STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT, UTAH

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INTRODUCTION

The Wasatch fault is an active intraplate fault that defines part of the boundary between the Rocky Mountains and Colorado Plateau provinces to the east, and the Basin and Range province to the west. It extends for more than 370 kilometers from Gunnison, Utah to Malad City, Idaho (Cluff and others, 1975) (Figure 1). It is a westward-dipping normal-slip fault having a cumulative displacement as great as 4600 meters, east side up (Crittenden, 1964; Eardley, 1939, 1944, 1951; and Morrison, 1965). The fault exhibits almost continuous geomorphic expression of late Quaternary faulting and displaces Pleistocene lacustrine sediments deposited by Lake Bonneville and its predecessors, and late Pleistocene and Holocene alluvial and colluvial sediments. The relationship of the Wasatch fault to these Quaternary sediments has been studied in several places (Baker, 1964; Bissell, 1963; Crittenden, 1964, 1965a, 1965b; Eardley, 1934; Hintze, 1972; Hunt and others, 1953; Marsell, 1964; Morrison, 1965; Van Horn, 1972a, 1972b).

Smith (1972) suggested that an earthquake of magnitude 7 could occur approximately every 76 years along the Wasatch fault based upon historical seismicity between 1932 and 1961. However, no earthquake of a magnitude greater than 6 is known to have occurred along the Wasatch fault since 1847 (Cook, 1972; Cook and Smith, 1967; Smith and others, 1978). Large prehistoric earthquakes are suggested by fresh fault scarps at various locations along the Wasatch fault. These and other young faulting features along the Wasatch fault have been delineated by Cluff and others (1970, 1973, 1974).

Investigations conducted in 1975 by Woodward-Clyde Consultants for the U.S. Geological Survey (Contract No. 14-08-001-14567) identified six sites that have a high probability of yielding information regarding recurrence of surface faulting along the

Wasatch fault. Detailed geologic mapping and subsurface investigations are being conducted at two of these sites, the Kaysville site and the Hobble Creek site (Figure 1), to measure fault displacements in strata that can be dated or correlated with dated units (Table 1). These data are used to estimate the frequency of recurrence of moderate to large earthquakes associated with surface faulting events along the Wasatch fault.

Detailed geologic mapping and subsurface investigations were conducted at the Kaysville site during June, 1978. Field investigations for the Hobble Creek site are scheduled for the latter part of September and early October, 1978. This report presents the findings, interpretations, and conclusions based on the work completed to date.

LOCATION AND SETTING OF THE KAYSVILLE SITE

The Kaysville site is located between Baer Creek and Shepard Creek, approximately 3 kilometers east-southeast of the town of Kaysville, Davis County, Utah (Section 1, T3N, R1W, Kaysville 7 1/2 minute quadrangle) (Figures 2 and 3). A series of small grabens occurs along this segment of the Wasatch fault (Figure 3). In the northern part of the site area these grabens are bounded by a prominent west-facing fault scarp on the east and by a series of en echelon antithetic fault scarps on the west. The height of the main fault scarp decreases from 22 meters in the central part of the site area to less than 10 meters to the north where it has been partly buried by alluvium from Baer Creek. Near Shepard Creek, where the main fault scarp swings eastward, a graben occurs 100 meters west of the main scarp (Figure 3). The antithetic fault scarps (Figure 15) vary in height from less than 1 meter to 2.5 meters.

Trenches and test pits were excavated across the southern end of a closed depression that occurs in the graben in the central part of the site area (Figure 3). The depression is closed to the south by a small alluvial fan and to the north by alluvial fan deposits derived from Baer Creek and two unnamed intermittent streams. The closed depression is intermittently occupied by a small pond that is fed by two springs located along the base of the main fault scarp.

The Kaysville site is at an elevation of 1410 meters. It is below the Bonneville and Provo shorelines (Figures 3, 4, 12, and 13). Lacustrine sediments deposited during repeated high stands of Lake Bonneville are exposed in the fault scarp and in outcrops along entrenched stream valleys. These sediments are unconformably overlain by coarser post-Provo alluvial fan deposits. Faulting has displaced the fan surfaces down to the west across the main fault scarp and grabens.

Other linear breaks in the post-Provo alluvial fan surfaces both east and west of the main fault scarp and graben (Figure 3) are of uncertain origin and may represent additional fault traces. The major linear break in slope east of the main fault scarp is at approximately the elevation of the Provo II shoreline along at least part of its length. Modification of this break in slope by road and powerline construction makes it difficult to determine if this break in slope is a fault or a recessional shoreline.

The Wasatch Range along this segment of the fault rises steeply eastward to an elevation of over 2750 meters in a horizontal distance of 3.2 kilometers. Rocks in the range consist of schist, gneiss, and migmatite of the Precambrian Farmington Canyon Complex.

PREVIOUS WORK

Possible active traces of the Wasatch fault were delineated by Cluff and others (1974) using 1:12000 low-sun-angle black and white aerial photographs. Additional photogeologic interpretation and preliminary field reconnaissance along this segment of the fault were conducted during a previous Woodward-Clyde investigation for the U.S. Geological Survey, in which the Kaysville site was selected for additional studies (Woodward-Clyde Consultants, 1975). The geology of the Kaysville area is also discussed briefly in a report by Feth and others (1966) on the occurrence and chemical quality of groundwater in the Weber Delta Water District.

METHODS OF STUDY

Methods of study used in geologic investigations at the Kaysville site included:

1. Detailed Surface Mapping - Based on photogeologic interpretation and field mapping, late Quaternary stratigraphic units within and adjacent to the fault zone from Baer Creek to Shepard Creek were mapped at a scale of 1:6000. Detailed mapping in this area provided data on the location of possible faults, and the relative age and correlation of stratigraphic units and geomorphic surfaces. Mapping also was used as a guide to locate trench and test pit sites. In turn, mapping was supplemented and refined by data from trenches and test pits.

2. Topographic Profiling - Topographic profiles across the main fault scarp, antithetic fault scarp, and adjacent geomorphic surfaces were measured using hand level, compass, and tape. The profiles varied in length from about 20 meters to 1100 meters. The profiles were used,

in conjunction with trenching and mapping data, to examine the relationship of the location of the fault plane to scarp morphology. The profiles were also used to compare variations in scarp height and form along the trace of the fault.

3. Test Pits - Five test pits, each approximately 5 meters to 6 meters deep, were excavated to locate the contact between alluvial fan and lake bed deposits on both sides of the graben and to search for datable material within the graben. Locations of these test pits are shown on Figure 3.

4. Trenching - Most of the structural and stratigraphic data were obtained from detailed examination of trenches. Seven trenches (A through G) totaling 189 meters in length and varying in depth from 2 meters to 6 meters were excavated. Approximately 160 meters of trench (excluding trench C) were logged in detail at a scale of 1:20 (5 centimeters = 1 meter). Trench locations are shown on Figure 3; logs of these trenches are shown on Plate 2 and Figures 6 through 10.

RESULTS OF MAPPING AND SUBSURFACE INVESTIGATIONS

STRATIGRAPHY

The Quaternary deposits exposed in the trenches at the Kaysville site consist of lake sediments deposited during the high stands of Lake Bonneville, alluvial fan and stream deposits, and sag fill and associated colluvium that occur in an area of subsidence adjacent to and at the toe of the main fault scarp. The soils that have developed on the fan surface adjacent to the graben and those buried beneath historical deposits in the graben are weakly developed, attesting to their young age. The stratigraphic and structural

relationships between these deposits and soils are shown on the trench logs (Plate 2 and Figures 6 through 10) and on geologic cross sections (Figures 4 and 5). Descriptions of the individual lithologic and soil units exposed in the trenches, and a correlation chart that summarizes their relative stratigraphic positions, are presented on Plate 1. The major stratigraphic units identified in the trenches at the Kaysville site are described below. The identification number following the unit name corresponds to those shown on the trench logs and on Plate 1.

Lithologic Units

Alpine-Bonneville lake deposits (undifferentiated) (unit 1). The oldest deposits exposed in the trenches and test pits are lakebed sediments deposited during high stands of Pleistocene Lake Alpine and/or Lake Bonneville. These deposits consist of thinly bedded pink silt and very pale brown very fine to fine sand; the interbedded silts and fine sands alternate with coarser sequences of well stratified medium to coarse sand and fine gravel. The deposits are flat-lying in the trench exposures and in nearby outcrops. Exposures at higher elevations to the north and to the south of the Kaysville site indicate that the lake deposits exhibit steep dips locally where they were deposited nearer to shore and are cross-bedded. The deposits thicken towards the Great Salt Lake and thin eastward where they onlap the range front; their exact thickness at the Kaysville site is not known.

These lake sediments were probably deposited when the lake level was at the Bonneville and/or Provo shorelines (Figure 4). They could be as old as the Alpine Formation or as young as the Bonneville Formation (Table 1). In either case, the lake deposits at the site undoubtedly predate recession of Lake Bonneville from the Provo shoreline to an elevation below 1430 meters. It is unlikely that lake

deposits of any significant thickness accumulated at the site during the Provo II stage (Draper Formation). Therefore, the lake deposits at the site are probably older than approximately 12,000 years B.P. (Table 1). They definitely predate the Stansbury and Gilbert shorelines which lie at lower elevations west of the Kaysville site.

The undifferentiated Alpine-Bonneville lake deposits are unconformably overlain by post-Provo alluvial fan deposits (Figures 4 and 5), and they are in fault contact with colluvial units derived from the fault scarp (Plate 2; Figures 10 and 14).

Post-Provo alluvial fan deposits (unit 2). Deposits that consist primarily of poorly sorted and stratified gravelly sand, and cobble and boulder gravel, unconformably overlie undifferentiated Alpine-Bonneville lake deposits. These deposits form an alluvial fan that extends approximately 690 meters west from the mountain front (Figure 13). Adjacent to the main fault scarp on the upthrown block the alluvial fan deposits are 11 meters thick. On the downthrown block immediately west of the graben they are 4.4 meters thick, and they continue to thin westward to the edge of the fan where they are less than 2 meters thick (Figure 4).

The exact age of the post-Provo alluvial fan deposits is not known. The deposits postdate the underlying erosional unconformity which could be as old as 12,000 years B.P. (recession of Provo I stage of Lake Bonneville) to about 9,000 years B.P. (recession of Provo II stage). The deposits predate the formation of the soil developed on the fan surface (soil S1) which probably began about middle Holocene time (see discussion of soil S1 below).

The most recent displacements along this segment of the Wasatch fault are represented by a prominent fault scarp that

traverses the surface of the post-Provo fans (Figures 12 and 13). Other linear breaks in slope across this surface may represent other traces of the fault (Figure 3).

In general, bedding within the alluvial fan deposits dips 3 degrees to 10 degrees to the west (steepest dips are in the eastern part of the fan). Across the antithetic scarp and in the graben, the fan deposits have been back-tilted and bedding generally dips 3 degrees to 5 degrees to the east; eastward dips up to 21 degrees were measured locally.

Although erosion and deposition still occur locally along the intermittent distributary channels that are incised into the fan surface, a weakly developed soil profile (unit S1) has formed on the fan surface between these intermittent streams.

Baer Creek alluvial fan deposits (not exposed in trenches). An alluvial fan formed primarily by Baer Creek lies north of the trench site. This fan postdates the post-Provo alluvial fan deposits. The streams that deposited the fan deposits have breached the main fault scarp and the fan deposits partially bury the fault scarp, resulting in a decrease in scarp height from 22 meters at the trench site to less than 10 meters towards the apex of the fan. Subsequent faulting of the fan is evidenced by pronounced grabens on the south flank and at the apex of the fan. These grabens can be seen on aerial photographs taken prior to urbanization of the Baer Creek area and are similar to the one at the trench locality.

Drainage channels visible on 1958 aerial photographs suggest that Baer Creek may have been diverted southward along the base of the main fault scarp and flowed down the valley that lies immediately south of the trench locality. Some of the sag fill exposed in the trenches may have originated from Baer Creek.

Sag fill derived from the north and associated colluvium (unit 3). The sag formed by the back-tilted post-Provo alluvial fan deposits on the downthrown side of the fault is filled by at least three distinct units which consist of colluvium that grades laterally into alluvium and/or pond deposits (Plate 2 and Figure 13).

The oldest of these units exposed in the trenches consists of colluvium (unit 3A), derived from the fault scarp, that grades laterally into and partly overlies sag fill deposits (units 3C and 3B). The sag fill onlaps and unconformably overlies the east-dipping (back-tilted) post-Provo alluvial fan deposits at the western margin of the sag (Plate 2). The lower part of these deposits consists of graded beds of fine sand and silt (unit 3C) that grade upwards into massive, unstratified pebbly, silty sand (unit 3B). The beds in units 3C and 3B have a 2 degree to 3 degree southward component to their dip suggesting that the sediments were derived from the north.

Detrital charcoal from a dark reddish brown silt layer within unit 3C exposed in trench C was radiocarbon dated at 1580 $\pm$ 150 years B.P. The silt layer containing the charcoal is 47 centimeters above the contact with the underlying post-Provo alluvial fan deposits.

Unit 3 is displaced by both the main fault and by the antithetic faults (Plate 2 and Figure 4). Initial dips of beds in the deposits were horizontal. Within 38 meters of the main fault in trench A (Plate 2) they have been rotated or back-tilted by faulting.

Locally derived sag fill and associated colluvium (unit 4). Adjacent to the main fault scarp unit 3 is overlain by colluvium (units 4A and 4B) that grades laterally into pond and alluvial fan deposits (units 4C, 4D, and 4E) (Plate 2). The alluvial and pond facies in unit 4 are markedly more

micaceous than unit 3, and they dip slightly northward. They were derived from the intermittent stream that breaches the main fault scarp immediately south of the trenches (Figures 3 and 13a).

The colluvium adjacent to the main fault scarp has two distinct facies. The basal part of the coluvium (unit 4A) consists of poorly sorted very fine to coarse sand derived from the lakebed deposits in the footwall of the fault (unit 1). Adjacent to the main fault this basal colluvial facies occupies a triangular shaped depression approximately 50 centimeters deep. The wedge shape is similar to that of fissure openings that form at the base of normal fault scarps (Wallace, 1977). The overlying colluvium (unit 4B) is a mixture of post-Provo alluvial fan deposits derived from the upper part of the fault scarp and lake deposits. A weakly developed A/C soil profile that has developed on unit 4B (see discussion of soil S2) has subsequently been buried by unit 6.

Both unit 4 and soil S2 have been displaced by faulting along the main fault and the antithetic faults (Plate 2; Figures 8 and 10).

Pond deposit (unit 5). The youngest depositional unit that shows evidence of being faulted is a thin (less than 0.25 meters) layer of clayey silt exposed in the middle of the sag in trench A (26 meters to 32 meters west of main fault, Plate 2). The deposit is finely laminated in places and is interpreted as having been deposited in a pond. The unit has two organic-rich layers approximately 3 centimeters thick that contain small fragments of detrital charcoal. Charcoal was collected for radiocarbon age dating analysis, but there was insufficient carbon to date the sample. Additional sampling is planned.

Young scarp colluvium (unit 6). Colluvium (units 6A and 6B) overlies the main fault and also overlies soil S2 adjacent to the main fault. Unit 6A is similar in texture to unit 4A and it fills a similar wedge-shaped depression in the top of the underlying deposits (Plate 2 and Figure 14). In contrast to the older colluvial units, it is not in fault contact with the lake sediments (Figure 14). This unit was deposited immediately after the most recent surface faulting event along this trace of the fault. Unit 6B consists of slopewash and colluvium that is actively accumulating. The exact relationship between unit 6 and the young fill deposits (units 7 and 8) in the fault sag could not be observed because backfill from a buried pipeline has obscured this relationship. Unit 6 is not as thick as the colluvial facies of units 3 and 4.

Pre-settlement pond deposit/soil (unit 7). The oldest depositional unit exposed in the trenches that is not displaced by faults is a clayey silt pond deposit that conformably overlies unit 5 and soil S2. The pond deposit is mottled by dark organic material that represents the incipient development of a gley soil. These deposits occupy the central portion of the graben and are the deposits that existed at the ground surface when the area was first settled in 1847. This unit has subsequently been buried by deposits that are historical in age.

Historical deposits (unit 8). Following settlement of this area in 1847, water from the two springs at the base of the main fault scarp was artificially impounded in the graben (R. Harvey, personal communication). This ponding is represented by massive fine silt (unit 8A). A flash flood during the fall of 1919 (R. Harvey, personal communication) added significant amounts of material (unit 8B) to the small alluvial fan located immediately south of the trench sites. Intermittent ponding of the graben subsequent to this flooding

event has deposited additional silty pond sediments (unit 8C).

Soil Units

Soil developed on post-Provo alluvial fan deposits (soil S1). A weak-to-moderately well developed relict soil occurs on the post-Provo alluvial fan deposits exposed in test pits 1, 3, and 4; in trench E (Figure 9); and in roadcut exposures east of the main fault zone. This soil exhibits an incipient textural B horizon characterized by very few, thin clay films along pebble and pore surfaces. In test pit 3 the soil profile consists of a 40 centimeter thick A horizon overlying a 20 centimeter thick A/B horizon that grades into unweathered parent alluvial fan sediments.

Soil S1 began to form after the deposition of the post-Provo alluvial fan deposits, and the soil forming processes have continued to the present. Based on the degree of soil profile development, this soil is tentatively correlated with the Midvale soil (Table 1) (R. B. Morrison, oral communication). This suggests the soil began to form approximately 6000 years ago.

Alluviated soil (soil S2). A weakly developed soil characterized by an accumulation of carbonaceous material has formed on gravelly colluvium (unit 4B) and finer-grained sag deposits (unit 3B). Although much of the organic material in this soil is illuvial in origin, some of the carbonaceous material appears to be alluviated material incorporated into the sediments during deposition. High groundwater conditions in the fault sag favor preservation of this organic material. Formation of this soil unit occurred during a period of time represented by the deposition of the sag fill deposits (correlation chart, Plate 1).

Topsoil (soil S3). A thin (5 centimeter to 10 centimeter) topsoil unit consisting of a micaceous silt loam is developed at the surface of the youngest deposits within the graben. In places, this soil unit has been disturbed by plowing, particularly in the southern part of the graben.

FAULTING AND DEFORMATION

Faulting Associated with the Main Scarp

Trenches A and G (Plate 2; Figure 11) were excavated across the main fault scarp and exposed the faults associated with this scarp. Faulting occurs across a zone at least 5.5 meters wide as: a) a zone of deformation that defines the main fault, b) minor displacements in lakebeds east of the main fault, and c) a narrow fault zone in colluvium 3.5 meters west of the main fault. These faults are described below.

The main fault juxtaposes undifferentiated Alpine-Bonneville lake sediments against a sequence of scarp-derived colluvial deposits (units 3, 4, and 6). Cumulative stratigraphic separation across the main fault is greater than the height of the exposures in trench excavations (greater than 11 meters, Plate 2). In trench A the fault is a zone that strikes N2E and varies in dip from 74 degrees west to 55 degrees west. The zone widens from 10 centimeters near the base of the trench to 40 centimeters near the surface. The fault zone is bounded on the east by a well defined plane. The eastern part of the zone (4 centimeters to 30 centimeters wide) consists of poorly sorted, pebbly, fine to coarse sand containing 10 percent to 15 percent subangular and subrounded pebbles up to 3 centimeters in diameter. The long axes of the pebbles generally parallel the dip of the fault. The western part of the fault is a zone (2 centimeters to 8 centimeters wide) of reddish yellow (5 YR 7/6, dry) silty sand bounded by a shear plane. The western boundary of the fault zone is clearly

defined in the lower part of the trench; it becomes more irregular and less clearly defined towards the ground surface. Several other well defined shears traceable for distances varying between 0.1 meter and 3 meters occur within the fault zone.

Similar relationships are observed along the main fault in trench G (Figure 11). At this location the fault zone varies from 10 centimeters to 50 centimeters in width and consists of slightly pebbly sand containing fragments and stringers of reddish brown silt derived from the undifferentiated Alpine-Bonneville lake sediments. It strikes N3-4W and dips from 57 degrees to 64 degrees west. The fault zone is bounded on the east by a well defined 1.5 centimeter-wide reddish brown sandy clay seam. Material within a 3 centimeter to 5 centimeter-wide zone west of this main shear is stained by iron oxide. A preferred orientation that parallels the dip of the fault is developed in sand within a 15 centimeter-wide zone west of the main shear plane. The western margin of the fault zone is defined by an irregular surface. Material within the upper part of the fault zone is similar in texture and composition to the colluvial sand that overlies and truncates the fault zone.

Numerous faults having minor displacements occur across a zone at least 1.5 meters wide in the well stratified undifferentiated Alpine-Bonneville lake sediments exposed in the footwall (Plate 2). These faults strike parallel and subparallel to the main fault and dip from 50 degrees west to 85 degrees east. Displacements range from less than 1 centimeter to an observed maximum of 25 centimeters. Displacements are predominantly normal down to the west, but high angle, west-dipping reverse faults also occur. Several faults having minor displacements (less than 2 centimeters) that appear to decrease downwards are also observed. These minor faults within the lake sediments are defined by

displaced bedding which occurs along paper-thin planes that lack distintive gouge.

A fault oriented N5E, 78W occurs 3.5 meters west of the main fault zone in trench A. On the south wall, the fault juxtaposes colluvial units (units 3A, 4A, and 4B). Between stations 5 and 6 a reddish brown basal colluvial sand (unit 4A) is displaced approximately 60 centimeters down to the west. The fault does not exhibit strong expression in the upper coarse colluvium (unit 4B) and is primarily defined by a soft zone within the colluvium. On the north wall of trench A the fault is marked by an iron-oxide stained contact between coarse, bouldery colluvium (unit 3A) and a down-faulted block of undifferentiated Alpine-Bonneville lake sediments. This fault may be coincident with the small, west-facing break in slope and small topographic bench that extends approximately 70 meters north from trench A and occurs just west of the base of the main fault scarp.

Faulting Associated with the Antithetic Scarps

The graben at the trench locality was crossed completely by trench A (Plate 2) and the east facing antithetic scarp that forms the graben's western boundary was also crossed by trenches C and E (Figure 9).

The most extensive faulting associated with the graben and antithetic scarp is exposed in trench A. A zone of faulting containing approximately one hundred individual fault planes extends 26 meters from the center of the graben across the antithetic scarp (station 24 to station 48). Most of the faults strike N-S, parallel to the strike of the antithetic scarp, but strikes of up to N12E are observed locally. Faults within the zone are defined by single straight to curvilinear planes and by clusters of planes that anastomose and branch upwards to produce a complex series of horsts and grabens.

Most of the faults approach vertical, although dips as low as 55 degrees to both the east and west are observed, especially where faults branch, refract through different layers or, rarely, appear to deflect along bedding planes (station 45.5). The main fault zones associated with the antithetic scarp (stations 42.5 and 45) have an average dip of 70 degrees east; these are coincident with the major breaks in slope of the antithetic scarp. Cumulative vertical displacement across these two zones is 210 centimeters.

Many faults in the western portion of trench A (Plate 2) appear to die out upwards. While some faults may actually not extend through the section, others do even though they are poorly exposed in the coarser colluvium (units 3B and 4B) and in the S2 soil developed on the colluvial deposits. This is clearly seen between stations 25 and 32 where faults cannot be traced much above the S2 soil contact; however, the base of silt unit 5 is displaced along the upward projection of each of these faults.

In the bedded deposits the faults associated with the antithetic scarps are planes or paper-thin zones that lack gouge. However, discontinuous zones of fine silt up to 1.5 centimeters wide occur for short distances along some of the fault planes. These silt zones appear to be most common at points where single faults splay to form small grabens and horsts, and especially where they emerge from gravel unit 2 into sandy silt and sand of unit 3C. At several locations in trench A (stations 24.5, 26.5, 27.7, 31, 33, 36, 39, 45), both V-shaped, and irregularly fault-bounded wedges containing organic-rich material are observed within the sag fill deposits. These wedges range in length from 55 centimeters to 150 centimeters and in width from 10 centimeters to 86 centimeters. They generally extend downward from the alluviated soil (S2), but some (stations 26.5 and 33) are completely enclosed within sag fill deposits. Some of these

organic-rich zones contain gravel in their lower part and grey black silt and silty sand in the upper part; some contain black silt that differs in texture and composition from the sediments on either side; and some (station 33) have a grey black coloration superposed on layered sediments. These wedges of organic-rich material along fault traces occur both as infillings of fissures by the overlying alluviated soil S2, and, in places, as illuvial organic material deposited by surface water percolating down along faults and fractures.

Faulting observed in association with the antithetic scarp in trench E (Figure 9) is confined to a narrower zone, 5 meters wide, that contains four faults. The major fault associated with the antithetic fault scarp coincides with the base of the scarp. It is a paper-thin plane that separates post-Provo alluvial fan deposits (unit 2) from gravelly sand sag deposits (unit 4B). The post-Provo alluvial fan deposits are displaced at least 2.3 meters down to the east across this fault. A wedge of organic-rich material 15 centimeters to 25 centimeters wide occurs along the fault at the base of the sag fill. The western-most fault in this trench is oriented N2W, 85E and is generally coincident with the crest of the antithetic scarp. This fault, defined by a 5 centimeter to 10 centimeter-wide zone of grayish black pebbly sand, displaces post-Provo alluvial fan deposits 44 centimeters down to the east. Fan deposits are also downdropped 9 centimeters across two small grabens located 1 meter and 2 meters east of the major antithetic fault. The eastern minor graben contains a wedge of organic-rich, grayish black sediment within the coarser colluvium (unit 4B).

The zone of faulting exposed in trench C extends 18 meters west from the center of the graben across two subtle east-facing scarps. In this zone a minimum of fourteen faults having displacements ranging from less than 1 centimeter to 26 centimeters were observed. The pattern of faulting in

trench A, characterized by numerous anastomosing and branching faults, small horst and graben structures, and wedges of organic-rich sediments, also is observed in this trench.

Careful observations were made for any systematic changes in displacement along individual fault planes. In the three trenches that cross the antithetic scarps consistent amounts of displacement of successively younger strata are observed across individual faults. The lack of recurrent displacement on faults associated with the antithetic scarp indicates that these faults and the graben formed during one surface faulting event. Evidence of liquefaction was not observed in any of the trenches.

Back-tilting

Eastward dips measured on stratigraphic units (units 2, 3C, and 4C) in trenches A and E indicate that the downthrown block was tilted back towards the main fault during at least two surface faulting events.

Between stations 50 and 58 in trench A (Plate 2) and stations 49 and 54 in trench E (Figure 9), post-Provo alluvial fan deposits have a measured dip of 3 degrees to 5 degrees east. Projection of the alluvial fan surface across the graben indicates that the fan deposits originally dipped approximately 5 degrees west. This suggests that within 58 meters of the main scarp these deposits have been rotated as much as 8 degrees to 10 degrees towards the main scarp. Bedding and interfingering relationships at the margins of the bedded sequence of sand, gravel, and silt (units 3B and 3C) and a younger pond deposit (unit 4C) in trench A indicate that original depositional contacts were horizontal. As shown on the log of trench A (Plate 2), these strata are tilted 5 degrees to 6 degrees to the east across a zone that extends 38 meters from the main scarp. Younger deposits (units 4E, 5,

7, and 8) overlying these units do not appear to be tilted, suggesting that this 5 degrees to 6 degrees of back-tilting occurred during one event. West of station 38 (trench A), the bedded deposits (unit 3C) that onlap the east-dipping post-Provo alluvial fan deposits are horizontal. This change in the attitude of unit 3C may define the hinge line for the tilt of these deposits or it may represent a rotation of the tilted beds back to horizontal during formation of the antithetic scarp.

SEQUENCE OF FAULTING AND DEPOSITION AT THE KAYSVILLE SITE

The structural and stratigraphic relationships observed during mapping and exploratory trenching at the Kaysville site suggest the following sequence of events:

1. Post-Provo alluvial fans (unit 2) were unconformably deposited on Alpine-Bonneville lake deposits (unit 1). The unconformity between these units was displaced by faulting and the fan deposits on the downthrown block were tilted back toward the main scarp, producing a fault sag.

2. The fault sag filled with a bedded sequence of sand, silt, and gravel (units 3B and 3C) derived from the north, and with associated scarp-derived colluvium (unit 3A). Detrital charcoal from unit 3C has yielded a radiocarbon date of 1580 $\pm$ 150 years B.P. The interval between the initial back-tilting of the post-Provo alluvial fans and deposition of unit 3C is uncertain. It is possible that more than one surface faulting event occurred during this time interval.

3. The main fault scarp was breached at the southern end of the fault sag. This resulted in formation of a small alluvial fan that blocked through-flowing drainage. A small pond, represented by unit 4C, and cut and fill

channels (unit 4D) developed within the sag.

4. Surface faulting occurred. This event resulted in tilting of the sag fill (units 3B and 3C) and pond deposits (unit 4C) toward the main fault scarp. Uplift of the scarp during this event exposed Alpine-Bonneville lake deposits.

5. Erosion of the lake deposits exposed in the fault scarp produced a basal facies colluvium (unit 4A). This colluvium filled a fissure that formed at the base of the scarp. As erosion of the scarp continued, post-Provo alluvial fan deposits became the dominant source for scarp-derived colluvium (unit 4B). At the same time, the main part of the sag continued to fill with sediments derived from the alluvial fan to the south. An alluviated soil (S2) formed during, and subsequent to, deposition of these units.

6. Surface faulting occurred. This faulting produced a graben and renewed uplift along the main fault scarp. The grabens to the north in the Baer Creek area, and to the south around Shepard Creek, also formed during this event. No detectable back-tilting of the downthrown block occurred during this event. Extension across the graben led to formation of numerous small faults in a 25 meter wide zone associated with the antithetic scarp. Infilling of fissures with organic-rich gravel derived from the S2 soil occurred at this time.

7. Erosion of the main fault scarp following this surface faulting event led to deposition of a sequence of scarp-derived colluvium consisting of a basal facies derived primarily from lake sediments (unit 6A) overlain by coarser colluvium (unit 6B) that incorporates material derived from the post-Provo alluvial fans. This colluvial

sequence is similar to the colluvial sequence (units 4A and 4B) derived from the scarp subsequent to the previous surface faulting event.

8. Deposition within the graben since the most recent surface faulting has continued. This is represented by pre-settlement silt (unit 7) and historical flood and pond deposits (unit 8).

DISPLACEMENT PER EVENT AND RECURRENCE OF SURFACE FAULTING AT THE KAYSVILLE SITE

DISPLACEMENT PER EVENT

Earthquake magnitude can be estimated from the amount of displacement that occurs during a faulting event. The displacement per event that has occurred along this segment of the Wasatch fault is discussed below.

The cumulative vertical tectonic displacement of the unconformity between Alpine-Bonneville sediments and post-Provo alluvial fan deposits across the main fault and graben is 10 meters to 11 meters down to the west; this value is approximately equal to the cumulative displacement of the alluvial fan surface based on projections across the graben (Figures 3 and 4). However, field mapping and trench exposures indicate that displacement across the main fault scarp is significantly greater (perhaps two times) than cumulative vertical tectonic displacement across the zone. This difference is the result of graben formation and back-tilting at this locality. In Figure 4, the unconformity has been projected toward the main fault using dips observed in the post-Provo alluvial fan deposits. If this projection is correct, it indicates displacement of the unconformity across the main fault of about 25 meters; this value is approximately equal to the present height of the scarp.

Back-tilting, graben formation, lack of distinctive stratigraphic horizons across the fault, and modification of the base of the scarp by erosion and deposition are factors that complicate estimates of displacement per event. One approach to evaluating displacement per event is to divide the cumulative tectonic displacement by the three events observed at this site. This yields values of 3.3 meters to 3.8 meters per event. These values will be altered if more than three events have occurred at the site and/or if the amount of displacement was not the same for each event.

Estimates of the displacement per event can be based on the geometry of the main fault, the scarp morphology, and the scarp-derived colluviual units. Geometrical relationships suggest that tectonic displacement during the most recent surface faulting event may have been approximately 2 meters. In trench A the point of intersection of the projection of the main fault plane with the ground surface is coincident with the lower inflection point on the scarp profile (Figure 4). This inflection point interpreted to be the top of the free face developed on the scarp during the most recent faulting event. The distance between this inflection point and the base of the colluvium derived from the fault scarp is approximately 3.5 meters. One-half meter of displacement also occurred across the west dipping fault at station 4.5 (trench A), producing a total down to the west displacement of at least 4 meters. Total displacement across the antithetic faults was 2.2 meters down to the east during this event. Models of graben formation discussed by Slemmons (1957) suggest the true tectonic displacement across the zone (slip on main fault minus height of graben) is at least 1.8 meters.

Analysis of the colluvial stratigraphy adjacent to the main scarp suggests that slip along the main fault during the second most recent faulting event was a minimum of 3.4 meters. This is based on the assumption that colluvial unit 3A was in

equilibrium with the scarp (i.e., not actively aggrading) prior to the second most recent event and on the measured thickness of colluvium derived from the fault scarp produced as a result of this event (unit 4). Back-tilting of deposits in the sag during this event contributed an unknown amount of slip along the main fault. As noted above, the amount of displacement across the main fault may be as much as two times the tectonic displacement. This suggests that the tectonic displacement during the second most recent faulting event was a minimum of 1.7 meters.

Assessment of displacement per event for the oldest event(s) recognized at the Kaysville site is more difficult because critical relationships are below depths that were exposed by the trenches. If the two most recent faulting events accommodated approximately one-third to one-half of the 10 meters to 11 meters of tectonic displacement, tectonic displacement associated with the oldest event recognized at the site would have to be 5 meters to 8 meters. Stratigraphic relationships allow the possibility that more than one event could have occurred prior to the second most recent event. This would reduce the displacement per event. Additional studies at the Kaysville site, including drilling to accurately locate the unconformity beneath the graben, are planned to better define the effects of back-tilting and to refine the estimates of displacement per event.

The data available to date indicate a range in values of between 1.7 meters and 3.8 meters of tectonic displacement per surface faulting event along this segment of the Wasatch fault. Compilation of displacement-magnitude curves for normal faults (Slemmons, 1977) shows that earthquakes of magnitude 7 and larger are commonly associated with surface displacements of 2 or more meters. The data obtained at the Kaysville site indicate that earthquakes of magnitude 7 or larger have occurred along this segment of the Wasatch fault.

RECURRENCE OF SURFACE FAULTING

At least three surface faulting events have produced a cumulative vertical tectonic displacement of 10 meters to 11 meters of the erosional unconformity between post-Provo alluvial fan deposits and Alpine-Bonneville lake sediments. The maximum age of this unconformity is estimated to be 12,000 years to 9000 years B.P. The post-Provo alluvial fan surface is displaced approximately the same amount. This surface is younger than soil S1; formation of this soil is estimated to have begun approximately 6000 years ago. These observations indicate that the 10 meters to 11 meters of vertical tectonic displacement may have occurred within the past 6000 years.

A radiocarbon age of 1580 ± 150 years B.P. was obtained on charcoal from a silt layer in unit 3C. Observations in trench A indicate at least one surface faulting event occurred between formation of the unconformity and deposition of unit 3C. Some erosion of the tilted fan deposits occurred prior to, and during, deposition of unit 3C. The time interval between faulting of the fan deposits and deposition of unit 3C is uncertain.

Observations made in the trenches indicate that two surface faulting events (back-tilting and graben formation) have occurred since deposition of the charcoal-bearing layer. At least 1.6 meters of sediment was deposited after the charcoal-bearing layer and prior to the second most recent faulting event. Therefore, the date of this event is 1580 ± 150 years B.P. less the time it took to deposit at least 1.6 meters of sediment. The exact rate of sediment accumulation in the sag is not known. The youngest unit displaced during the most recent faulting event is a thinly laminated organic silt (unit 5). The silt is overlain by a 25 to 30 centimeter thick pond deposit (unit 7) and 35 to 40 centimeters of historical

(1847 and (younger) flood and pond deposits. These stratigraphic relationships suggest that the age of unit 5 is probably several hundred years (perhaps 500). The available data suggest that the interval between the two most recent events is unlikely to be greater than 1000 years, or less than 500 years.

If it is assumed that the interval between the two most recent surface faulting events is typical of past events, there would have been six to twelve events during the past 6000 years. If the displacement during the most recent event is typical of past events, it would take five to six events to produce the observed 10 meters to 11 meters of cumulative tectonic displacement. This suggests the interval between past events was probably closer to 1000 years than to 500 years. However, sufficient data are not yet available to determine whether or not the interval between these events has been uniform through time.

The recurrence of surface faulting inferred at the Kaysville site represents the time between events along one segment of the Wasatch fault. However, the Wasatch fault is 370 kilometers long and geomorphic and geologic relationships indicate that the fault is composed of a number of different segments. It is unlikely that all, or even most, of these segments rupture during any single earthquake. Therefore, the recurrence of surface faulting events for the entire fault zone is significantly more frequent than the recurrence along any individual segment.

CONCLUSIONS AND OBSERVATIONS

The following conclusions and observations are based on geologic studies completed to date at the Kaysville site:

1. Cumulative vertical tectonic displacement of the

unconformity between Alpine-Bonneville lake sediments and post-Provo alluvial fan deposits is 10 meters to 11 meters down to the west across the main fault scarp and graben. This unconformity has a maximum age of 9000 years to 12,000 years. The post-Provo alluvial fan surface, estimated to be 6000 years old, is displaced approximately the same amount.

2. At least three episodes of surface faulting that have been associated with large earthquakes have occurred along this trace of the fault in post-Provo time. The oldest recognized event(s) tilted the post-Provo alluvial fans, resulting in the formation of a sag that was subsequently filled by a bedded sequence of sand, silt, and gravel. The second most recent event tilted these deposits toward the main fault, and the sag filled with additional pond, alluvial, and colluvial deposits. The most recent event produced a graben but did not produce tilting toward the main scarp.

3. A radiocarbon date of 1580 $\pm$ 150 years B.P. has been obtained on detrital charcoal frorm the bedded silt-sand-gravel sequence. The two most recent surface faulting events have occurred subsequent to deposition of the charcoal. Stratigraphic relationships suggest that the most recent event may have occurred within the past few hundred years. The interval between these two events is probably 500 years to 1000 years.

4. Analysis of the relationship between the main fault and the scarp-derived colluvium suggests that the amount of tectonic displacement during at least some of the past events at this locality was several meters, indicating that earthquakes of magnitude 7, or larger, have occurred along this segment of the fault.

In addition to these conclusions, the following observations were made at the Kaysville site; these observations affect geologic interpretations of amount of tectonic displacement per event and recurrence intervals of surface faulting:

1. Back-tilting of the downthrown block toward the main fault may have increased the vertical stratigraphic separation across the main fault plane by as much as a factor of 2, relative to the true tectonic displacement. This phenomenon should be considered in developing estimates of earthquake magnitudes based upon fault displacement.

2. The most recent surface faulting along this segment of the Wasatch fault produced a series of grabens bounded on the east by en echelon, antithetic faults. This represents a change in the pattern of surface faulting.

3. Detailed study of sequences of scarp-derived colluvium provides a useful technique for evaluating recurrence of surface faulting.

REFERENCES CITED

Baker, A. A., 1964, Geologic map and sections of the Orem quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-241, scale 1:24,000.

Bissell, H. J., 1963, Lake Bonneville -- Geology of southern Utah Valley, Utah: U.S. Geological Survey, Professional Paper 257-B, p. 101-130.

Cluff, L. S., Brogan, G. E., and Glass, C. E., 1970, Wasatch fault, northern portion, earthquake fault investigation and evaluation: Woodward-Lundgren & Associates, Oakland, California.

Cluff, L. S., Brogan, G. E., and Glass, C. E., 1973, Wasatch fault, southern portion, earthquake fault investigation and evaluation: Woodward-Lundgren & Associates, Oakland, California.

Cluff, L. S., Glass, C. E., and Brogan, G. E., 1974, Investigation and evaluation of the Wasatch fault north of Brigham City and Cache Valley faults, Utah and Idaho; a guide to land-use planning with recommendations for seismic safety: Woodward-Lundgren & Associates, Oakland, California.

Cluff, L. S., Hintze, L. F., Brogan, G. E., and Glass, C. E., 1975, Recent activity of the Wasatch fault, northwestern Utah, U.S.A.: Tectonophysics, v. 29, p. 161-168.

Cook, K. L., 1972, Earthquakes along the Wasath Front, Utah--the record and the outlook, in Environmental Geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. H1-H29.

Cook, K. L., and Smith, R. B., 1967, Seismicity in Utah, 1850 through June 1965: Seismological Society of America Bulletin, v. 57, no. 4, p. 689-718.

Crittenden, M. D., Jr., 1964, General geology of Salt Lake County, in Geology of Salt Lake County: Utah Geological and Mineralogical Survey, Bulletin 69, p. 11-48.

Crittenden, M. D., Jr., 1965a, Geology of the Draper quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-377, scale 1:24,000.

Crittenden, M. D., Jr., 1965b, Geology of the Sugar House quadrangle, Salt Lake County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-380, scale 1:24,000.

Eardley, A. J., 1934, Structure and physiography of the southern Wasatch Mountains, Utah: Michigan Academy of Sciences Papers, v. 19, p. 377-400.

Eardley, A. J., 1939, Structure and physiography of the southern Wasatch Mountains, Utah: Michigan Academy of Sciences Papers, v. 19, p. 377-400.

Eardley, A. J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 55, no. 7, p. 819-894.

Eardley, A. J., 1951, Structural geology of North America: Haper & Bros., New York, 624 p.

Feth, J. H., Barker, D. A., Moore, L. G., Brown, R. J., and Veirs, C. E., 1966, Lake Bonneville -- Geology and hydrology of the Weber Delta District, including Ogden, Utah: U.S. Geological Survey, Professional Paper 518, 76 p.

Hintze, L. F., 1972, Wasatch fault zone east of Provo, Utah, in Environmental Geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. F1-F10.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953, Lake Bonneville -- Geology of northern Utah Valley, Utah: U.S. Geological Survey, Professional Paper 257-A, 99 p.

Marsell, R. E. (ed.), 1964, The Wasatch fault zone in north-central Utah; Guidebook to the Geology of Utah, no. 18: Utah Geological Society, 62 p.

Morrison, R. B., 1965, Lake Bonneville -- Quaternary stratigraphy of eastern Jordan Valley, south of Salt Lake City, Utah: U.S. Geological Survey, Professional Paper 477, 80 p.

Myers, B., and Hamilton, W., 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geological Survey, Professional Paper 435-I, 98 p.

Slemmons, D. B., 1957, Geological effects of the Dixie Valley-Fairview Peak, Nevada, earthquakes of December 16, 1954: Seismological Society of America Bulletin, v. 47, no. 4, p. 353-375.

Slemmons, D. B., 1977, State-of-the-art for assessing earthquake hazards in the United States, Report 6 -- Faults and earthquake magnitude: National Technical Information Service, Miscellaneous Paper S-73-1.

Smith, R. B., 1972, Contemporary seismicity, seismic gaps, and earthquake recurrences of the Wasatch Front, in Environmental Geology of the Wasatch Front, 1971: Utah Geological Association Publication 1, p. I1-I9.

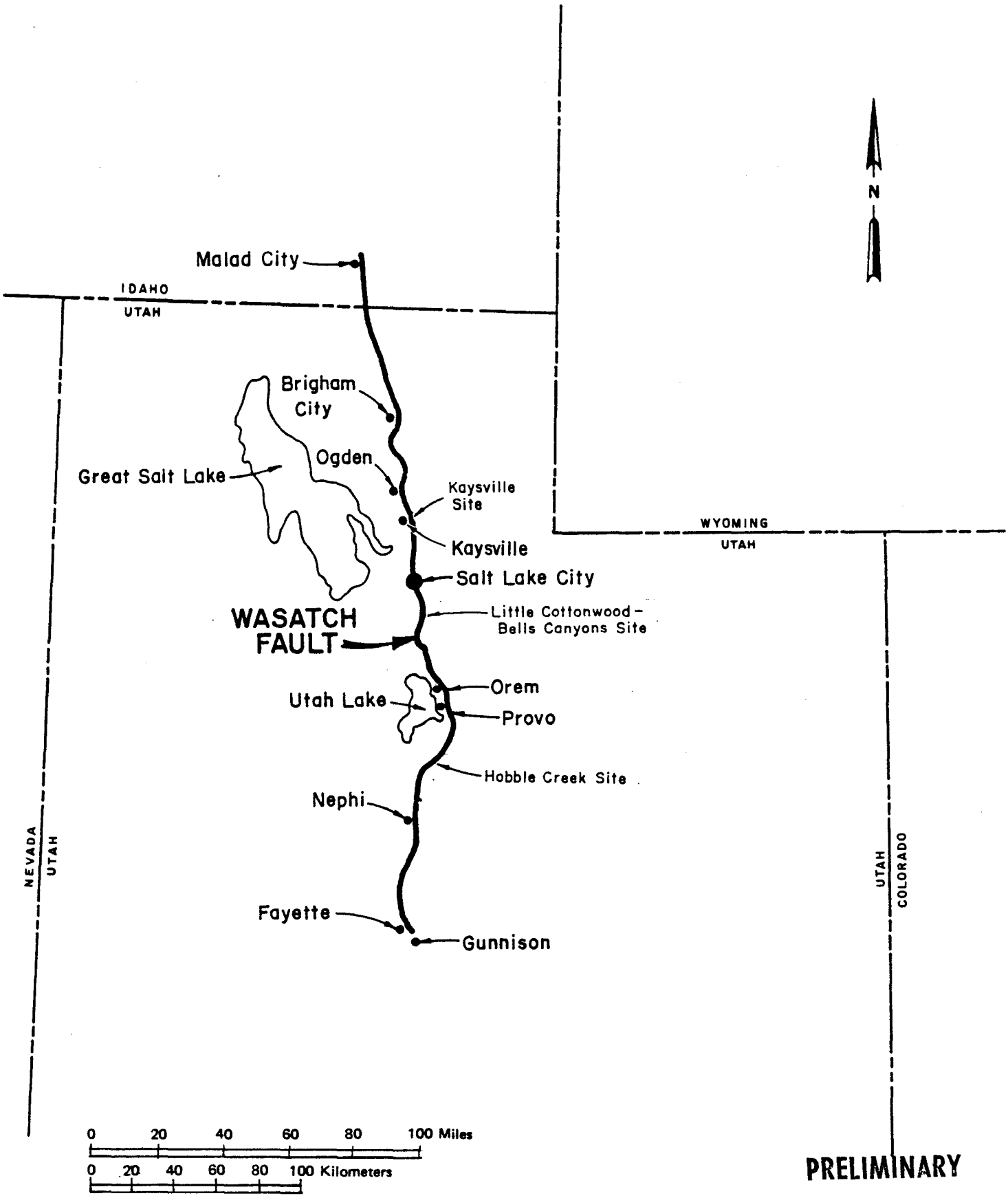
Smith, R. B., Arabasz, W. J., Cook, K. L., and Ward, S. H., 1978, Earthquake research on the Wasatch Front, Utah: U.S. Geological Survey, National Earthquake Hazards Reduction Program, Summaries of Technical Reports, v. 5, p. 303-305.

Van Horn, R., 1972a, Surficial geologic map of the Sugar House quadrangle, Salt Lake County, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-766-A, scale 1:24,000.

Van Horn, R., 1972b, Map showing relative ages of faults in the Sugar House quadrangle, Salt Lake County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-766-B, scale 1:24,000.

Wallace, R. E., 1977, Profiles and ages of young fault scarps, north-central Nevada: Geological Society of America Bulletin, v. 88, p. 1267-1281.

Woodward-Clyde Consultants, 1975, Study of earthquake recurrence intervals on the Wasatch fault, Utah; final technical report, 1975: prepared for the U.S. Geological Survey under Contract No. 14-08-0001-14567, by Woodward-Clyde Consultants, San Francisco, California, 37 p.

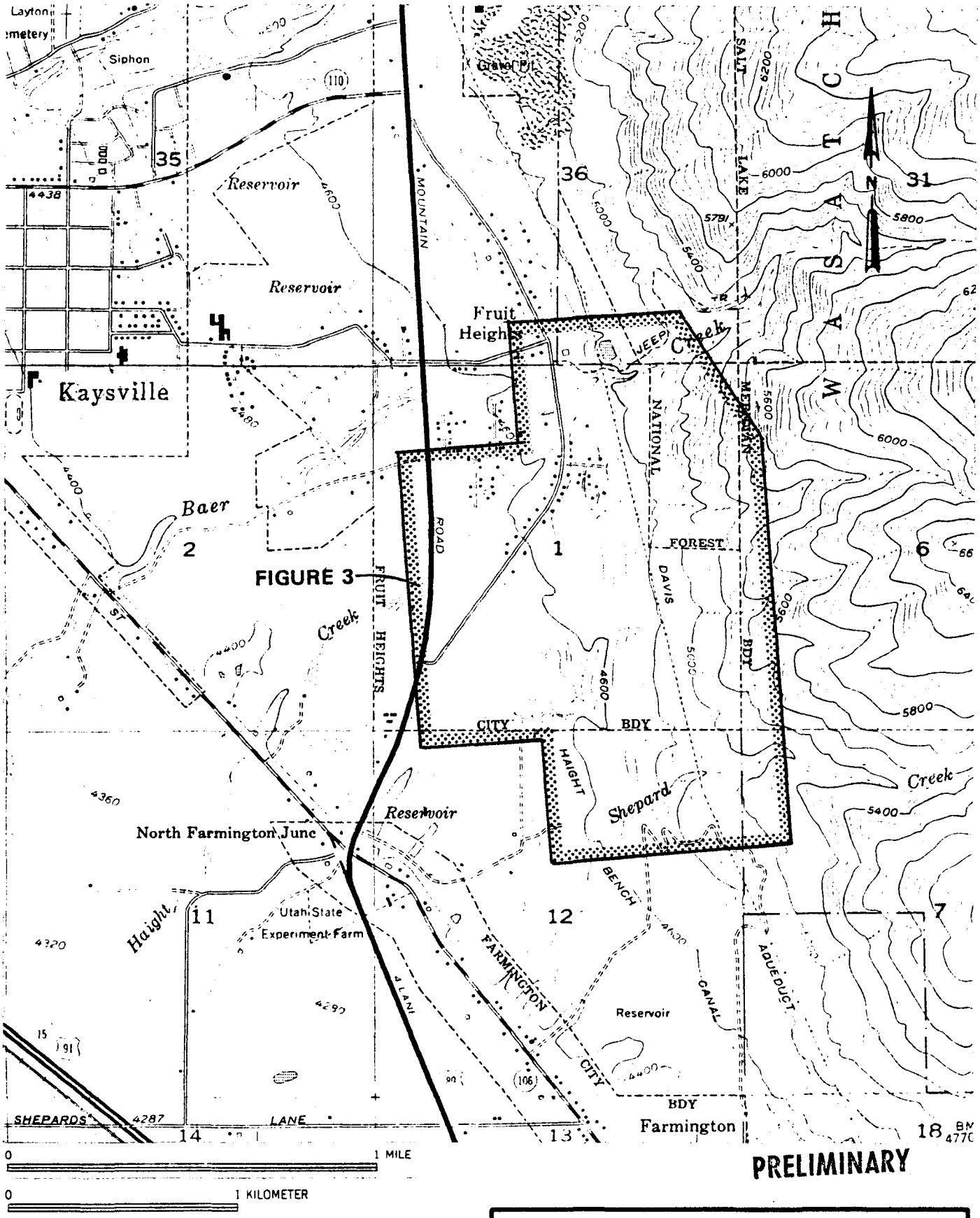


PRELIMINARY

REGIONAL LOCATION MAP

Woodward-Clyde Consultants

14093-1A
Figure 1

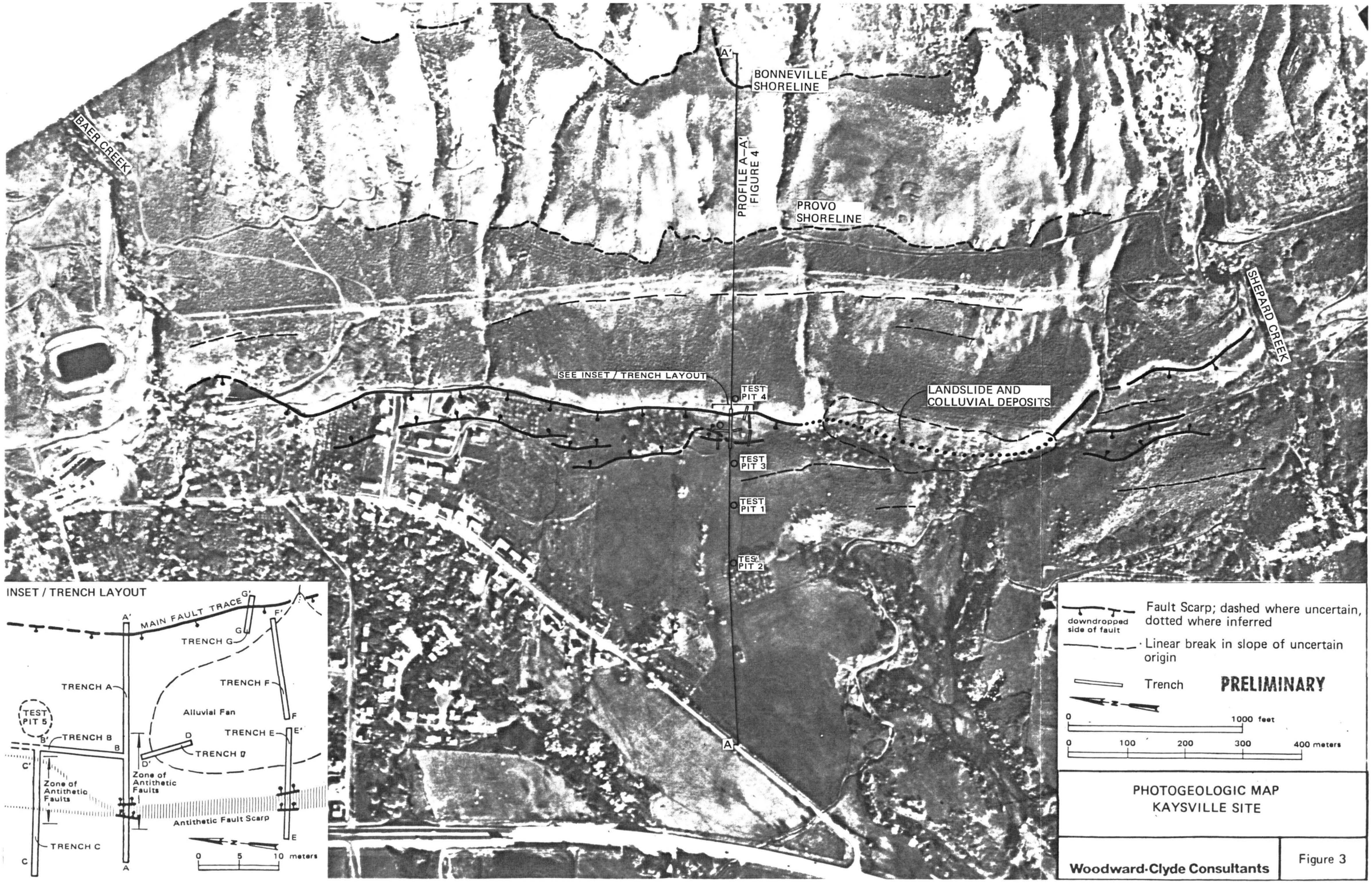


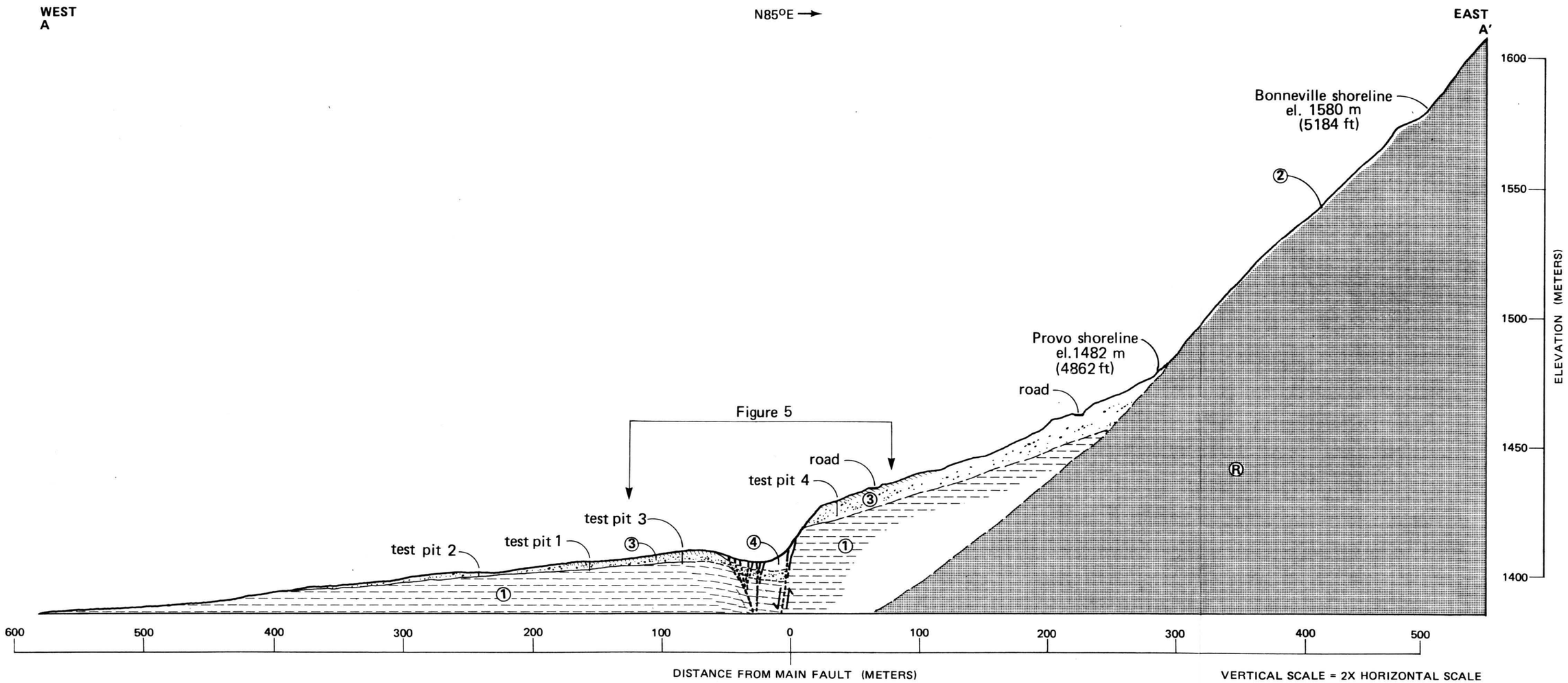
Map source: USGS 7½' quadrangle, Kaysville, Utah

LOCATION MAP
OF KAYSVILLE SITE

Woodward-Clyde Consultants

Figure 2


A'
BONNEVILLE SHORELINE
BAER CREEK
PROFILE A–A'
FIGURE 4
PROVO SHORELINE
SHEPARD CREEK
SEE INSET / TRENCH LAYOUT
TEST PIT 4
LANDSLIDE AND COLLUVIAL DEPOSITS
TEST PIT 3
TEST PIT 1
TEST PIT 2
A
INSET / TRENCH LAYOUT
MAIN FAULT TRACE
G'
F'
G
TRENCH G
TRENCH A
TRENCH F
TEST PIT 5
Alluvial Fan
F
TRENCH E
E'
B'
TRENCH B
B
D
TRENCH D
D'
C'
Zone of Antithetic Faults
Zone of Antithetic Faults
Antithetic Fault Scarp
E
TRENCH C
C
A
0 5 10 meters
downdropped side of fault
Fault Scarp; dashed where uncertain, dotted where inferred
Linear break in slope of uncertain origin
Trench
PRELIMINARY
0 1000 feet
0 100 200 300 400 meters
PHOTOGEOLOGIC MAP
KAYSVILLE SITE
Woodward-Clyde Consultants
Figure 3



EXPLANATION

- ④ Sag fill and associated colluvium
- ③ Post-Provo alluvial fan deposits
- ② Lake Bonneville recessional deposits and colluvium
- ① Alpine-Bonneville lake deposits (undifferentiated)
- Ⓡ Bedrock (schist, gneiss, and migmatite of Precambrian Farmington Canyon Complex)
- Lithologic contact; dashed where inferred
- Fault; dashed where inferred; arrows indicate relative sense of displacement

PRELIMINARY

Note: see Figure 3 for location of profile

GEOLOGIC CROSS SECTION
OF KAYSVILLE SITE ALONG
PROFILE A–A'

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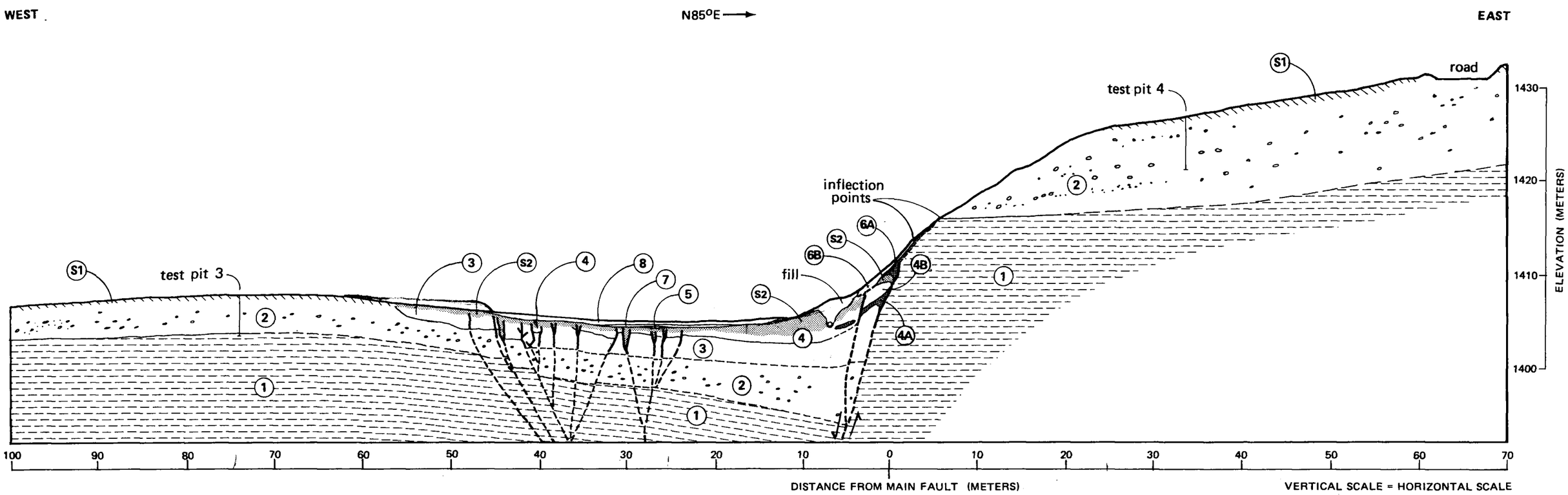
Figure 4



EXPLANATION

LITHOLOGIC UNITS

OLDER ↓

- (8) Historical alluvium / pond deposits
- (7) Pre-Settlement deposit
- (6B) Colluvium / slopewash deposits
- (6A) Colluvium—basal facies
- (5) Pond deposit
- (4) Locally derived sag fill including:
  - (4B) Colluvium
  - (4A) Colluvium—basal facies
- (3) Sag fill derived from north and associated colluvium
- (2) Post-Provo alluvial fan deposits
- (1) Alpine-Bonneville lake deposits (undifferentiated)

SOIL UNITS

- (S1) Relict soil developed on post-Provo alluvial fan deposits
- (S2) Alluviated soil

Lithologic contact; dashed where inferred

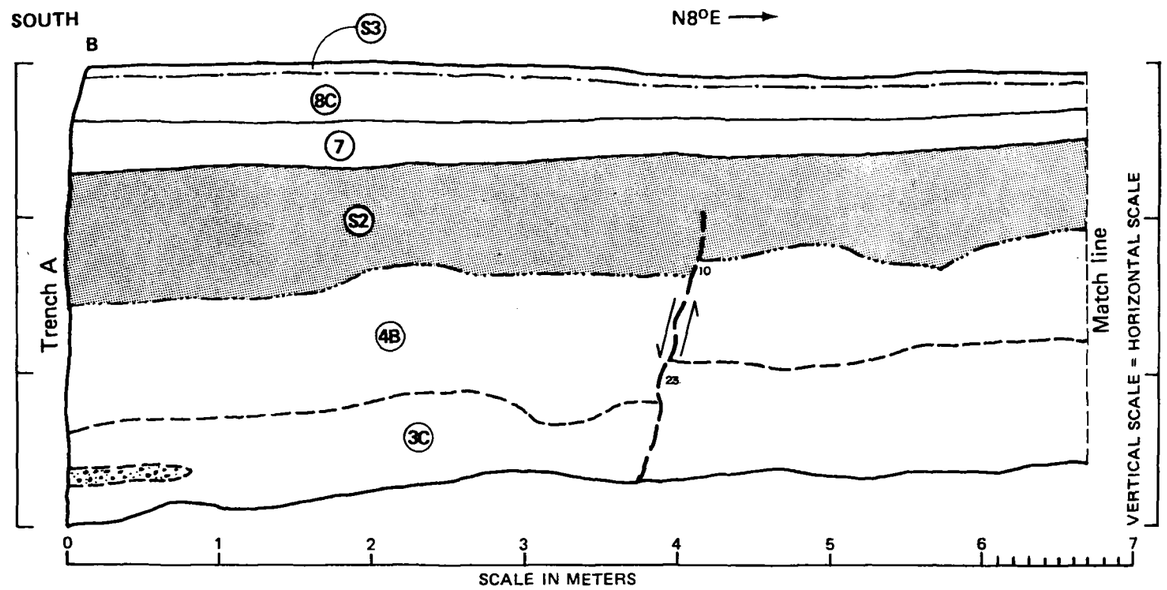
Fault; dashed where inferred; arrows indicate relative sense of displacement

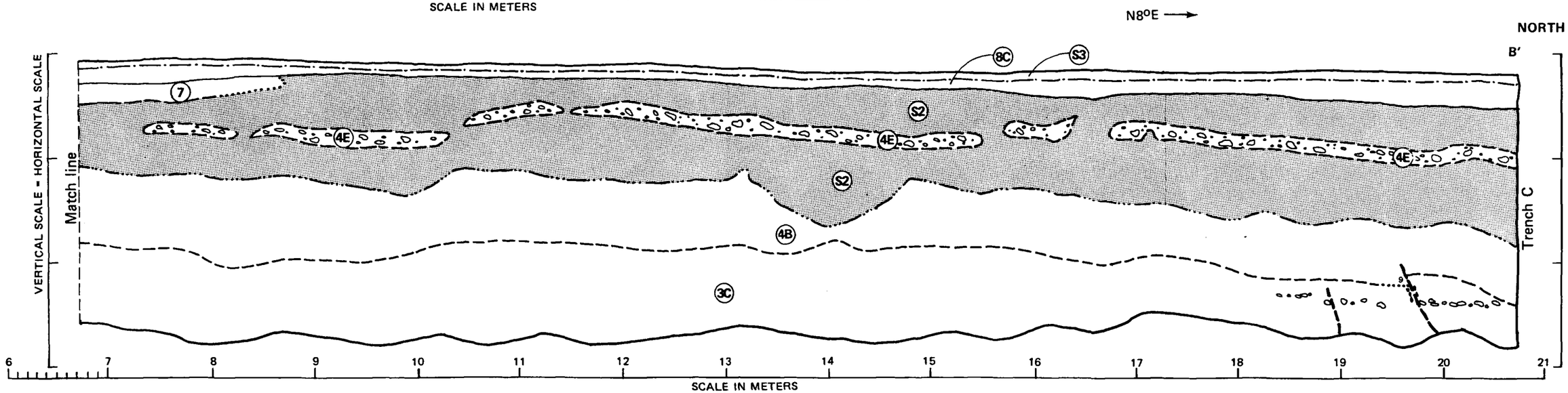
PRELIMINARY

Note: see Figures 3 and 4 for location of profile

GEOLOGIC CROSS SECTION
OF GRABEN
AT THE KAYSVILLE SITE

Woodward-Clyde Consultants | Figure 5





PRELIMINARY

EXPLANATION

LITHOLOGIC UNITS

- 8C Historical pond deposit
- 7 Colluvium; queried where uncertain
- 4E Pond deposit / soil
- 4B Mudflow deposit
- 3C Pond deposits

—— Lithologic contact; dashed where less distinct; dotted where approximate or gradational

SOIL UNITS

- S3 Topsoil
- S2 Alluviated soil developed on 4B

—·—·— Soil boundary; abrupt, transition zone is between 1 mm and 2.5 cm thick

—··— Soil boundary; gradual, transition zone is between 6 and 12.5 cm thick

Fault trace; solid line where well defined; dashed where less distinct; small numbers indicate stratigraphic seperation in cm; arrows indicate relative sense of displacement

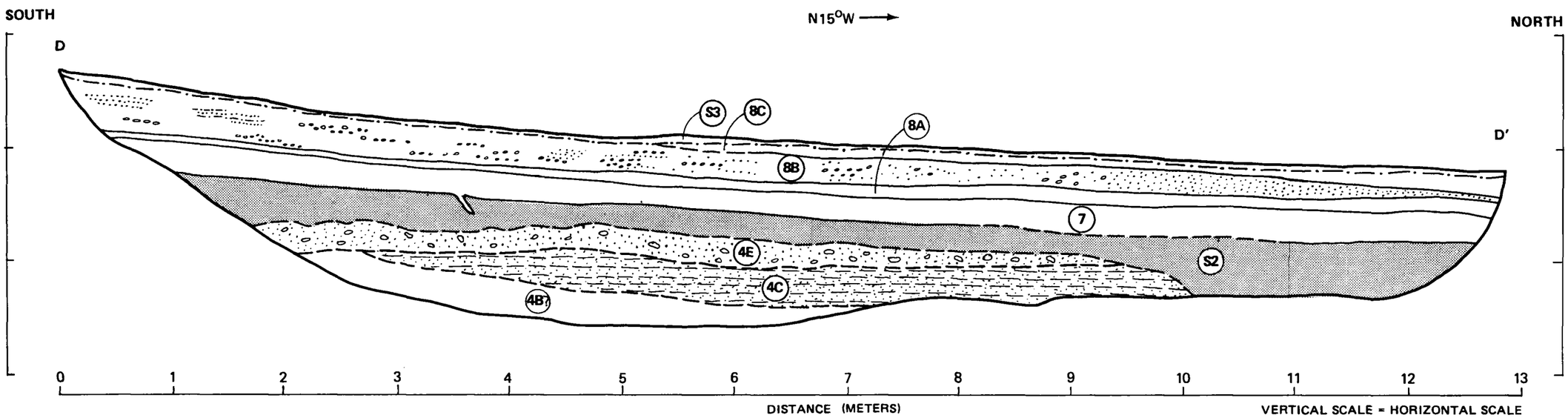
Note: Trench excavated parallel to strike of faults; only better defined faults are shown, dips are apparent

Note: see Plate 1 for detailed description of units; location of trench is shown on Figure 3

LOG OF TRENCH B
KAYSVILLE SITE

Woodward-Clyde Consultants

Figure 6



EXPLANATION

LITHOLOGIC UNITS

- (8C) Historical pond deposit
- (8B) Alluvial fan deposit from 1919 flood
- (8A) Historical pond deposit
- (7) Pond deposit / soil
- (4E) Mudflow deposit
- (4C) Pond deposit
- (4B) Colluvium; queried where uncertain

SOIL UNITS

- (S3) Topsoil
- (S2) Alluviated soil

——— — — Lithologic contact; dashed where less distinct

—·—·— Soil boundary; abrupt, transition zone is between 1 mm and 2.5 cm thick

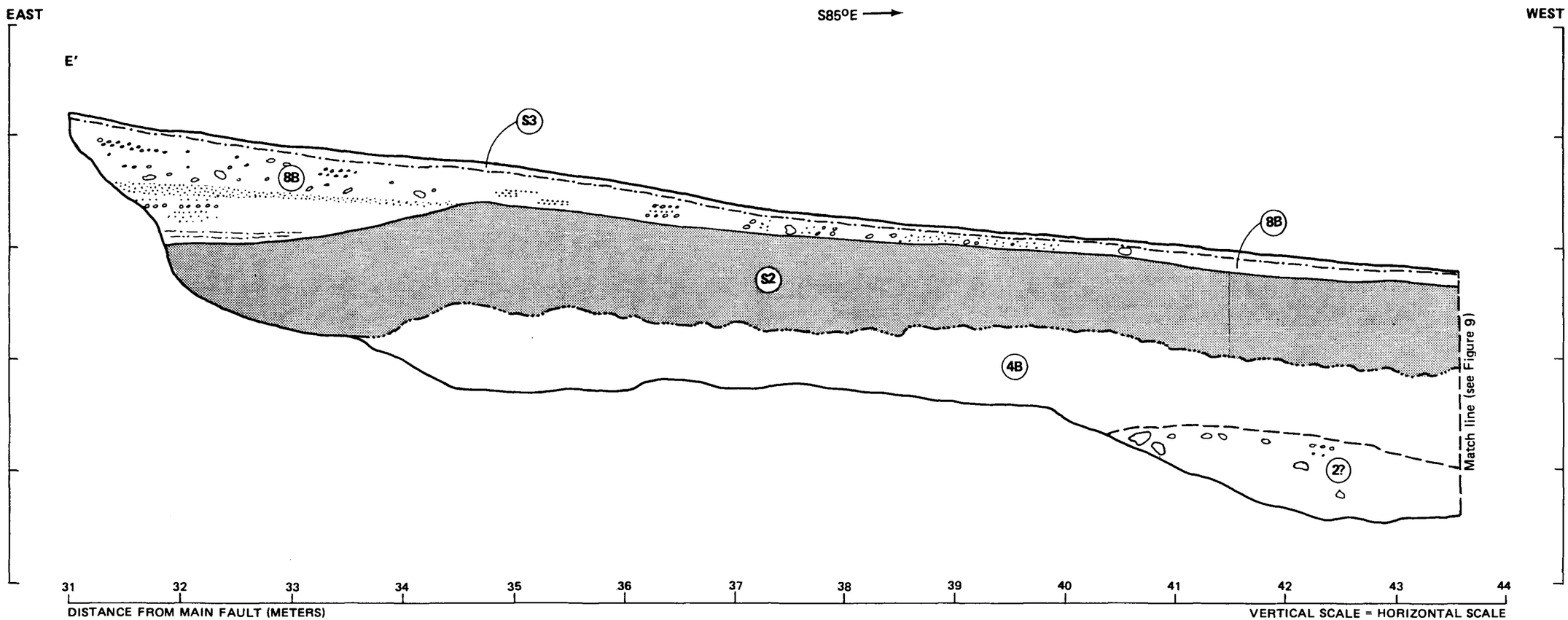
PRELIMINARY

Note: see Plate 1 for detailed description of units; location of trench shown on Figure 3

LOG OF TRENCH D
KAYSVILLE SITE

Woodward-Clyde Consultants

Figure 7



EXPLANATION

LITHOLOGIC UNITS

- (8B) Alluvial fan deposit from 1919 flood
- (4B) Colluvium
- (2) Post-Provo alluvial fan deposits; queried where uncertain

Note: see Plate 1 for detailed description of units; location of trench shown on Figure 3.

SOIL UNITS

- (S3) Topsoil
- (S2) Alluviated soil developed on 4B; occurs locally as infills
- (S1) Soil developed on Post-Provo alluvial fan deposits; occurs locally as infills

Lithologic contact; dashed where less distinct

Soil boundary; abrupt, transition zone is between 1mm and 2.5 cm thick

Soil boundary; gradual, transition zone is between 6 and 12.5 cm thick

Fault trace: solid line where well defined; dashed where less distinct; bold numbers indicate strike and dip of fault plane; small numbers indicate stratigraphic separation in cm; arrows indicate relative sense of displacement

Note:
n_1 Gravelly sand containing carbonacious material

PRELIMINARY

LOG OF TRENCH E
SHEET 1
KAYSVILLE SITE

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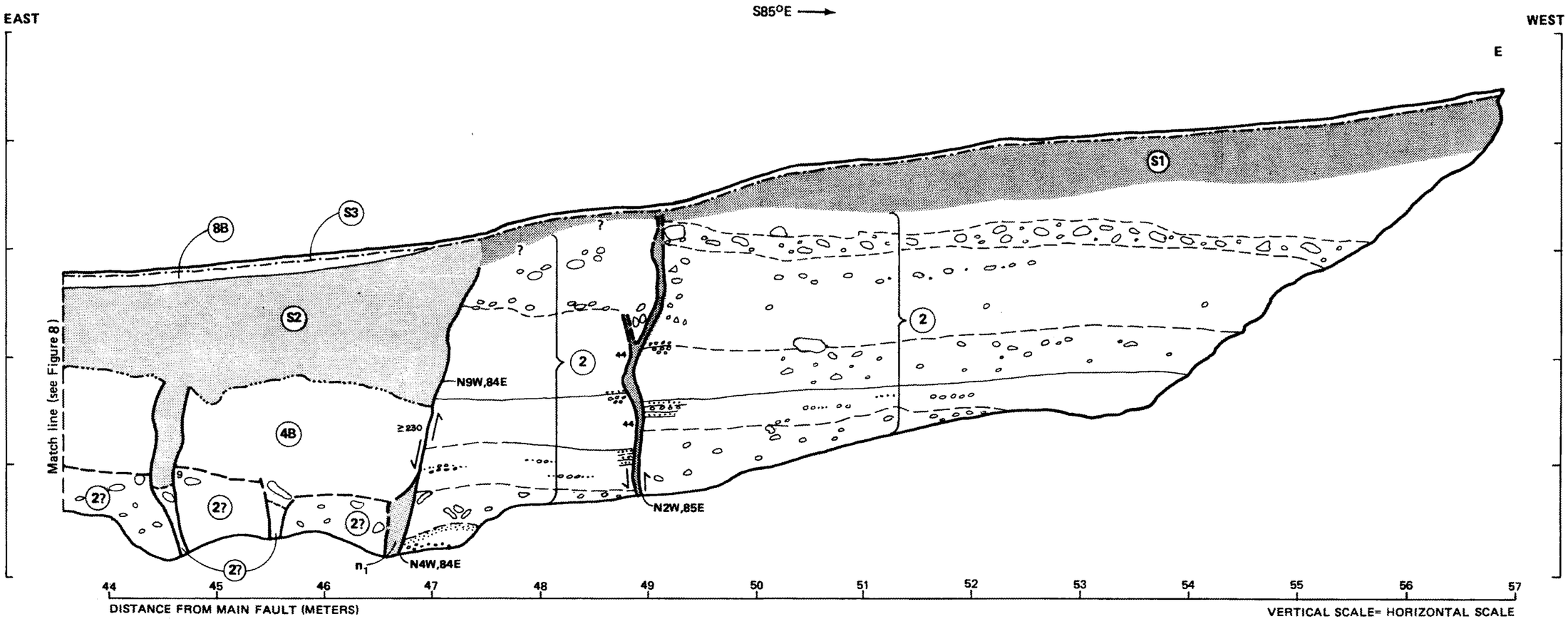
Figure 8



PRELIMINARY

Note: See Figure 8 for Explanation

LOG OF TRENCH E
SHEET 2
KAYSVILLE SITE

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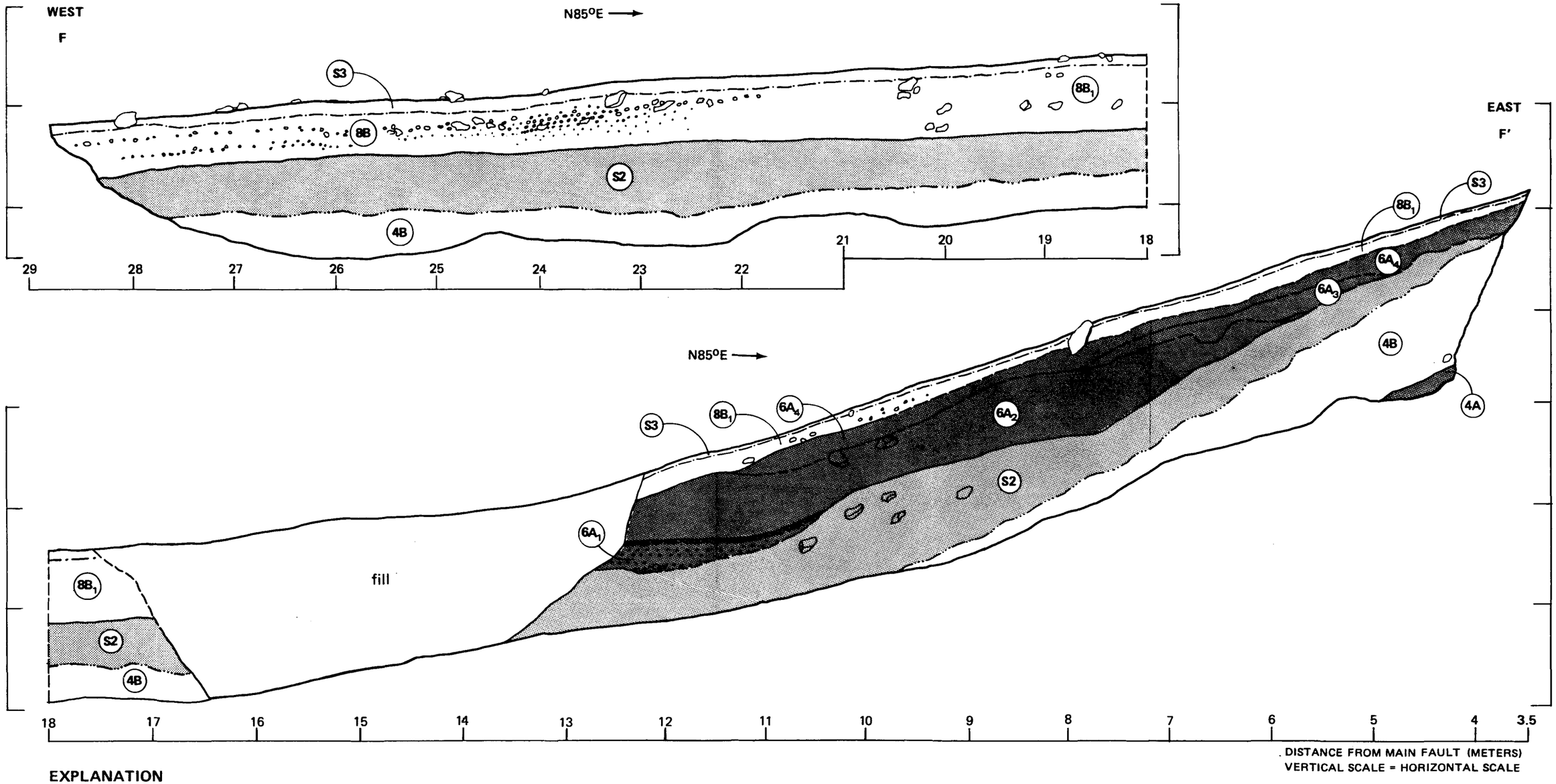
Figure 9



EXPLANATION

LITHOLOGIC UNITS

- 8B, 8B1 — Alluvial fan deposit from 1919 flood
- 6A4, 6A3, 6A2, 6A1 — Colluvium—basal facies
- 4A — Colluvium—basal facies
- 4B — Colluvium

SOIL UNITS

- S3 — Topsoil
- S2 — Alluviated soil developed on 4B

- Lithologic contact; dashed where less distinct
- Soil boundary; abrupt, transition zone is between 1mm and 2.5 cm thick
- Soil boundary; gradual, transition zone is between 6 and 12.5 cm thick

Note: see Plate 1 for detailed description of units; location of trench shown on Figure 3

PRELIMINARY

LOG OF TRENCH F
KAYSVILLE SITE

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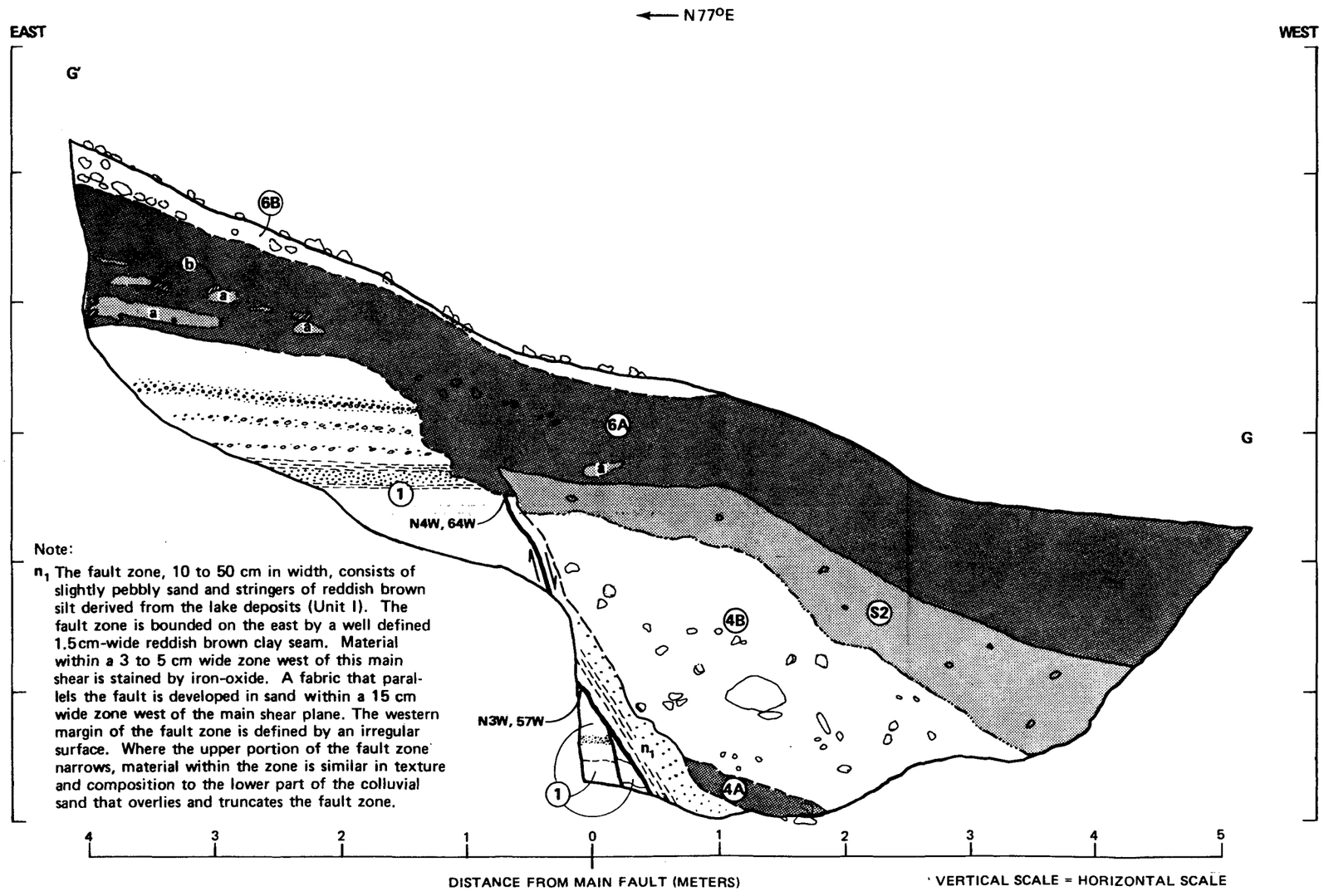
Figure 10



Note:

n_1 The fault zone, 10 to 50 cm in width, consists of slightly pebbly sand and stringers of reddish brown silt derived from the lake deposits (Unit I). The fault zone is bounded on the east by a well defined 1.5cm-wide reddish brown clay seam. Material within a 3 to 5 cm wide zone west of this main shear is stained by iron-oxide. A fabric that parallels the fault is developed in sand within a 15 cm wide zone west of the main shear plane. The western margin of the fault zone is defined by an irregular surface. Where the upper portion of the fault zone narrows, material within the zone is similar in texture and composition to the lower part of the colluvial sand that overlies and truncates the fault zone.

EXPLANATION

LITHOLOGIC UNITS

- (6B) Colluvium / slopewash deposits
- (6A) Colluvium—basal facies
  a) grayish brown sandy loam
  b) reddish brown sand and silt
- (4B) Colluvium
- (4A) Colluvium—basal facies
- (1) Alpine—Bonneville lake deposits (undifferentiated)

SOIL UNIT

- (S2) Alluviated soil developed on 4B

— — — Lithologic contact; dashed where less distinct

—·····— Soil boundary; gradual, transition zone is between 6 and 12.5cm thick

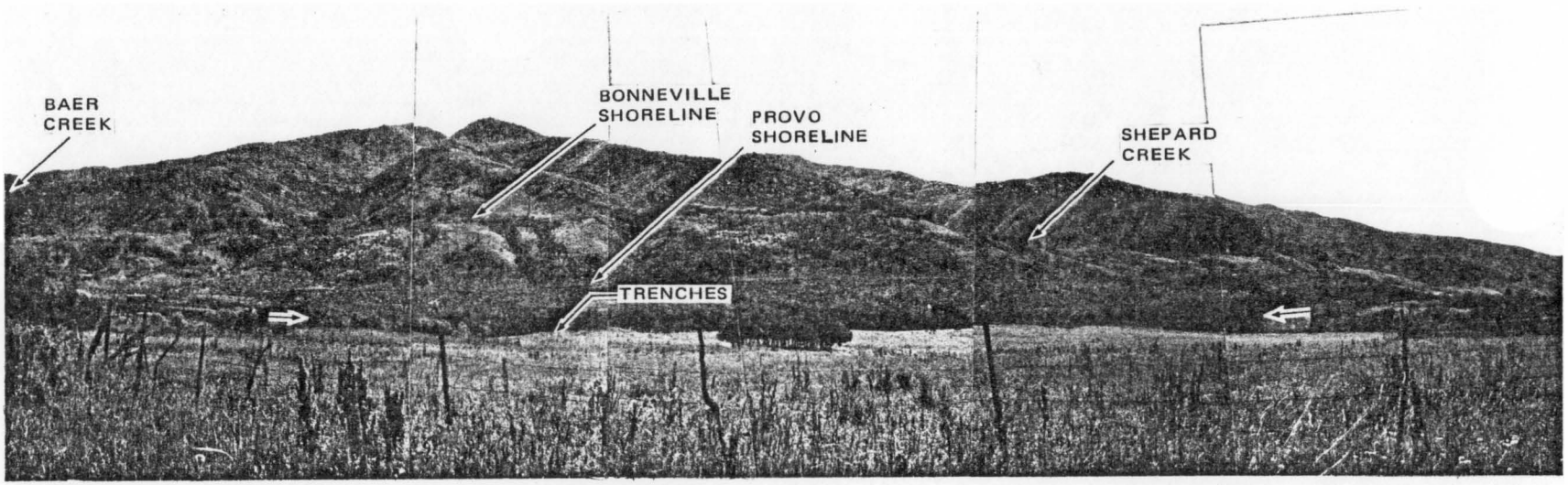
—·····— Soil boundary; diffuse, transition zone is greater than 12.5cm thick

N5E, 78W — Fault: solid line where well defined; dashed where inferred; bold numbers indicate strike and dip of the fault plane; arrows indicate relative sense of displacement

PRELIMINARY

Note: see Plate 1 for detailed description units; location of trench shown on Figure 3.

LOG OF TRENCH G KAYSVILLE SITE	
Woodward-Clyde Consultants	Figure 11



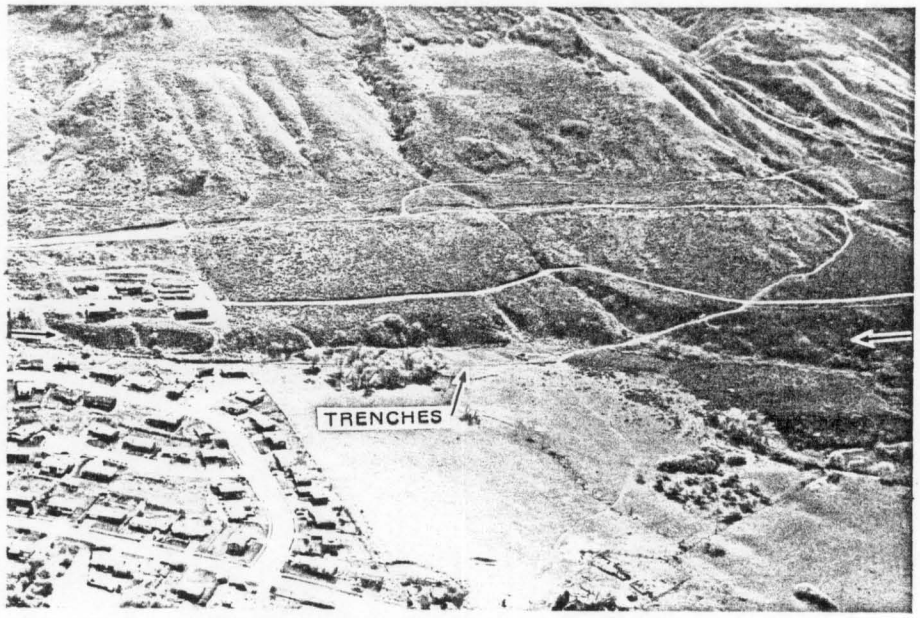
Panoramic view of Wasach Front between Baer Creek and Shepard Creek near Kaysville, Utah, showing the recent fault scarp (arrows) and location of trenches

PRELIMINARY

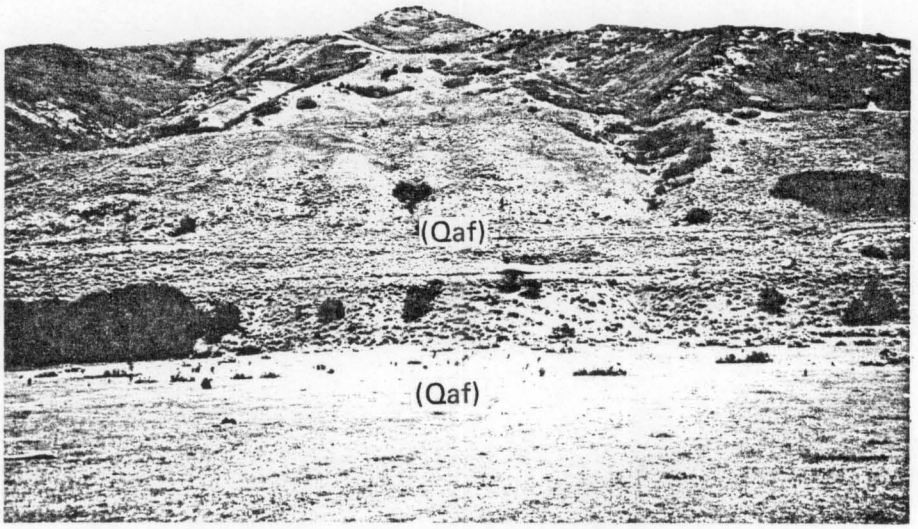
PHOTOGRAPH SHOWING WASATCH FRONT
NEAR KAYSVILLE, UTAH

Woodward-Clyde Consultants

Figure 12



(a) Aerial view of main fault scarp, (arrows), and associated graben at Kaysville Site.



(b) View east across graben and main fault scarp showing displaced alluvial fan surface (Qaf).

PRELIMINARY

PHOTOGRAPHS SHOWING RECENT FAULT SCARP AT KAYSVILLE SITE

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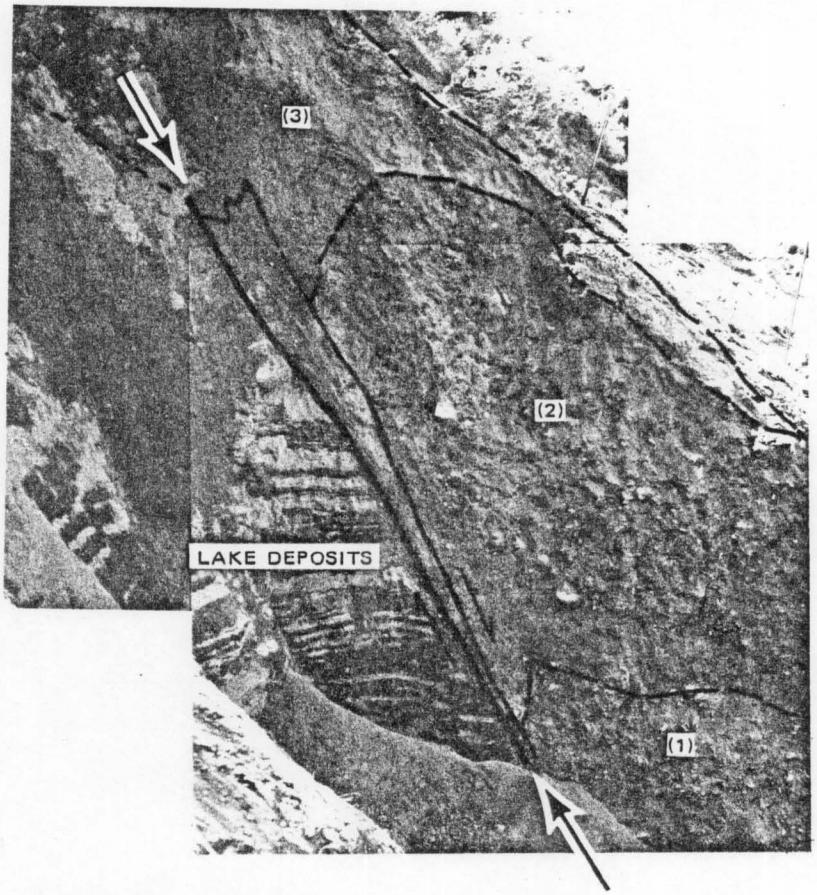
Figure 13



Main fault, (arrows), exposed in the south wall of Trench A, Kaysville site. The two lower colluvial units, (1 and 2), are in fault contact with well bedded lake deposits. The upper colluvial unit, (3), which formed subsequent to the most recent displacement, is in depositional contact with the fault scarp.

PRELIMINARY

PHOTOGRAPH SHOWING MAIN FAULT EXPOSED AT KAYSVILLE SITE	
Woodward-Clyde Consultants	Figure 14

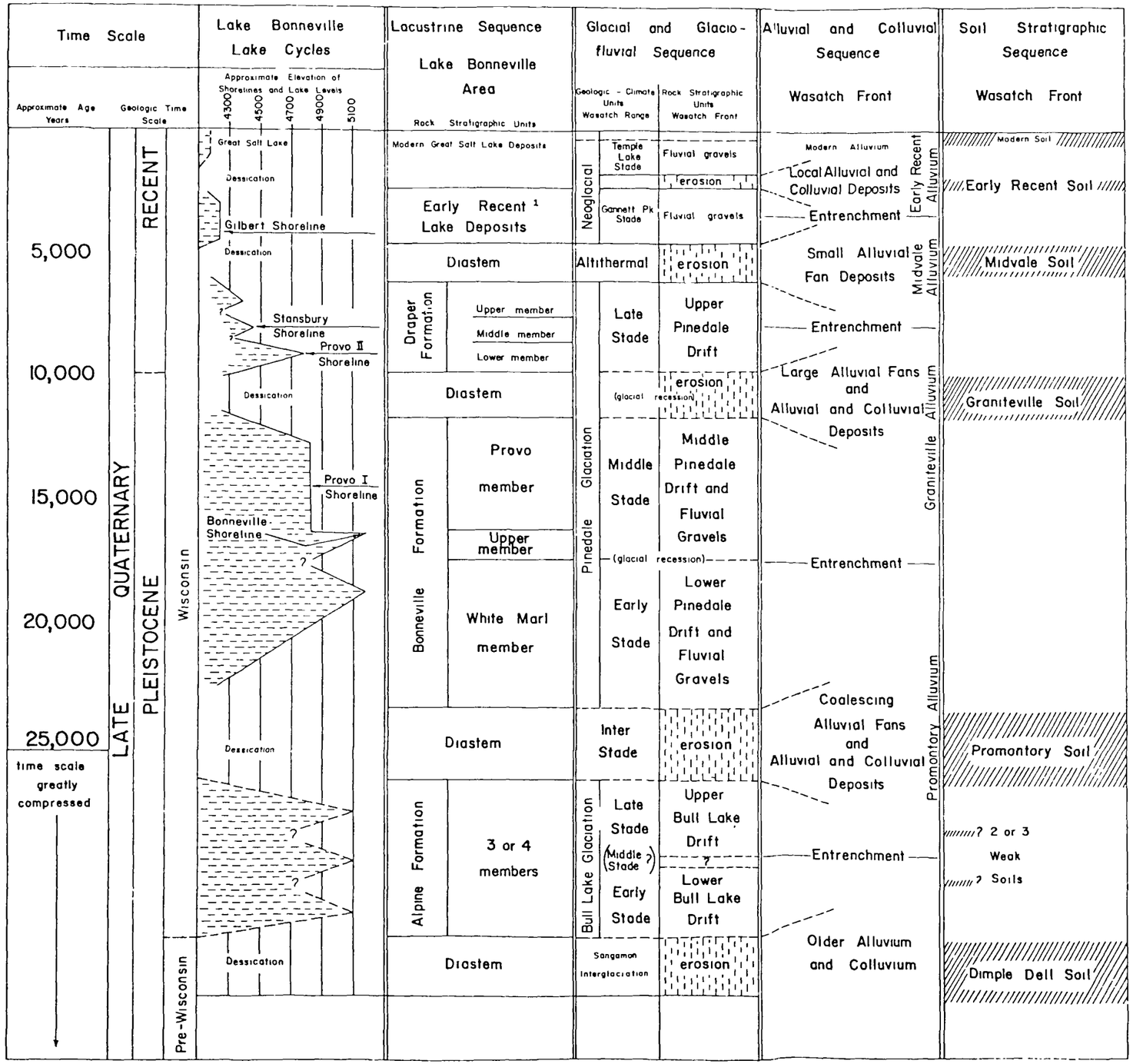
Antithetic fault scarps (arrows) at northern end of the graben at the Kaysville site. View is west towards the Great Salt Lake.

PRELIMINARY

PHOTOGRAPH SHOWING ANTITHETIC FAULT SCARPS AT KAYSVILLE SITE	
Woodward-Clyde Consultants	Figure 15

CORRELATION CHART

Late Quaternary Stratigraphic Sequences — Wasatch Fault Region



Source: Woodward-Clyde Consultants, 1975

[1] Proposed Ridgeland Formation – Van Horn, Personal Communication

PRELIMINARY

STRATIGRAPHIC CORRELATIONS FOR WASATCH FAULT SYSTEM

Woodward-Clyde Consultants

Table 1

STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT, UTAH

U.S.G.S. Contract No. 14-08-0001-16827

Lloyd S. Cluff, Principal Investigator
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Summary of Interim Technical Report, September, 1978

Purpose of Study

The Wasatch fault is an active intraplate fault that extends more than 370 km from Gunnison, Utah to Malad City, Idaho. The fault exhibits almost continuous geomorphic expression of late Quaternary faulting and displaces Pleistocene lacustrine sediments deposited by Lake Bonneville and its predecessors, and late Pleistocene and Holocene alluvial and colluvial sediments. However, no earthquake of a magnitude greater than 6 is known to have occurred along the Wasatch fault since the region was settled in 1847. Investigations conducted in 1975 by Woodward-Clyde Consultants (Contract No. 14-08-001-14567) identified six sites that have a high probability of yielding information regarding recurrence of surface faulting along the Wasatch fault. Detailed geologic mapping and subsurface investigations are being conducted at two of these sites, the Kaysville site (32 km north of the Salt Lake City) and the Hobble Creek site (28 km southeast of Provo), to measure fault displacements in strata that can be dated or correlated with dated units. These data are used to estimate the frequency of recurrence of moderate to large earthquakes associated with surface faulting events along the Wasatch fault.

Field Investigations

Field investigations were conducted at the Kaysville site during June, 1978. These investigations included: a) photointerpretation using 1:12,000 low-sun-angle black-and-white aerial photographs; b) detailed surface mapping of faults and late Quaternary stratigraphic units at a scale of 1:6,000; c) topographic profiling of fault scarps; and d) excavation of test pits and exploratory trenches. Seven

trenches totaling 189 meters in length and varying in depth from 2 to 6 meters were excavated. Trenches were logged in detail at a scale of 5 cm = 1 m.

Results

The following conclusions and observations are based on the geologic mapping and on stratigraphic and structural relationships observed in colluvial and sag fill deposits exposed in trenches excavated across the main Wasatch fault scarp and an associated graben at the Kaysville site:

1. Cumulative vertical tectonic displacement of the unconformity between Alpine-Bonneville lake sediments and post-Provo alluvial fan deposits is 10 to 11 meters down to the west across the main fault scarp and graben. The unconformity has a maximum age of 9000 to 12,000 years. The post-Provo alluvial fan surface, estimated to be 6000 years old, is displaced approximately the same amount.

2. At least three episodes of surface faulting that have been associated with large earthquakes have occurred along this trace of the fault in post-Provo time. The oldest recognized event(s) tilted the post-Provo alluvial fans, resulting in the formation of a sag that was subsequently filled by a bedded sequence of sand, silt, and gravel. The next event tilted these deposits toward the main fault, and the sag filled with additional pond, alluvial and colluvial deposits. The most recent event produced a graben but did not produce tilting toward the range.

3. Stratigraphic relationships suggest that the most recent event may have occurred within the past few hundred years. A radiocarbon date of 1580 $\pm$ 150 years B.P. has been obtained on detrital charcoal from the bedded silt-sand-gravel sequence. The two most recent events of surface faulting have occurred subsequent to deposition of the charcoal. The interval between these two events is probably 500 to 1000 years.

4. Preliminary analysis of the relationship between the main fault and the scarp-derived colluvium suggests that the amount of tectonic displacement during at least some of the past events at this locality was several meters, indicating that earthquakes of magnitude 7, or larger, have occurred along this segment of the fault.

In addition to these conclusions, the following observations were made at the Kaysville site; these observations affect geologic interpretations of amount of tectonic displacement

per event and recurrence intervals of surface faulting:

1. Back-tilting of the downthrown block toward the main fault may have increased the vertical stratigraphic separation across the main fault plane by as much as a factor of 2, relative to the true tectonic displacement. This phenomenon should be considered in developing estimates of earthquake magnitudes based upon fault displacement.

2. The most recent surface faulting along this segment of the Wasatch fault produced a series of grabens bounded by en echelon, antithetic faults. This represents a change in the pattern of surface faulting.

3. Detailed study of sequences of scarp-derived colluvium provides a useful technique for evaluating recurrence of surface faulting.