STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT, UTAH

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By

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INTRODUCTION

The Wasatch fault zone is a major zone of active normal-slip faulting within the Intermountain seismic belt. It extends approximately 370 km from Gunnison, Utah, to Malad City, Idaho. South of Brigham City, Utah, there is abundant geomorphic evidence for repeated displacement of the late Pleistocene and Holocene surficial deposits (Figure 1). North of about Brigham City, there is no apparent evidence for Holocene displacement on the main trace of the Wasatch fault zone. Along this northern section, the late Quaternary displacement appears to be distributed across a 20- to 40 km-wide zone that includes the East Cache fault as well as the main trace of the Wasatch fault zone (Figures 1 and 2). Evidence of late Quaternary displacement along these traces is markedly less pronounced than it is along the sections of the Wasatch fault zone south of Brigham City. Along the northern part of the zone, the record of late Quaternary faulting is best preserved where the East Cache fault displaces the sequence of lake and deltaic sediments that were deposited near the mouth of Logan Canyon. This report describes the results of studies conducted along the East Cache fault in the vicinity of Logan, Utah between Green and Providence canyons (Figure 3) to collect data that characterize the late Pleistocene and Holocene behavior of the fault. Detailed mapping, topographic profiling, and exploratory trenching were done to obtain information on the cumulative displacement in Quaternary strata of different ages, slip rate, amount of displacement per event, and the magnitude and recurrence of earthquakes associated with past surface faulting events on the East Cache fault.

PREVIOUS INVESTIGATIONS

Gilbert (1890), Peterson (1936), and Cluff and others (1974) discuss the age of the most recent faulting along the East Cache fault. Gilbert (1890, p. 357) states: "... There are obscure

indications of late movements, either during or just after the lake epoch, and at one point, near Logan, a post-lacustrine fault scarp crosses a Provo data. The displacement is about six feet."

Peterson (1936) describes the fault scarps in the vicinity of Logan, which he refers to as the Bear River fault or the Bear River Range fault after the mountains to the east. He concludes, as Bailey (1927) had previously, that the scarp on the west face of the Bear River Range is a fault scarp and not a resequent fault-line scarp as Blackwelder (1928) had proposed. He rules out a landslide origin for the scarps on the Provo delta near the mouth of Logan Canyon because they can be traced into alluvial material lying close to the range front beyond the delta.

Based primarily on interpretation of low-sun-angle aerial photographs, Cluff and others (1974) delineated the probable late Pleistocene and Holocene fault traces along the East Cache fault zone, including the post-Provo scarps near the mouth of Logan Canyon. Based on the subdued nature of the scarps, Cluff and others (1974) suggest the faulting along the East Cache fault is older than the faulting in the area of Salt Lake City.

As part of a geotechnical feasibility study conducted prior to the development of the Logan East Bench area, Rogers (1978) excavated test pits across west-facing scarps in the area immediately north of the Logan Country Club (Figure 4). Rogers concluded that faulting has occurred in recent geologic time along the East Cache fault, but his report provides no data on the amount or timing of the displacement.

The Logan area is one of five localities that have been investigated by Woodward-Clyde Consultants as part of a five-year study to assess earthquake recurrence intervals on the Wasatch fault zone (Figure 1). The results of the investigations at the other sites are presented in numerous reports and publications that are listed in Appendix A. The data on earthquake recurrence from

these investigations are summarized in two guidebooks for field trips along the Wasatch Front (Hanson and Schwartz, 1982; Schwartz and others, 1983).

METHODS OF STUDY

Geologic investigations of the East Cache fault for this study included:

1. Photo Interpretation - Analysis of 1970, 1:12,000, low-sun-angle (morning) black-and-white and 1953, 1:24,000, black-and-white aerial photographs was made to identify possible fault traces (Figures 4, 5 and 6) and to aid in selecting locations for test pits.

2. Aerial Reconnaissance - A brief aerial reconnaissance on 9 December, 1981, provided an opportunity to observe and photograph some of the linear features that had been delineated on the vertical aerial photographs under different light conditions.

3. Topographic Profiling - Topographic profiles (Figure 7) were measured across fault scarps in surfaces of different ages to assess the changes in the amount of cumulative displacement with time and to obtain data for calculating slip rates.

4. Excavation of Test Pits - Two exploratory test pits were excavated across a break in slope near the base of a scarp below the Bonneville shoreline approximately 150 m south of Green Canyon (Figure 4). The test pits were excavated to assess whether the break in slope was due to shoreline erosion by Lake Bonneville or resulted from displacement along the fault subsequent to recession of the lake from the Bonneville shoreline.

LOCATION AND SETTING OF THE EAST CACHE FAULT

The East Cache fault lies on the east side of Cache Valley along the western base of the Bear River Range approximately 20 to 40 km east of the Wasatch fault zone (Figure 2). It extends as a zone of west-dipping Quaternary normal faults in a north-south direction for a distance of about 70 km from just north of James Peak in Utah, to Preston, Idaho (Cluff and others, 1974). Late Quaternary fault scarps along the East Cache fault are discontinous and in many locations are subdued due to erosion or are buried by Holocene alluvial fans. The lateral extent of the late Pleistocene - Holocene faulting along the East Cache fault is not known.

Quaternary Stratigraphy

In the vicinity of Logan, the Bonneville and Provo shorelines are at elevations of approximately 1564 m (5,130 ft) and 1464 m (4802 ft), respectively. These shorelines are important datums that can be used to assess the amount and timing of surface faulting along the East Cache fault. Recent investigations by Scott (1978, 1980a, 1980b) and by Scott and others (1982) provide radiocarbon age-dates that constrain the ages of these features. Beginning before 26,000 yr B.P. the lake rose steadily, with apparently only minor fluctuations, and reached the Bonneville shoreline at about 16,000 yr B.P. The lake remained at the Bonneville shoreline until sometime between about 15,000 and 14,000 yr B.P., being maintained at a stable level by overflow through Red Rock Pass, Idaho. Eventually, catastrophic downcutting of the pass caused the Bonneville flood (Malde, 1968) and resulted in a rapid drop of the lake level of about 100 m. After a period of rapid isostatic uplift, the Provo shoreline was formed and continued to be occupied until about 13,500 yr B.P. Thereafter, the lake level dropped and by 11,000 years B.P. the level was to within 15 m of the present level of Great Salt Lake.

Remnants of deltas that prograded into Lake Bonneville from the level of the Bonneville shoreline are observed at the mouths of Logan, Providence, and Blacksmith Fork canyons. More extensive deltas, which are still largely intact, also formed at the mouths of these canyons while the lake was at the Provo level. Stream incision and deposition of widespread alluvial fans occurred subsequent to recession of the lake from the Bonneville and Provo levels.

Seismicity

The earthquake epicenter map of Utah, which shows data from the University of Utah Seismograph Network from 1974 to 1980, shows a pronounced north-south trend in the seismicity data within the Bear River Range to the east of the East Cache fault. Arabasz and Smith (1981) suggest that this activity may represent strain release on secondary faults associated with stress build up along the East Cache fault. The largest historical earthquake in the vicinity of the East Cache fault was a magnitude ML 5.7 event near Logan in 1962.

DESCRIPTION OF THE EAST CACHE FAULT ZONE BETWEEN GREEN AND PROVIDENCE CANYONS

Although discontinuous, the zone of most recent surface fault rupture along the East Cache fault can be traced from Green Canyon southwards to Logan Canyon (Figures 3 and 4). The trace is marked by an alignment of subdued scarps in the post-Bonneville deposits and by breaks-in-slope near the base of the higher scarps in older deposits. The scarps along the fault trace are breached and buried by alluvium from numerous drainages and intermittent westward flowing streams.

The fault lies below, and is subparallel to, the Bonneville shoreline and in places it is difficult to distinguish between

fault scarps and erosional scarps along shorelines that formed during transgression of the lake to the Bonneville shoreline. Two test pits were excavated across a linear break in slope approximately 150 m south of Green Canyon (Figure 4) to confirm that the break-in-slope is the result of post-Bonneville faulting and not an erosional feature. Each test pit exposed a 20 m-wide zone containing 6 to 7 faults having down-to-the-west displacement. With the exception of one fault that dips 40 degrees to the west, all the faults were nearly vertical. The faults displace well stratified lacustrine sands and fine gravels against scarp-derived colluvial deposits and extend upwards into the modern soil where they appear to die out. The complexity of the zone and the observation that scarp-derived colluvial deposits are faulted indicate that the fault scarp was produced by more than one surface faulting event.

The elevation of the fault trace decreases southwards from the test pits, which are at elevation 1520 m. The fault trace intersects the Provo shoreline obliquely at an elevation 1464 m (Figure 4) and it is difficult to distinguish between the two. Immediately north of its intersection with the Provo shoreline, the fault scarp is largely buried by alluvial fan deposits. Test pits excavated in this area by Rogers (1978) (Figure 4) exposed stratigraphic and bedrock features that he interpreted as faults. South of its intersection with the shoreline, the fault crosses the Provo delta. The post-Provo faulting is clearly visible on the golf course of the Logan Country Club where the fault zone is expressed as a 100 m-wide backtilted zone bounded on the east by a 3 m-high west facing scarp (Figures 7 and 8a). No inflections were observed in the scarp profiles that suggest the scarp was formed by multiple events. The cumulative net tectonic displacement of the Provo surface across the zone is 1.4 m (Profile A-A' on Figure 7). The surface of a strath terrace that is inset about 12 m (40 ft) below the Provo delta appears to be displaced the same amount. Peterson (1927, Plate 10) shows a photograph of

a roadcut across one of the faults that crosses this strath terrace. The cut, which was excavated during the construction of Canyon Road, is no longer exposed due to degradation of the cut and burial by colluvium. The photograph shows Bonneville deltaic deposits overlain by several feet of bouldery gravel that was deposited by Logan River when it cut the strath terrace. The deltaic deposits are displaced more than 4.9 m (16 ft), which was the thickness exposed in the cut. The exact amount of displacement of the contact between the deltaic deposits and the overlying strath deposits was not reported by Peterson, but based on the photograph, it only appears to be displaced a couple of meters, which is consistent with the heights of the scarps across the strath terrace.

Where the fault trace projects across Logan River, there is no clear indication of faulting on any of the younger terraces. Immediately south of the river, the post-Provo scarp is obscured by a gully along the fault trace (Figure 9).

South of Logan Canyon, the fault can be traced as a nearly continuous scarp across a series of dissected lobes of deltaic deposits that grade to the Bonneville shoreline (1564 m) (Figures 5 and 9). In addition to the fault scarp, there are numerous scarps due to landsliding of the Bonneville deltaic deposits (Figure 5). The lateral extent of the landslide scarps is limited and the scarps heights are generally highly variable, changing abruptly from one lobe to the next (in some cases by as much as 10 m). The landslide scarps do not affect the Provo deltaic deposits and the scarps all pre-date the dissection of the Bonneville deltaic deposits into discrete lobes by gully erosion. The fault scarp is laterally continuous; is associated with well defined graben and/or a zone of backtilting on the downthrown side; and is visible on the steep sides of the gullies, indicating that at least some of the faulting that produced the scarp occurred after the Bonneville deltaic deposits were eroded.

Inflections in the scarp profile suggest the fault scarps were produced by multiple events. Topographic profile B-B' (Figures 5 and 7) across the faulted Bonneville deltaic sediments shows the pronounced graben associated with the fault scarp and the inflection in the scarp profile. The scarp height, which is 7.0 m, and the cumulative net tectonic vertical displacement across the graben, 2.75 m, are approximately twice the values measured on the surface of the Provo age delta (Figure 7). The fault scarp can be traced for about 1.3 km south of profile B-B'. Farther to the south, the fault trace encroaches upon the steep range front and it is nearly completely masked by the recent (post-Provo) alluvial fan and colluvial deposits which bury the fault and do not appear to be displaced. Between Elbow Hollow and Providence Canyon, (Figure 6) well-defined fault scarps were observed at only two locations, one is approximately 350 m south of Elbow Hollow, the other is immediatly south of Providence Canyon. The fault scarp south of Elbow Hollow displaces Bonneville Lake deposits and appears to have been produced by at least two events based on an inflection in the profile of the fault scarp. Between this scarp and Providence Canyon, there are a few less distinct lineaments between the Bonneville and Provo shorelines (Figure 6) that may also be the result of late Quaternary displacements on the East Cache fault. The fault scarp at Providence Canyon, which is 3.75 m high, displaces the surface of the delta formed at the Bonneville shoreline. Topographic profile C-C' across the fault scarp and zone of back-tilting on the downthrown side (Figure 7) indicates that the cumulative net vertical tectonic displacement across the zone is 1.5 to 1.75 m. An inflection in the scarp profile suggests that the cumulative displacement was produced by two events. These events must post-date recession of Lake Bonneville below elevation 1564 m approximately 15,000 to 14,000 years ago. The southern end of this scarp is buried by unfaulted alluvial fan deposits. To the south, the East Cache fault is close to the range front and the fault scarps are nearly completely masked by recent alluvial fan deposits.

POST-BONNEVILLE HISTORY OF SURFACE FAULTING

There is stratigraphic and geomorphic evidence for two surface faulting events since Lake Bonneville receded from the Bonneville shoreline (elevation 1564 m) about 15,000 to 14,000 years ago. The sequence of events can be summarized as follows.

The level of Lake Bonneville began to rise before 26,000 and continued to rise until it reached elevation 1564 m about 16,000 years ago where the lake level remained until about 15,000 to 14,000 years ago. During this time large deltas formed at the mouths of the major canyons. Any surface faulting events that may have occurred along the East Cache fault near Logan during this interval were masked by subsequent deposition and/or by littoral erosion.

Between 15,000 and 14,000 years ago, the lake level dropped about 100 m as a result of catastrophic downcutting of the lake's outlet through Red Rock Pass at the north end of Cache Valley. The saturated deltaic deposits were unstable and large landslides occurred either during or shortly after the recession of the lake from the Bonneville shoreline. At about this time, a surface faulting event associated with 1.35 m of net vertical tectonic displacement produced a scarp about 4 m-high near the mouth of Logan Canyon (i.e., the displacement measured in profile B-B' less the displacement along profile A-A' on Figure 8). The total extent of the surface faulting is not known, but the rupture extended at least 2 km north of the Logan River and 6 km to the south. It is conceivable that this event triggered the landsliding observed in the Bonneville lake sediments, but it is more likely that it post-dates the landslide. It seems unlikely that the next surface faulting event would occur along exactly the same trace if the deposits had been disrupted by landsliding.

This surface faulting event occurred before the lake receded below the Provo shoreline. Therefore, the time of the event can be constrained as post 15,000 to 14,000 years B.P. and pre about 13,500 years B.P.

After about 13,500 years B.P., flow into Lake Bonneville was insufficient to maintain the lake-level at the Provo shoreline and the lake began to recede below the level of the outlet at the north end of Cache Valley. The lake had receded at least 12 m before the second and most recent surface faulting event occurred. This event produced the 3 m-high scarps observed on the Provo delta and the post-Provo strath terrace at the mouth of Logan Canyon.

The age of the most recent faulting event is not well constrained. Based on evidence from Salt Lake Valley, it is known that the lake dried up fairly rapidly; by 11,000 years ago the level was within 15 m of the present level of Great Salt Lake. Therefore, the maximum limiting age could be fairly close to the age of the Provo shoreline. The minimum limiting age is less well constrained. Along much of its trace, the fault is either partially or completely buried by unfaulted alluvial fan deposits. The extent of these deposits suggest some antiquity; comparison of these fans to those that have been dated elsewhere along the Wasatch front suggest a middle Holocene or older age (greater than 6,000 years B.P. and possibly as old as 10,000 years B.P.?). There have been no major surface faulting events along the East Cache fault zone since these fans were deposited.

RECURRENCE OF SURFACE FAULTING

As discussed in the previous section there have been two major surface faulting events during the past 14,000 to 15,000 years along the East Cache fault at Logan. An average recurrence based on these data is 7,250 ± 250 years. However, because the age of

the most recent event is not well constrained,. the actual interval between the two events is not known. If the elapse time since the most recent event has been only 6,000 to 7,000 years, the actual interval between events may approximate the average value. Alternatively, the two events may have both occurred within a 2,000 to 3,000 year period of time, in which case, elapse time since the most recent event could be greater than 10,000 years. In either case, there is a marked difference in the behavior of the East Cache fault compared to that of the Wasatch fault zone south of Brigham City where there have been repeated surface faulting events during the late Holocene.

SLIP RATE

The late Pleistocene-Holocene slip rate (vertical slip) along the segment of the East Cache fault at Logan is between 0.1 and 0.2 mm per year based on the following data. The 14,000 to 15,000 year old Bonneville shoreline deposits south of Logan Canyon are displaced 2.75 m yielding an average slip rate of 0.19 ± 0.01 mm per year. The cumulative net vertical displacement of the 13,500 year old Provo delta across the fault zone is 1.4 m yielding an average slip rate of 0.10 mm per year.

The slip rate on the East Cache fault zone is an order of magnitude slower than the slip rate along the Wasatch fault zone south of Brigham City (Figure 10). Based on geomorphic analysis (interpretation of low-sun-angle aerial photographs and field reconnaissance) of the two fault segments, the late Quaternary slip rate of the segment of the Wasatch fault zone north of Brigham City is estimated to be less than or equal to the slip rate on the East Cache fault.

DISPLACEMENT PER EVENT AND EARTHQUAKE MAGNITUDE

Displacement Per Event.

The geomorphic and geologic evidence indicate there have been two surface faulting events that post-date the Bonneville shoreline. Near the mouth of Logan Canyon these events were associated with fault displacements comparable to those observed elsewhere on the Wasatch fault zone (Figure 10). The displacements associated with the two events are as follows:

Event	Vertical Displacement on Main Fault (m)	Net Vertical Tectonic Displacement Across Fault Zone
post 15,000-pre 13,500	3 - 4 ?	1.35
post 13,500	3.0	1.4

Topographic profile C-C' (Figure 7) shows that the cumulative displacement for these two events was only 1.5 to 1.75 m near the mouth of Providence Canyon suggesting that this rupture segment may be dying out to the south.

Magnitude of Past Surface Faulting Earthquakes.

If the amount of displacement per event is known, the empirical relationship between the logarithm of maximum displacement and earthquake magnitude (Slemmons, 1977, 1982) can be used to estimate the size of the past earthquakes. The reported displacements used to develop this relationship for normal-slip faults include both fault slip and distortion; for many of these events, the amount of distortion is uncertain.

Estimates of the net vertical tectonic displacement for each of the past two surface faulting events at Logan are about 1.4 m. According to Slemmons' (1982) relationship for normal-slip faults, displacements of 1.4 m are associated with magnitude Ms 6.8 earthquakes. Along this segment of the fault, distortion has produced a fault scarp having a height approximately twice the cumulative net tectonic displacement. If distortion is included in the estimate, the amount of displacement for a single event would be between 3 and 4 m which gives magnitudes of 7.0 to 7.1. Estimates of earthquake magnitude should be based on as many parameters as possible. Average displacement data will not necessarily define the maximum earthquake that has occurred on a fault. Nonetheless, the available data indicate that surface faulting events associated with earthquakes in the magnitude range of 6-1/2 to 7-1/4 have occurred repeatedly along the segment of the East Cache fault zone at Logan.

LIKELIHOOD THAT FAULTING EVENTS WERE TRIGGERED BY FLUCTUATIONS IN LEVEL OF LAKE BONNEVILLE

> "It is therefore theoretically conceivable that during the presence of the lake, the process of faulting along the mountain bases was stimulated..." G.K. Gilbert (1890, p. 357)

As early as 1890, G.K. Gilbert speculated on the influence that Lake Bonneville must have had on the faulting and he observed that some of the Basin and Range fault scarps appear to be temporally related to either the Bonneville or Provo stages of the lake. There has been no comprehensive study of the possible spatial and temporal association of Basin and Range faulting with the many Pleistocene lakes that occupied the basins. If the presence of these pluvial lakes did trigger earthquakes, it is not clear how this might affect estimates of earthquake recurrence based on paleoseismological analysis of early Holocene and late Pleistocene faults.

Numerous cases have been documented where the filling of and/or sudden fluctuations in the water level in man-made reservoirs have triggered strain release along pre-stressed faults (Perman and others, 1981). Empirical studies of the geologic, hydrologic and seismologic characteristics associated with "reservoir induced seismicity" (RIS) have shown that there is a high correlation between RIS and very deep (> 150 m) and very large (> 10^{10} m^3) reservoirs. The maximum depth of Lake Bonneville was about 340 m. At its maximum level, the lake had a surface area of 49,000 km^2. Assuming an average depth of one half the maximum depth, the reservoir volume was on the order of $10^{12}m^3$. In addition, the region occupied by Lake Bonneville is in an extensional stress environment and it is underlain by sedimentary rocks. Both of these characteristics show higher correlations with RIS than reservoirs in compressional or strike-slip environments and those underlain by igneous or metamorphic rocks. There are numerous Basin and Range faults that would have been within hydrologic regime of Lake Bonneville, including the Wasatch and East Cache fault zones, and most of these structures show evidence of late Quaternary displacement.

Between 15,000 and 14,000 years ago, Lake Bonneville was catastrophically lowered more than 100 m. In light of the recent studies of RIS, it is inconceivable that such an event did not have some effect on crustal stresses and the occurrences of earthquakes, particularly when one considers the rapid crustal rebound that occurred immediately afterwards (Crittenden, 1963; Passay, 1981). Although a direct correlation between the catastrophic lowering of the lake and the surface faulting on the East Cache fault cannot be demonstrated based on the available data, the age of the second-to-the-most-recent faulting event is constrained within the relatively short interval (500 to 1,500 years long) between the abandonment of the Bonneville shoreline and the formation of the Provo shoreline. It is likely that the drastic change in water depth and volume associated with this rapid drop

in the lake triggered strain release along the already pre-stressed fault.

SUMMARY AND CONCLUSIONS

Two surface faulting events have occurred along the East Cache fault east of Logan, Utah since Lake Bonneville receeded from the Bonneville shoreline between 15,000 and 14,000 years ago. The first event occurred prior to 13,500 year B.P. and may have been temporarily related to the catastrophic drop in the level of Lake Bonneville from the Bonneville to the Provo shoreline. The most recent event post-dates the recession of the lake below the Provo shoreline (about 13,500 years ago). Extensive burial of the fault scarp by alluvial fans suggest that this event occurred prior to about 6,000 to 8,000 years B.P. The average recurrence based on two events is calculated to be 7,250 ± 250 years. The actual interval between the two events could have been as short as 2,000 to 3,000 years or as long as 7,000 to 8,000 years. The recurrence history for major surface faulting events along the East Cache fault is markedly different than for the Wasatch fault zone south of Brigham City, where there have been repeated surface faulting events during the late Holocene.

Estimates of the net vertical tectonic displacement for each of the past two surface faulting events at Logan are approximately 1.4 m. Distortion resulting from graben formation and backtilting has been approximately twice the net vertical tectonic displacement during each of these events. Empirical relationships between displacement per event and earthquake magnitude suggest that these displacements were associated with earthquakes in the magnitude range of M_S 6-1/2 to 7-1/4.

The late Pleistocene-Holocene slip rate along the segment of the East Cache fault at Logan is between 0.1 and 0.2 mm per year, which is about an order of magnitude slower than the slip rate along the Wasatch fault zone south of Brigham City.

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APPENDIX A

REPORTS AND PUBLICATIONS

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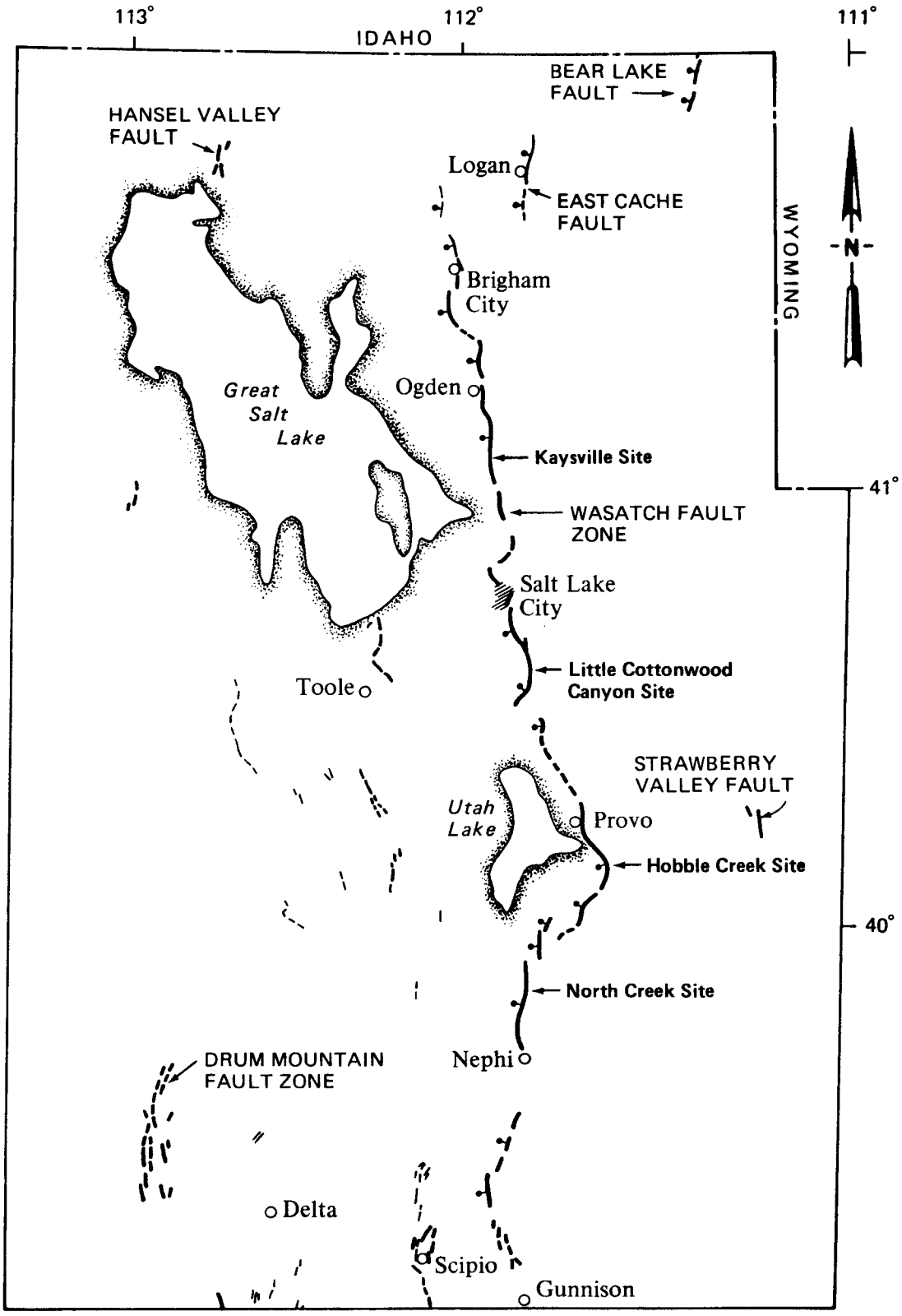


EXPLANATION

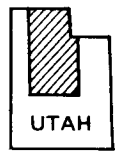
Holocene fault scarp, bar and ball on downthrown side

Late Pleistocene—Early Holocene fault scarp

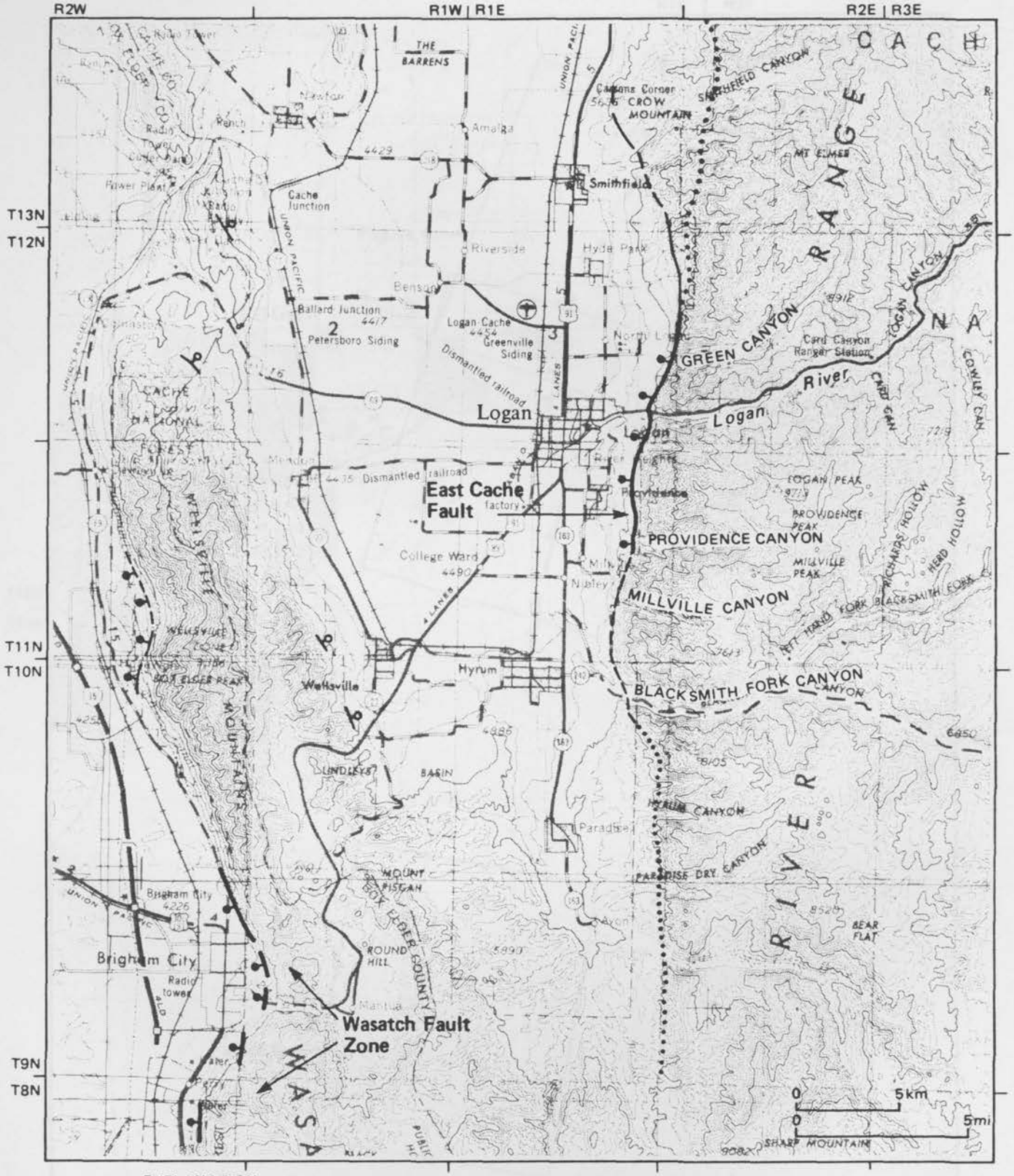
Late Pleistocene scarp

(Modified from Anderson and Miller, 1979; Buchnam and Anderson, 1979a; Cluff and others, 1970, 1973, 1974; Everitt and Kaliser, 1979; Nelson, 1982; this report.)

0 25 50 km



Project No. 14093D	USGS Contract No. 14-08-0001-19842	LATE PLEISTOCENE AND HOLOCENE FAULT SCARPS, WASATCH FRONT AND VICINITY	Figure 1
Woodward-Clyde Consultants			



EXPLANATION

Post-Provo (<13,500 yr B.P.) fault scarps, bar and ball on downthrown side, buried locally by younger deposits.

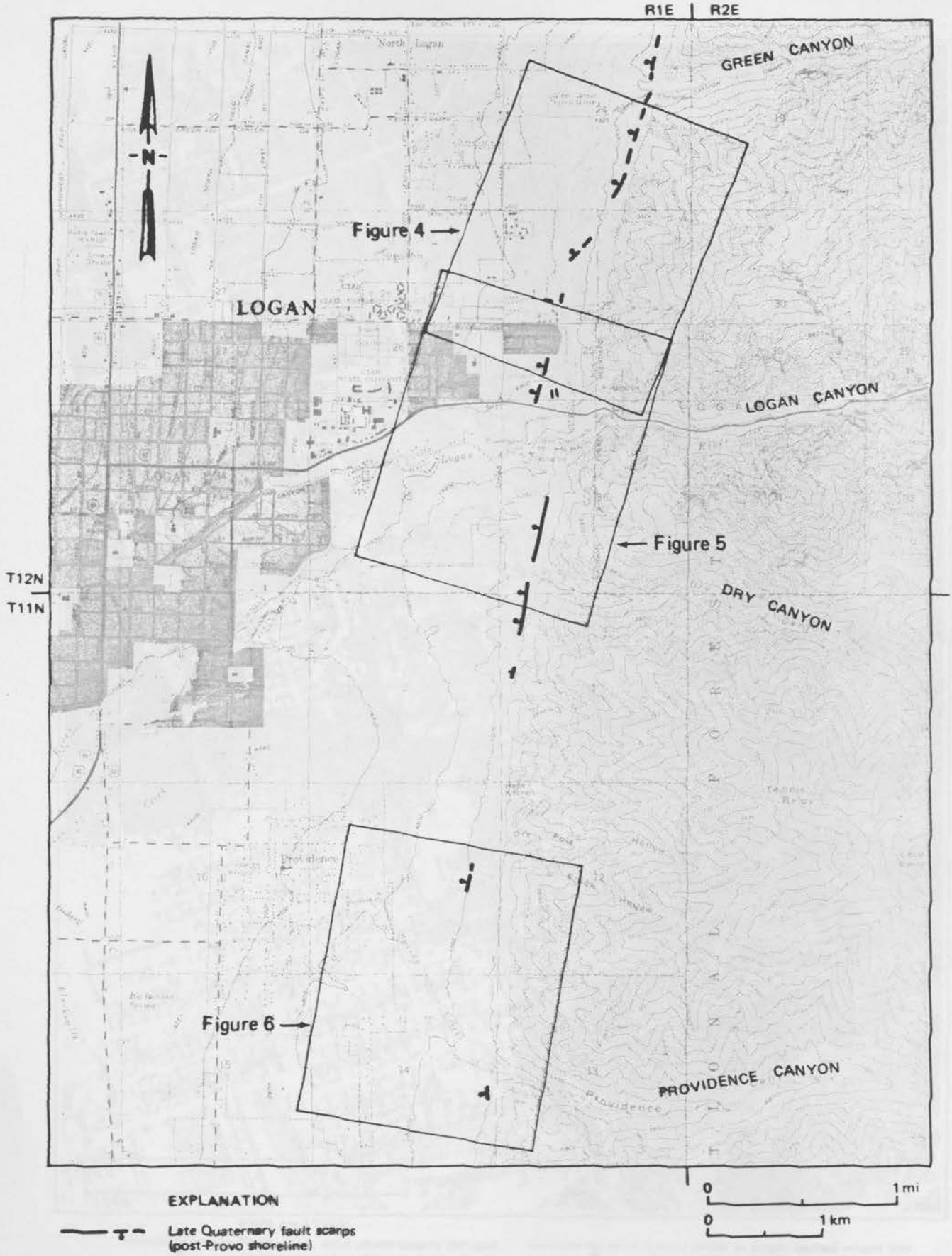
Late Pleistocene fault scarps, dashed where less well defined, age of most recent event is uncertain, bar and ball on downthrown side.

Bedrock fault scarps, age of most recent displacement uncertain.

Scarps of uncertain origin, bar and circle on lower side.

UTAH

Project No. 14093D	USGS Contract No. 14-08-0001-19842	MAP SHOWING LOCATION AND AGE OF FAULT SCARPS ALONG THE NORTHERN WASATCH AND EAST CACHE FAULT ZONES	Figure 2
Woodward-Clyde Consultants			



Project No. 14093D	USGS Contract No. 14-08-0001-19842	INDEX MAP OF EAST CACHE FAULT BETWEEN GREEN AND PROVIDENCE CANYONS	Figure 3
Woodward-Clyde Consultants			

EXPLANATION

Fault scarp; solid where clearly defined, dashed where less distinct, bar and ball on downthrown side

Linear break in slope; dashed where less distinct, bar and circle on lower side

Location of photograph shown on Figure 3

Project No. 14093D	USGS Contract No. 14-08-0001-19842	LOW-SUN-ANGLE PHOTOGRAPH OF EAST CACHE FAULT BETWEEN GREEN AND LOGAN CANYONS	Figure 4
Woodward-Clyde Consultants			

EXPLANATION

Fault scarp; solid where clearly defined, dashed where less distinct, bar and ball on downthrown side

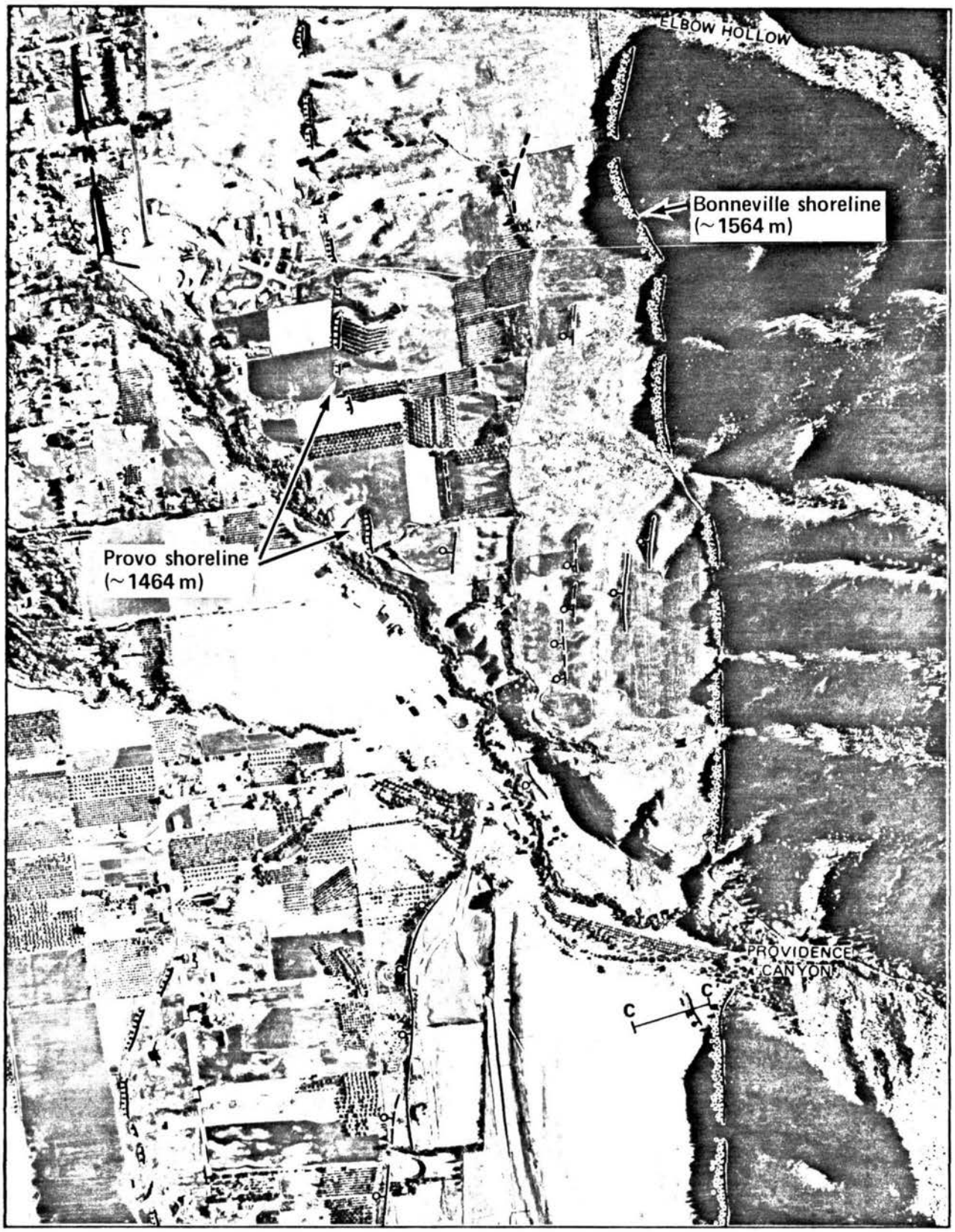
Linear break in slope; dashed where less distinct, bar and circle on lower side

Landslide scarp; ticks on downthrown side

Location of topographic profile

A A' Location of photograph shown on Figure 3

Project No. 14093D	USGS Contract No. 14-08-0001-19842	LOW-SUN-ANGLE PHOTOGRAPH OF EAST CACHE FAULT, LOGAN CANYON AREA	Figure 5
Woodward-Clyde Consultants			



EXPLANATION

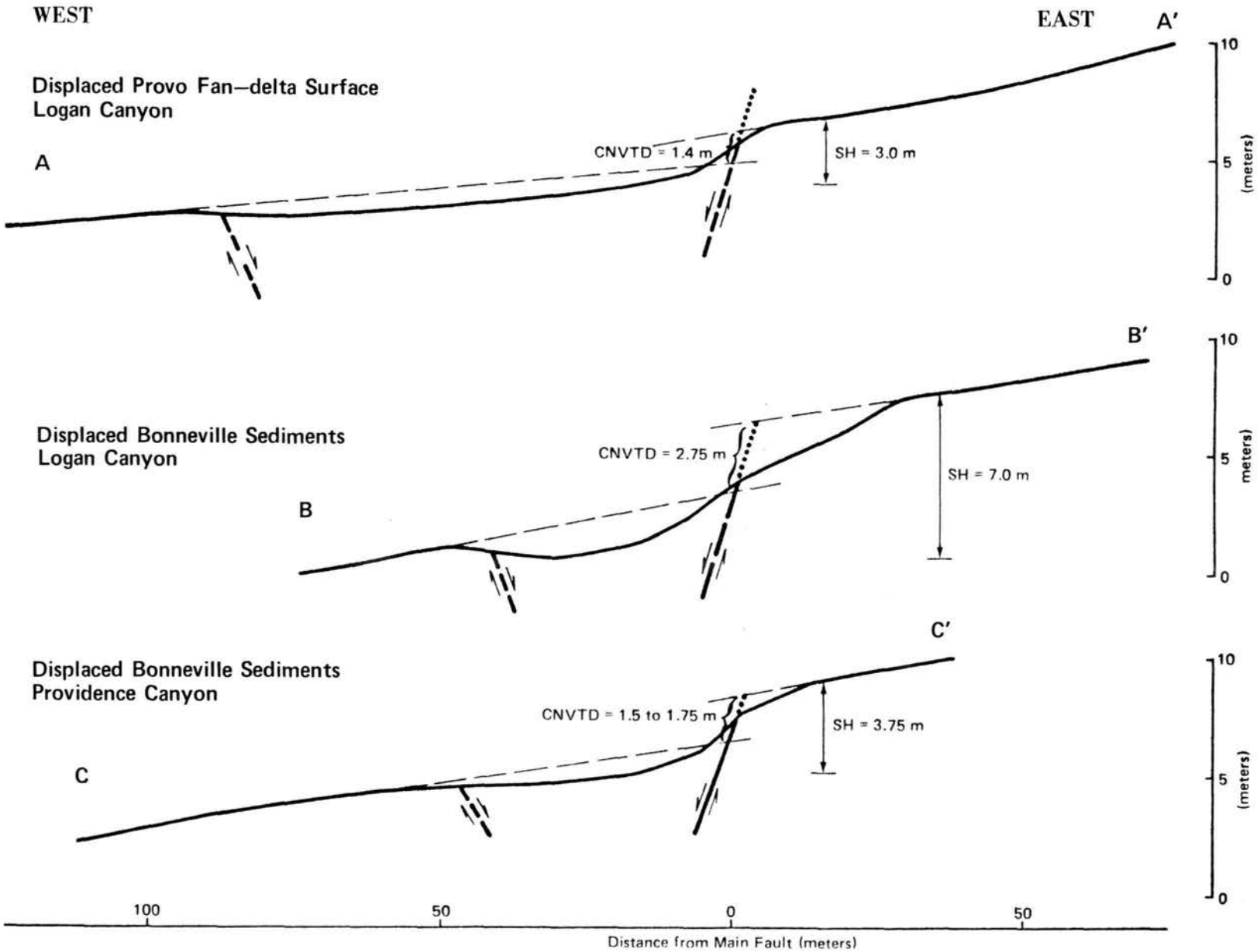
Fault scarp; solid where clearly defined, dashed where less distinct, bar and ball on downthrown side

Linear break in slope; dashed where less distinct, bar and circle on lower side

C — C' Location of topographic profile

Location of photograph shown on Figure 3

Project No. 14093D	USGS Contract No. 14-08-0001-19842	LOW-SUN-ANGLE AERIAL PHOTOGRAPH OF EAST CACHE FAULT, PROVIDENCE CANYON AREA	Figure 6
Woodward-Clyde Consultants			



EXPLANATION

CNVTD	Cumulative net vertical tectonic displacement
SH	Scarp height
— — —	Projected surface

NOTE: Locations of profiles A–A' and B–B' are shown on Figure 5; location of profile C–C' is shown on Figure 6.

Woodward-Clyde Consultants

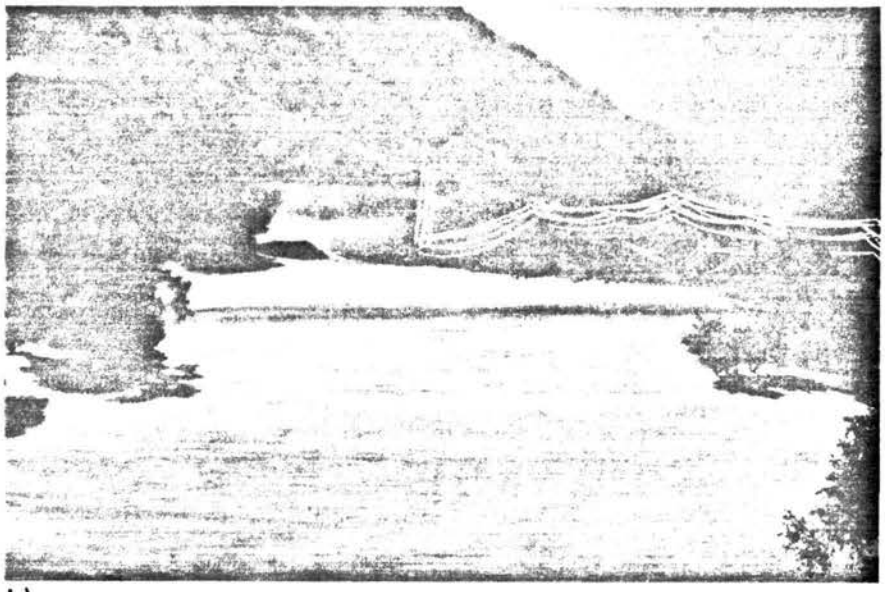
Project No. 14093D

USGS Contract No. 14-08-0001-19842

TOPOGRAPHIC PROFILES OF LATE PLEISTOCENE–HOLOCENE FAULT SCARPS, EAST CACHE FAULT

Figure 7

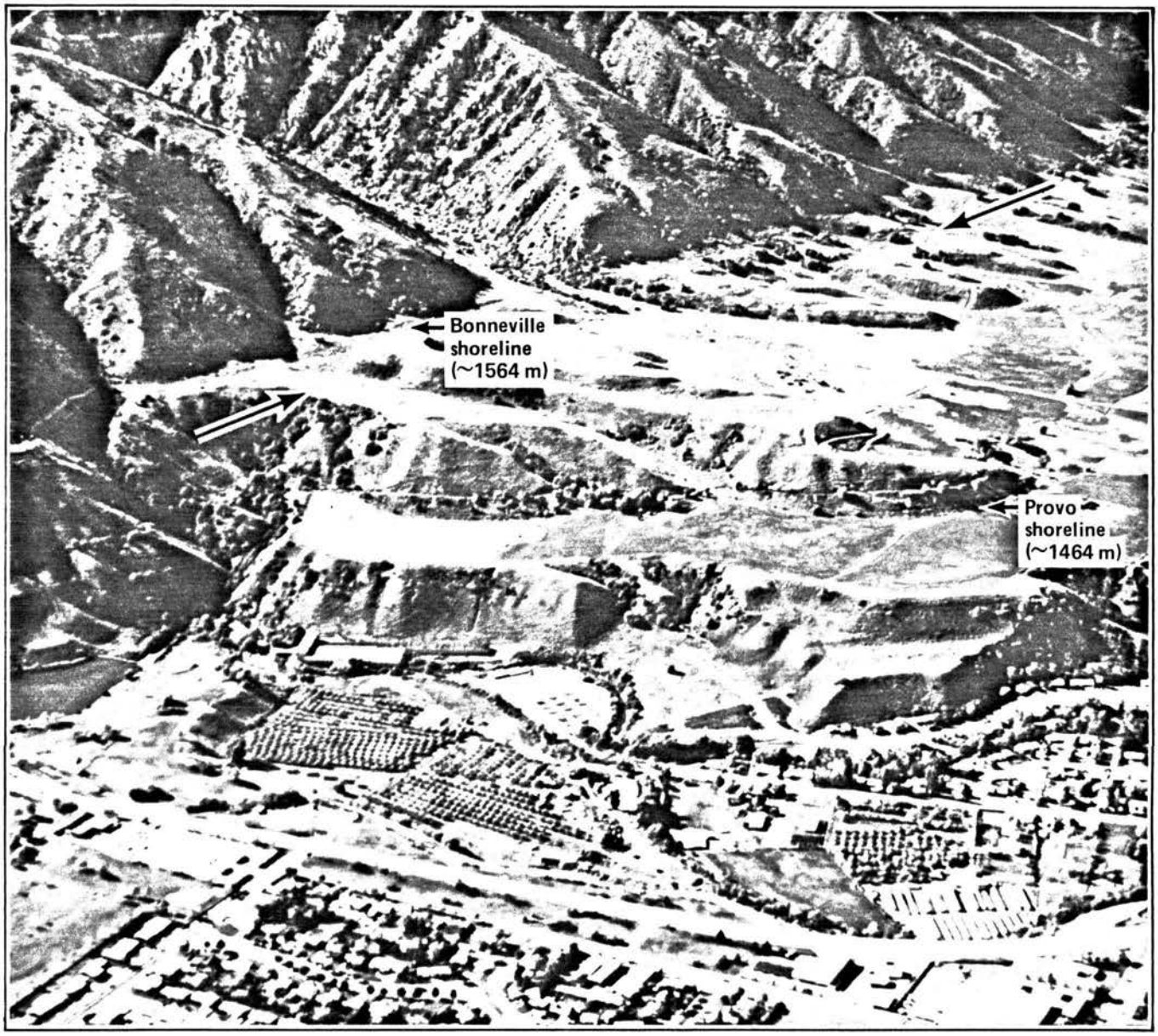
a)



b)

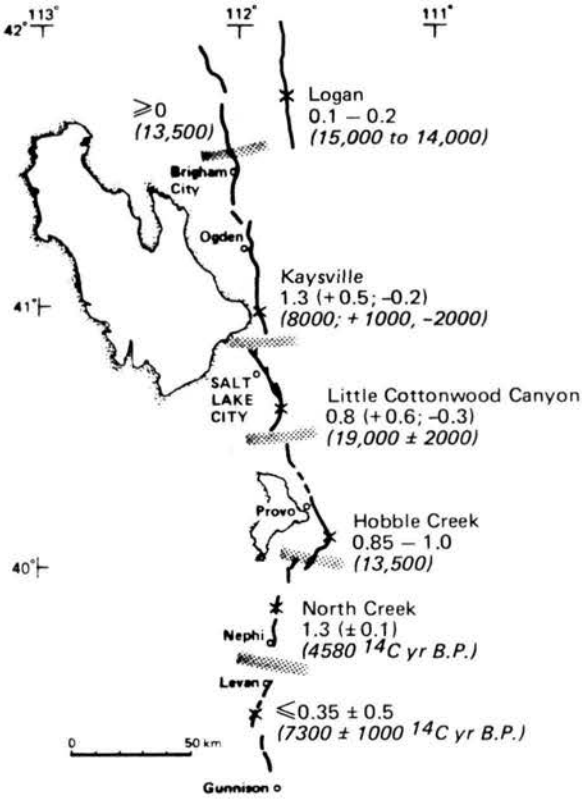
On the Logan golf course immediately north of Logan Canyon Provo-age (~13,500 yr B.P.) fan-delta deposits (photo a) and a post-Provo strath terrace (photo b) are displaced by fault scarps produced during the most recent surface faulting event along the East Cache fault. The height of the main fault scarp on the Provo fan delta (photo a) is 3.0 m; the net tectonic displacement across the main fault and associated graben is 1.4 m (figure 7-A). Views are to the east.

Project No. 14093D	USGS Contract No. 14-08-0001-19842	PHOTOGRAPHS OF POST-PROVO FAULT SCARPS NORTH OF LOGAN CANYON	Figure 8
Woodward-Clyde Consultants			

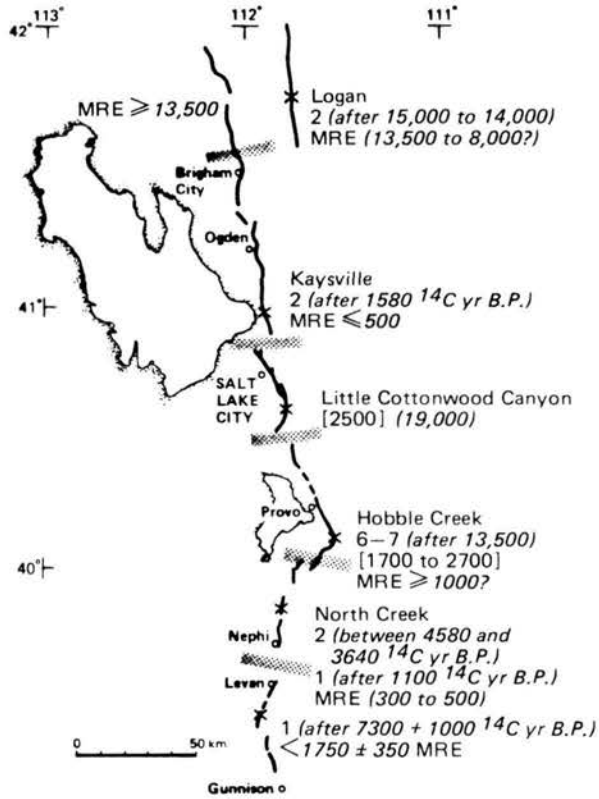


South of Logan Canyon the East Cache fault (arrows) can be traced as a nearly continuous scarp across a series of dissected lobes of deltaic deposits that grade to the Bonneville shoreline (~1564 m). Additional scarps in these deposits west of the fault were produced by landsliding that probably occurred during or shortly after the rapid drop of the lake from the Bonneville to the Provo level.

Project No. 14093D	USGS Contract No. 14-08-001-19842	OBLIQUE AERIAL PHOTOGRAPH OF EAST CACHE FAULT SOUTH OF LOGAN CANYON	Figure 9
Woodward-Clyde Consultants			



A) Slip Rate



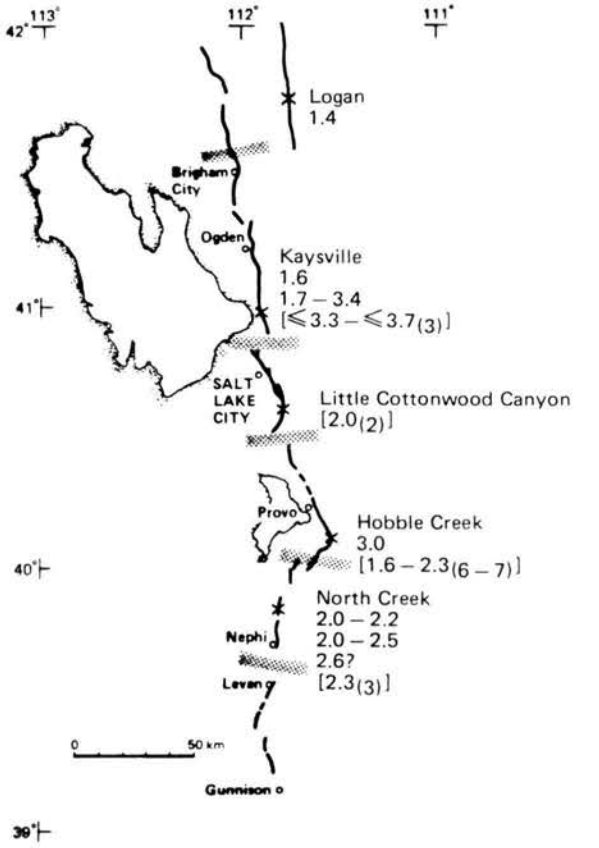
B) Recurrence

A) Slip rate in mm/yr age of the displaced datum (yr B.P.) on which rate is based is shown in italics.

B) Large numerals represent the number of surface faulting earthquakes after the dates shown in italics; brackets contain average recurrence (yr) for the interval shown in italics; MRE is the elapsed time (yr) since the most recent surface faulting earthquake.

C) Measured displacement per event in meters; average displacement per event and number of events are shown in italics. Dashed lines represent proposed major segment boundaries.

Based on Hanson and others, 1981; Hanson and Schwartz, 1982; Schwartz and others, 1982; Swan and others, 1980, 1981, 1982; and this report.



C) Displacement per Event

Project No. 14093D	USGS Contract No. 14-08-0001-19842	SUMMARY OF FAULT BEHAVIOR DATA FOR THE WASATCH AND EAST CACHE FAULT ZONES	Figure 10
Woodward-Clyde Consultants			

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUMMARIES OF TECHNICAL REPORTS, VOLUME XIV

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

July 1982

OPEN-FILE REPORT 82-840

This report (map) is preliminary and has not been reviewed for conformity with U.S.Geological Survey editorial standards (and stratigraphic nomenclature). Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S.G.S.

Menlo Park, California

1982

STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT ZONE, UTAH

14-08-0001-19842

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Investigations

1. Eleven additional radiocarbon age-dates have been obtained for samples collected from trenches across the Wasatch fault at the North Creek site using accelerator mass spectrometry techniques. Sample analysis was conducted by Dr. A. B. Tucker (San Jose State University) using an existing MP Tandem Van de Graaff accelerator at Chalk River Nuclear Laboratories, Ontario, Canada.

2. Detailed geologic studies including mapping of the late Quaternary deposits, topographic profiling of displaced geomorphic surfaces, and excavation of test pits, have been conducted along the East Cache fault.

Results

1. Radiocarbon age-dates obtained for the suite of North Creek samples using the accelerator mass spectrometry technique are in general agreement with age-dates measured using conventional beta counting techniques and with ages estimated based on the relative stratigraphic positions of the samples (Table 1). These age-dates, some of which were obtained for samples too small to be dated by conventional methods, support previous estimates for recency and intervals of time between individual surface faulting earthquakes at this site (Hanson and others, 1981; Swan and others, 1981).

2. The East Cache fault lies parallel to the Wasatch fault zone. The fault extends in a north-south direction for a distance of about 70 km from the latitude of Brigham City, Utah, to Preston, Idaho, passing immediately east of Logan, Utah. At the golf course on the north side of the river near the mouth of Logan Canyon, there are two west facing scarps that are less than 2 m-high on a post-Provo strath terrace. Minor backtilting occurs on the downthrown side of the eastern scarp. On projection of these scarps to the north, two test pits were excavated across a subtle break in slope near the

base of a scarp immediately below the Bonneville shoreline. The test pits were located between Logan and Green Canyon in an area that has not been affected by landslides. The Bonneville age sediments exposed in both test pits are displaced by numerous small faults. To the south of the Logan River, the fault scarp crosses extensive landslides developed in Bonneville late deposits. The geologic mapping and data from the test pits provide evidence that there has been only one surface faulting event post recession below the Provo shoreline (approximately 12,000 years B.P.).

Reconnaissance along the northern Wasatch fault zone indicates that there is a significant decrease in Holocene fault activity from approximately the latitude of Brigham City north to the northern end of the Wellsville Range (Swan and others, 1981). There are a number of faults subparallel to the Wasatch fault zone north of the latitude of Brigham City, including the **Hansel** Valley fault, the East Cache fault, and the Bear Valley fault, that have experienced late Pleistocene and/or Holocene faulting. It appears that the Holocene deformation in north-central Utah is distributed across a wide zone that includes all of these faults.

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SAMPLE NO.	LOCATION	SAMPLE DESCRIPTION	AGE-DATE		COMMENTS
			Conventional (^{14}C yr B P)	Accelerator (^{14}C yr B P)	
	NORTH CREEK SITE				
WC-12-80-2	Trench NC-1	detrital charcoal – From buried organic-rich soil developed on scarp-derived colluvium or alluvium		300 ± 300	Decayed wood and the soil fraction from this deposit yielded conventional radiocarbon dates of modern and 130 ± 95 ^{14}C yr B.P., respectively. All the age-dates obtained for this deposit appear to be too young and probably reflect some contamination by younger material.
WC-12-80-3	Trench NC-1A	soil – Buried organic-rich soil developed on North Creek alluvium	2180 ± 80	4500 ± 300	The age-date obtained by accelerator mass spectrometry for this soil sample is in agreement with the age-date obtained for the underlying parent deposit (sample WC-12-80-11). The younger conventional age-date probably reflects contamination by younger carbonaceous material.
WC-12-80-4	Trench NC-1A	detrital charcoal – From burn layer at the base of an historical mudflow		250 ± 300	The historical age assigned to the mudflow is based on the presence of nails and pieces of metal associated with the burn layer at the base of the unit
WC-12-80-5	Trench NC-2	detrital charcoal – From sandy silt alluvium	1350 ± 70	1550 ± 300	
WC-12-80-6	Trench NC-3	detrital charcoal – From buried soil developed on faulted alluvium	1110 ± 60	700 ± 250	These age-dates provide a maximum limiting age for the most recent faulting event
WC-12-80-7 7u	Trench NC-3	soil – Buried organic-rich soil developed on colluvium derived from the fault scarp subsequent to the second most recent surface faulting event	3640 ± 75	1700 ± 300 3850 ± 400	Samples 7 and 7u were obtained from the same bulk soil sample; sample WC-12-80-9, which consists of detrital charcoal, is also from the same soil. The older dates obtained for this unit most likely represent a minimum age for the underlying scarp-derived colluvium on which the soil is developed.
WC-12-80-8	Trench NC-3	detrital charcoal – From buried soil within alluvium		1200 ± 300	The age-date obtained for this sample is consistent with age-dates from stratigraphically older and younger deposits
WC-12-80-9	Trench NC-3	detrital charcoal – From same deposit as sample WC-12-80-7		1350 ± 250	
WC-12-80-10	Trench NC-3	detrital charcoal – From unfaulted mudflow deposit		0 ± 300	
WC-12-80-11	North Creek Site stream cut	detrital charcoal – From North Creek alluvial fan deposit	4580 (1)	4000 ± 400	

NOTE (1) Bucknam, 1978

TABLE 1 SUMMARY OF AGE-DATING RESULTS