Gravelly sand: Light gray (10YR 7/2) with minor reddish yellow (7.5YR 6/8) iron staining; <5% cobbles, 35% gravel, 60% sand, 5% fines, maximum clast size 15 cm; subrounded; nonplastic; nonstratified, some rotation of clasts due to fault shear; noncemented; remnant of penultimate-earthquake scarp free face.

Unit B3

Coarse-grained fluvial sediment interbedded with B2

B3 Sand with gravel: Light gray (10YR 7/2) with minor reddish yellow (7.5YR 6/8) iron staining; 10% cobbles, 25% gravel, 65% sand, <5% fines, maximum clast size 25 cm; subrounded; nonplastic; crudely bedded with thin, discontinuous clay stringers and beds of gravelly sand; weakly cemented (stage I- $CaCO_3$); upper contact abrupt; interfingers with unit B2.

Unit B2

Fine-grained fluvial sediment filling buried-stream channel, the resulting cut-and-fill structure truncates several subunits in B1

B2 Silty clay with stringers of sand: Dark yellowish brown (10YR 4/4); 15% mostly very fine sand, 85% fines; low to moderate plasticity; consists of interbedded silt and clay lamina, with clay predominating, some sand stingers near west edge of deposit; noncemented; upper contact abrupt and unconformable; contains numerous flecks of detrital charcoal; interfingers with unit B3 and truncates several subunits in unit B1.

Unit B1

Coarse-grained fluvial deposits truncated, interbedded with, or buried by unit B2

B1j Gravelly Sand: Light gray (10YR 7/2) with minor reddish yellow (7.5YR 6/8) iron staining; 10% cobbles, 25% gravel, 65% sand, maximum clast size 29 cm; subrounded; nonplastic; alternating discontinuous sand and gravelly sand layers; noncemented; upper contact abrupt.

B1i Sand with gravelly sand stringers: Light gray (10YR 7/2); <5% cobbles; 15% gravel, 85% sand, maximum clast size 10 cm; subrounded; nonplastic; thinly bedded; noncemented; upper contact abrupt.

B1h Gravelly sand with cobbles: Light gray (10YR 7/2) with minor reddish yellow (7.5YR 6/8) iron staining; 5% cobbles, 25% gravel, 70% sand, maximum clast size 15 cm; subrounded; nonplastic; alternating discontinuous layers of sand and gravelly sand; weakly cemented (stage I+ $CaCO_3$); upper contact abrupt.

B1g Gravel: Strongly mottled with black (10YR 3/1) manganese and red (7.5YR 6/8) iron staining; <5% cobbles and boulders, 95% gravel, maximum clast size 30 cm; subrounded; nonplastic; imbricated openwork structure; noncemented; upper contact abrupt.

B1f Cobbly gravel with boulders: Mottled with manganese and iron staining ranging from very dark gray (10YR 3/1) to reddish yellow (7.5 YR 6/8), where not mottled very pale brown (10YR 7/3); 10% boulders, 40% cobbles, 50% gravel, maximum clast size 35 cm; subrounded; nonplastic; imbricated openwork structure, grades finer upward; noncemented; upper contact abrupt.

B1e Gravelly sand with clay and silt stringers: Light gray (10YR 7/2); 30% gravel, 70% sand, % fines, maximum clast size 10 cm; subrounded; nonplastic; moderately bedded, alternating coarse and fine sand layers; weakly cemented; upper contact abrupt.

B1d Cobbly gravel with boulders: Mottled with manganese and iron staining ranging from very dark gray (10YR 3/1) to reddish yellow (7.5 YR 6/8), where not mottled very pale brown (10YR 7/3); 10% boulders, 40% cobbles, 50% gravel, maximum clast size 35 cm; subrounded; nonplastic; imbricated openwork structure, grades finer upward; noncemented; upper contact abrupt.

B1c Gravelly sand with clay and silt stringers: Light gray (10YR 7/2); <5% cobbles and boulders, 30% gravel, 65% sand, <5% fines, maximum clast size 45 cm; gravel subrounded, sand subrounded to subangular; nonplastic; poorly to moderately stratified with alternating layers of sand and gravel and clay/silt stringers, grades from finer to coarser upward; non- to very weakly cemented; upper contact abrupt; interfingers with unit B1d.

B1b Gravel: Strongly mottled with manganese and iron staining ranging from very dark gray (10YR 3/1) to reddish yellow (7.5 YR 6/8), where not mottled very pale brown (10YR 7/3); 10% cobbles, 90% gravel, maximum clast size 20 cm; subrounded; nonplastic; nonstratified, imbricated, openwork structure (no matrix); weakly cemented (stage I- $CaCO_3$); upper contact abrupt.

B1a Cobbly, sandy gravel: Light gray (10YR 7/2) with reddish yellow (7.5YR 7/8) iron staining; <5% boulders, 25% cobbles, 40% gravel, 35% sand, <5% fines, maximum clast size 30 cm; cobbles and gravel subrounded, sand subrounded to angular; nonplastic; crudely stratified with stringers of sand up to 5 cm thick; noncemented, loose, ravels freely; upper contact abrupt.

STRATIGRAPHIC PACKAGE C

Penultimate surface-faulting earthquake colluvial wedge. The wedge consists of material eroded from the upper part of the scarp formed by the penultimate earthquake and deposited at the base of the scarp. Both debris-element and wash-element facies are present in the wedge; however, the fine-grained texture of the material in the wedge made it difficult to distinguish between the two or to clearly identify individual gravity-derived blocks. Therefore, the wedge is described here and shown on the Pole Canyon trench log as a single unit. A paleosol is present on the wedge.

Unit C

Paleosol S3 Buried Soil on Unit C: Buried soil consisting of a weak clay-enriched Bt horizon overlying a Bk horizon. The Bt horizon averages 12 cm thick (probably partially eroded), is light yellowish gray (2.5Y 6/2), and exhibits poorly developed prismatic soil structure with thin clay skins. The Bk horizon ranges from white (10YR 8/2) to very light brown (10YR 7/3) with depth and, where best developed, exhibits stage II $CaCO_3$ accumulation. Thickness of the Bk horizon varies, reaching 30 cm in places.

C Gravelly, clayey sand and clayey, sandy gravel (colluvial wedge): Generally very pale brown (10YR 7/3) but locally moderate to strong carbonate accumulation gives the wedge a white (10YR 8/2) color; texture variable, <5% boulders and cobbles, 15-40% gravel, 30-50% sand, 10-30% fines, maximum clast size 37 cm; subrounded; low to moderate plasticity; crudely stratified, especially near the top of the wedge where slope-wash depositional processes dominated; moderately cemented (stage II $CaCO_3$ grading to stage I downward); upper contact abrupt and unconformable; paleosol developed at top of unit.

STRATIGRAPHIC PACKAGE D

Lacustrine deposits of the Bonneville lake cycle. Lake Bonneville transgressed across the Pole Canyon trench site (elevation 1,448 m) about 20,000 ^{14}C years ago and regressed from the site shortly after 14,200 ^{14}C years ago. When the lake reached its high stand (Bonneville level, 1,552 m) the trench site was beneath about 135 meters of water.

Unit D4

Regressive beach deposit - the only faulted stratigraphic unit that can be correlated across the fault zone

D4 Bouldery, cobbly, sandy gravel: Light gray (10YR 7/2) except where strongly cemented by white (10YR 8/1) tufa; texture highly variable, 15-50% boulders, 10-30% cobbles, 30-50% sand, <5% fines, maximum clast size 1 m; boulders, cobbles, and gravel are rounded to subrounded, sand is subrounded; nonplastic; nonstratified; strongly cemented locally (particularly on the upthrown side of the fault zone) by tufa; upper contact abrupt and unconformable; no soil development at top of unit.

Unit D3

Deep-water sediments

D3 Silty clay: Brown (10YR 5/3); 10% fine sand, 90% predominantly clay fines with a strong silt component; moderate plasticity; very thinly bedded to laminated, alternating layers of silt and clay; noncemented; upper contact abrupt and unconformable; numerous hairline vertical cracks outlined by $CaCO_3$, possible evidence of liquefaction in underlying sand deposit (unit D2c); thin, locally convoluted black marker horizon extends the length of this unit, non-organic, possibly manganese.

D2

Nearshore transgressive deposits on upthrown side of the fault zone

D2c Gravelly sand: Light gray (10YR7/2) with white (10YR 8/1) carbonate mottling; <5% cobbles, 20% gravel, 80% sand, <5% fines, maximum clast size 15 cm; subrounded, nonplastic; homogeneous; weakly cemented; upper contact abrupt.

D2b Sandy gravel with cobbles: Light gray (10YR 7/2) with reddish yellow (7.5YR 6/8) iron stains; <5% boulders, 5% cobbles, 65% gravel, 30% sand, <5% fines, maximum clast size 30 cm; subrounded; nonplastic; imbricate openwork structure in places, otherwise crudely bedded; noncemented; upper contact abrupt.

D2a Sand: Brownish yellow (10YR 6/8); 5% gravel, 90% sand, 5% fines, well sorted, maximum clast size 4 cm; subrounded to subangular; nonplastic; noncemented; upper contact abrupt; contact with underlying unit B2 clay is unconformable and erosional, stratigraphic relations show as much as 1.5 m of unit B2 were eroded when Lake Bonneville transgressed across the fault scarp.

Unit D1

Nearshore transgressive deposits on downthrown side of the fault zone

D1c Cobbly, sandy gravel: Light gray (10YR 7/2); texture highly variable, <5% boulders, 10-15% cobbles, 40-70% gravel, 20-40% sand, no fines, maximum clast size 65 cm; subrounded to rounded; nonplastic; nonstratified; weakly to moderately cemented (stage II- $CaCO_3$ coatings on clasts); upper contact abrupt.

D1b Sandy gravel with cobbles (prograding bar): Very pale brown (10YR 7/3) with streaks and blotches of reddish yellow (7.5YR 7/8) iron staining along coarse gravel stringers; texture highly variable, 0-15% boulders and cobbles, 30-100% gravel, 0-70% sand, 0-10% fines, maximum clast size 35 cm; subrounded; nonplastic; well stratified, texture is highly variable between individual beds, ranging from well-sorted, openwork gravel with no matrix to gravelly sand with fines, unit becomes finer grained upward and to the west; moderately to strongly cemented (stage II+ $CaCO_3$), strongest cementation along upper contact with overlying tufa cemented regressive Bonneville beach deposit (D4); primary dips on bedding as high as 35 degrees to the east.

D1a Silty clay with sand (marsh deposit): Pale yellow (2.5Y 5/4) with streaks and blotches of yellow (10YR 7/6); 15% fine sand, 85% silty fines, maximum clast size 1 cm; subrounded; moderate plasticity; thin beds and lamina of silty clay with stringers of sand and clayey sand along the lower contact; weakly cemented; upper contact abrupt; contains small flecks of charcoal; mantles penultimate-earthquake colluvial wedge.

STRATIGRAPHIC PACKAGE E

Post-Lake Bonneville colluvium (debris-flow deposit?) deposited after the lake regressed from the trench site and before the most-recent surface-faulting earthquake occurred.

Unit E

E Clayey, sandy gravel: Brown (10YR 5/3); 10% cobbles, 50% gravel, 15% sand, 25% clayey fines, maximum clast size 25 cm; rounded; moderate plasticity; nonstratified; weakly cemented (stage I $CaCO_3$); upper contact gradational with modern colluvium (unit H).

SHEARED FAULT ZONE MATERIAL

Material in the fault shear zone, predominantly coarse-grained sand and gravel derived from stratigraphic packages B and D.

FZ Sandy gravel with cobbles: Very pale brown (10YR 7/3); 10% cobbles, 50% gravel, 40% sand, <5% fines, maximum clast size 20 cm; subrounded to rounded; nonplastic; strong shear fabric parallel to fault; noncemented; fault zone width varies from about 8 to 45 cm.

STRATIGRAPHIC PACKAGE F

Most-recent surface-faulting earthquake colluvial wedge. The wedge consists of material eroded from the upper part of the scarp formed by the most-recent earthquake and deposited at the base of the scarp. Both debris-element and wash-element facies are present in the wedge; however, the boundary between the two facies is gradational and the wedge is described here and shown on plate 1 as a single unit.

Unit F

F Clayey, sandy gravel (colluvial wedge): Brown (10YR 5/3); 5% boulders, 10% cobbles, 40% gravel, 20% sand, 25% fines, maximum clast size 50 cm; subrounded to rounded; low to moderate plasticity; nonstratified in lower part of wedge, in the upper part of the wedge the clasts parallel the upper wedge contact (slope-wash facies); noncemented; upper contact abrupt.

STRATIGRAPHIC PACKAGE G

Post-most-recent-event colluvium mantling the fault scarp and both the up- and downthrown sides of the fault zone.

Unit G

G **Gravelly, sandy clay/gravelly and clayey sand (colluvium):** Brown (10YR 5/3); texture highly variable, 0-10% boulders and cobbles, 20-50% gravel, 20-40% sand, 20-50% fines, maximum clast size 85 cm; subrounded to rounded; low to moderate plasticity; nonstratified; noncemented.

UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

Utah Geological Survey Special Study 88
NEHRP Grant 1434-92-G-2218
Surficial Geologic Map of the Oquirrh Fault Zone

DESCRIPTION OF MAP UNITS

Qft Tailings and slag (Holocene) - *Unconsolidated, fine-grained residue (tailings) from washed or milled ore and coarse-grained rock fragments (slag) associated with smelter by- products.*

Qpm Playa mud (Holocene) - *Unconsolidated, poorly sorted deposits of clay, silt, and small amounts of sand. Locally, gypsum, halite, and other salts accumulate on playa surfaces. Only mapped near Great Salt Lake.*

Qa Undifferentiated alluvium (Holocene and latest Pleistocene) - *Unconsolidated alluvium on gentle slopes near the confluence of streams lacking well-defined flood plains. Primarily sandy, with lesser amounts of boulders, gravel, silt, and clay.*

Qac Alluvium and colluvium (Holocene and latest Pleistocene) - *Unconsolidated, poorly sorted deposits of clay, silt, sand, gravel, cobbles, and boulders, in first-order drainages and on wash slopes. Coarser on steeper slopes .*

Qal Alluvium in channels and flood plains (Holocene and latest Pleistocene) - *Unconsolidated clay, silt, and sand, with thin gravel layers and lenses. Deposits typically extend from alluvial channels in bedrock to channels and associated flood plains on adjacent piedmont slopes.*

Qmt Talus (Holocene and latest Pleistocene) - *Unconsolidated deposits of coarse, angular, cobble and boulder rock-fall debris on Oquirrh Mountains slopes. Accumulates where the Bonneville shoreline abrasion platform undercuts bedrock outcrops.*

Qaf_1 Alluvial-fan deposits younger than the Bonneville shoreline (Holocene and latest Pleistocene) - *Unconsolidated, poorly sorted, stream and debris-flow deposits of clay, silt, sand, and gravel. Deposits are principally below the Bonneville shoreline and obscure later, regressive shorelines on the piedmont slope. Fans taper to a feather edge in distal parts, and deposits are finer grained down the fan slope.*

Qla Undifferentiated lacustrine and alluvial deposits (Holocene and latest Pleistocene) - *Unconsolidated deposits of sand, gravel, and cobbles consisting of alluvial-fan deposits reworked by Lake Bonneville. The thin veneer of lacustrine sediment is coarser grained in the proximal piedmont sector and finer grained in the distal sector. The unit is commonly expressed geomorphically as pre-Bonneville alluvial fans etched by Lake Bonneville shorelines.*

Qlg Lacustrine gravel (Holocene and latest Pleistocene) - *Shore-zone deposits of Lake Bonneville and Great Salt Lake consisting of unconsolidated, coarse-grained, well-rounded sand, gravel, and cobbles. Sand is commonly oolitic at low elevations in gravel beaches at the level of the Holocene highstand of Great Salt Lake. Deposits are thickest in benches along the Oquirrh Mountains.*

Qlf Lacustrine mud (Holocene and latest Pleistocene) - *Unconsolidated deposits of silt and clay, with smaller amounts of sand and marl, on the lower piedmont. Deposited in quiet water, either offshore in deeper water of Lake Bonneville, or nearshore in the bay of Great Salt Lake in northeastern Tooele Valley.*

Qat_1 Younger alluvial-terrace deposits (latest Pleistocene) - *Thin veneer of unconsolidated clay, silt, sand, gravel, and cobbles on terraces above modern channels and flood plains. Younger alluvial-terrace deposits are truncated by the Bonneville shoreline.*

Qat_2 Alluvial-terrace deposits of intermediate age (latest Pleistocene) - *Thin veneer of unconsolidated clay, silt, sand, gravel, and cobbles on terraces above modern channels and flood plains. Alluvial-terrace deposits of intermediate age are adjacent to, and at higher elevations than, younger alluvial-terrace deposits near Middle, Dry, Pine, and Swensons Canyons.*

Qat_3 Older alluvial-terrace deposits (latest Pleistocene) - *Thin veneer of unconsolidated clay, silt, sand, gravel, and cobbles on terraces above modern channels and flood plains. Older alluvial-terrace deposits are adjacent to, and at higher elevations than, alluvial-terrace deposits of intermediate age near Middle Canyon.*

Qaf_2 Intermediate age alluvial-fan deposits older than the Bonneville shoreline (latest Pleistocene) - *Unconsolidated, poorly sorted, stream and debris-flow deposits of clay, silt, sand, gravel, cobbles, and boulders. The deposits are found above the Bonneville shoreline and are truncated by it near the mouth of Middle Canyon, west of the map boundary. Fans have relatively smooth surfaces that are inactive and undergoing erosion.*

Qaf_3 Older alluvial-fan deposits older than the Bonneville shoreline (middle to late Pleistocene) - *Unconsolidated, poorly sorted, stream and debris-flow deposits of clay, silt, sand, gravel, cobbles, and boulders found above the Bonneville shoreline only near the mouth of Pine Canyon. Fan surfaces are more incised than those of intermediate-age deposits.*

QTaf Oldest alluvial-fan deposits older than the Bonneville shoreline (early Pleistocene and Pliocene) - *Unconsolidated to semi-consolidated, poorly sorted, stream and debris-flow deposits of clay, silt, sand, gravel, cobbles, and boulders found above the Bonneville shoreline. Locally lithified with carbonate cement. Fan surfaces are extremely dissected. Deposits of this unit are buried by older and intermediate-age alluvial-fan deposits.*

---------- Unconformity ----------

Tp Porphyritic Dikes and Sills (Oligocene) - *Small dikes and sills intruded into the Markham Peak Member of the Upper Pennsylvanian Bingham Mine Formation in the Bingham nappe, south of Tooele. Mainly quartz monzonite to quartz latite porphyries.*

---------- Unconformity ----------

Pp Pass Canyon nappe (Lower Permian) - *Allochthonous (thrust- transported), complexly folded and faulted sequence of sedimentary rocks in the Oquirrh Group. Provisionally divided (Tooker and Roberts, 1988) into the Dry Fork unit, predominantly sandstone, siltstone, shale, and quartzite; and the Flood Canyon unit, predominantly sandstone, quartzite, dolomite, and limestone. A reliable thickness for these rocks has not been determined due to structural complexities.*

IPb Bingham nappe (Pennsylvanian) - *Allochthonous, complexly folded and faulted sedimentary rocks of the Oquirrh Group, divided (Tooker and Roberts, 1988) into the Butterfield Peaks Formation and the Bingham Mine Formation. Both formations are predominantly sandstone, quartzite, and limestone. At their type localities, the Butterfield Peaks Formation is about 8,990 feet (2,740 m) thick and the Bingham Mine Formation is about 7,320 feet (2,230 m) thick (Tooker and Roberts, 1970).*

PMr Rogers Canyon nappe (Mississippian to Permian)- *Allocthonous, complexly folded and faulted sequence of sedimentary rocks of the Oquirrh Group and Park City Formation. Oquirrh Group rocks are divided (Tooker and Roberts, 1988) into the Lake Point Limestone, the Erda Formation, and the Kessler Canyon Formation. Rocks on the Rogers Canyon nappe are predominantly sandstone, quartzite, limestone, and dolomite, and are about 9,840 feet (3,000 m) thick.*

MAP SYMBOLS

CONTACT- *Dashed where location inferred,contacts shown between individual alluvial fans younger than the Bonneville shoreline (Qaf_1)*

HIGH-ANGLE FAULT-*Dashed where location inferred,dotted where concealed,bar and ball on downthrown side*

THRUST FAULT-*Dashed where location inferred,saw teeth on upper plate*

STANSBURY SHORELINE

SUB-PROVO SHORELINE

BONNEVILLE SHORELINE

PROVO SHORELINE

GILBERT SHORELINE

HOLOCENE-HIGHSTAND SHORELINE

SPRING

TRENCH LOCATION FOR PALEOSEISMIC STUDY (Olig and others, 1994; this volume)

STUDY-AREA BOUNDARY

14°11'
252 mils

1995 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SURFICIAL GEOLOGIC MAP OF THE OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH

by

Barry J. Solomon

1996

Base map from U.S. Geological Survey 1:24,000: Tooele,1969; Farnsworth Peak and Mills Junction, 1972; and Bingham Canyon, 1975.

Contour intervals 10 (Mills Junction quad.), 20 (Tooele quad.),and 40 (Bingham Canyon and Farnsworth Peak quads.) feet

Field work by B. J. Solomon, 1990-91
Lori J. Douglas, Cartographer

Mapping by William R. Lund and Bill D. Black
May, June 1993

A STATIONS 0 TO 45

Planimetric base constructed on a 1 m x 1 m grid
Drafted by Bea H. Mayes

EXPLANATION

UNIT DESCRIPTIONS[1]
(See appendix in text for detailed descriptions)

<-Holocene->

STRATIGRAPHIC PACKAGE G - Post-Most-Recent-Event Colluvium
- G Gravelly, sandy clay/Gravelly, clayey sand

STRATIGRAPHIC PACKAGE F - Most-Recent - Event Colluvial Wedge
- F Clayey, sandy gravel

STRATIGRAPHIC PACKAGE FZ - Sheared Fault-Zone Material
- FZ Sandy gravel with cobbles

<-Pleistocene/Holocene->

STRATIGRAPHIC PACKAGE E - Post-Lake Bonneville/Pre-Most-Recent-Event Colluvium
- E Clayey, sandy gravel

Pleistocene

STRATIGRAPHIC PACKAGE D - Lacustrine Deposits of the Bonneville Lake Cycle[2]
- D4 Regressive beach deposit
  - Bouldery, cobbly, sandy gravel
- D3 Deep-water deposit
  - Silty clay
- D2 Nearshore transgressive deposits - upthrown side of fault
  - D2c Gravelly sand
  - D2b Sandy gravel with cobbles
  - D2a Sand
- D1 Nearshore transgressive deposits - downthrown side of fault
  - D1b Sandy gravel with cobbles (prograding bar)
  - D1a Silty clay with sand (marsh deposit)

Pleistocene

STRATIGRAPHIC PACKAGE C - Penultimate-Event Colluvial Wedge
- S3 Paleosol, formed on unit C
- C Gravelly, clayey sand and clayey, sandy gravel

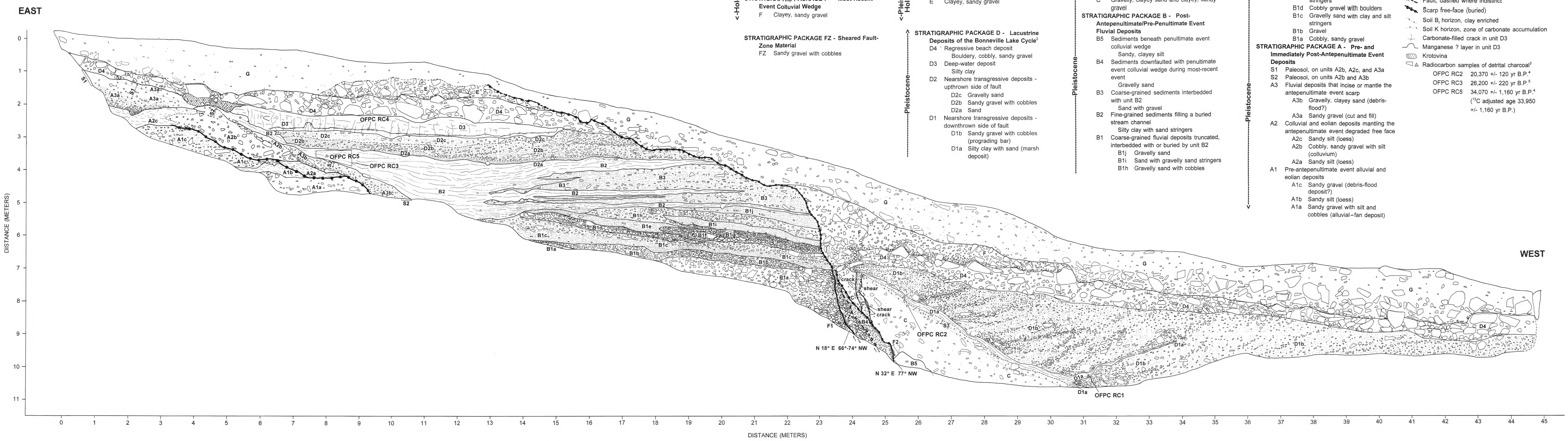
STRATIGRAPHIC PACKAGE B - Post-Antepenultimate/Pre-Penultimate Event Fluvial Deposits
- B5 Sediments beneath penultimate event colluvial wedge
  - Sandy, clayey silt
- B4 Sediments downfaulted with penultimate event colluvial wedge during most-recent event
  - Gravelly sand
- B3 Coarse-grained sediments interbedded with unit B2
  - Sand with gravel
- B2 Fine-grained sediments filling a buried stream channel
  - Silty clay with sand stringers
- B1 Coarse-grained fluvial deposits truncated, interbedded with or buried by unit B2
  - B1j Gravelly sand
  - B1i Sand with gravelly sand stringers
  - B1h Gravelly sand with cobbles
  - B1g Gravel
  - B1f Cobbly gravel with boulders
  - B1e Gravelly sand with clay and silt stringers
  - B1d Cobbly gravel with boulders
  - B1c Gravelly sand with clay and silt stringers
  - B1b Gravel
  - B1a Cobbly, sandy gravel

Pleistocene

STRATIGRAPHIC PACKAGE A - Pre- and Immediately Post-Antepenultimate Event Deposits
- S1 Paleosol, on units A2b, A2c, and A3a
- S2 Paleosol, on units A2b and A3b
- A3 Fluvial deposits that incise or mantle the antepenultimate event scarp
  - A3b Gravelly, clayey sand (debris-flood?)
  - A3a Sandy gravel (cut and fill)
- A2 Colluvial and eolian deposits mantling the antepenultimate event degraded free face
  - A2c Sandy silt (loess)
  - A2b Cobbly, sandy gravel with silt (colluvium)
  - A2a Sandy silt (loess)
- A1 Pre-antepenultimate event alluvial and eolian deposits
  - A1c Sandy gravel (debris-flood deposit?)
  - A1b Sandy silt (loess)
  - A1a Sandy gravel with silt and cobbles (alluvial–fan deposit)

SYMBOLS

- Rock
- Laminations in silts and clays
- Contact, dashed where indistinct
- Fault, dashed where indistinct
- Scarp free-face (buried)
- Soil B_t horizon, clay enriched
- Soil K horizon, zone of carbonate accumulation
- Carbonate-filled crack in unit D3
- Manganese ? layer in unit D3
- Krotovina
- Radiocarbon samples of detrital charcoal[3]
  - OFPC RC2 20,370 +/- 120 yr B.P.[4]
  - OFPC RC3 26,200 +/- 220 yr B.P.[5]
  - OFPC RC5 34,070 +/- 1,160 yr B.P.[4] (^{13}C adjusted age 33,950 +/- 1,160 yr B.P.)



Footnotes:
[1]Descriptions do not necessarily include all of units A through G; only units exposed in this part of this trench are included.
[2]Deposited during the Bonneville lake cycle. Lake Bonneville occupied part of the eastern Great Basin from about 30 kya to 12 kya (Scott and others, 1983; Oviatt and others, 1992). Lake Bonneville first transgressed across the Pole Canyon site about 20 kya and regressed across the site about 13-14 kya.

[3]Ages in radiocarbon years before 1950 A.D. Corrections for isotope fractions shown where made. All ages obtained using an atomic mass spectrometer.
[4]Age obtained from a single piece of detrital charcoal.
[5]Age obtained from numerous flecks of charcoal combined to form a single sample. Result represents an average age for the charcoal in unit B2.

LOG OF SOUTH WALL, POLE CANYON TRENCH OQUIRRH FAULT ZONE, TOOELE COUNTY, UTAH stations 0-45 (A) and stations 45-76 (B)

1996

Special Study 88
Utah Geological Survey
a division of
Utah Department of Natural Resources

Mapping by William R. Lund and Bill D. Black
June 1993

B STATIONS 46 TO 76

Planimetric base constructed on a 1 m x 1 m grid
Drafted by Bea H. Mayes

EXPLANATION

UNIT DESCRIPTIONS[1]
(See appendix in text for detailed descriptions)

<-Holocene->

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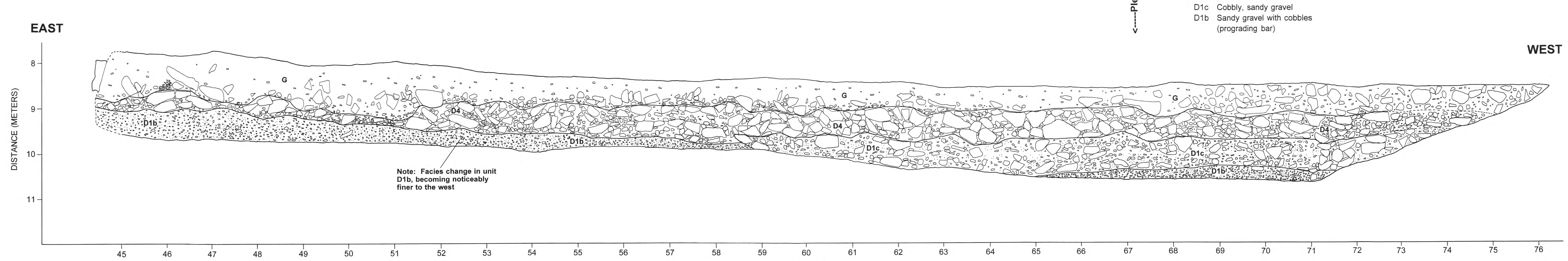
- G Gravelly, sandy clay/gravelly, clayey sand

<-Pleistocene->

STRATIGRAPHIC PACKAGE D - Lacustrine Deposits of the Bonneville Lake Cycle[2]
- D4 Regressive beach deposit
  - Bouldery, cobbly, sandy gravel
- D1 Nearshore transgressive deposits - downthrown side of fault
  - D1c Cobbly, sandy gravel
  - D1b Sandy gravel with cobbles (prograding bar)

SYMBOLS

- Rock
- Contact, dashed where indistinct



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Oquirrh fault zone