STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT AT THE KAYSVILLE SITE, 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 km 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 m, 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 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).

Based upon the historical seismicity between 1932 and 1961, Smith (1972) suggested that an earthquake of magnitude 7 could occur approximately every 76 years in the Wasatch Front area. 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 several of these sites 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. This report presents the findings, interpretations, and conclusions based on this work.

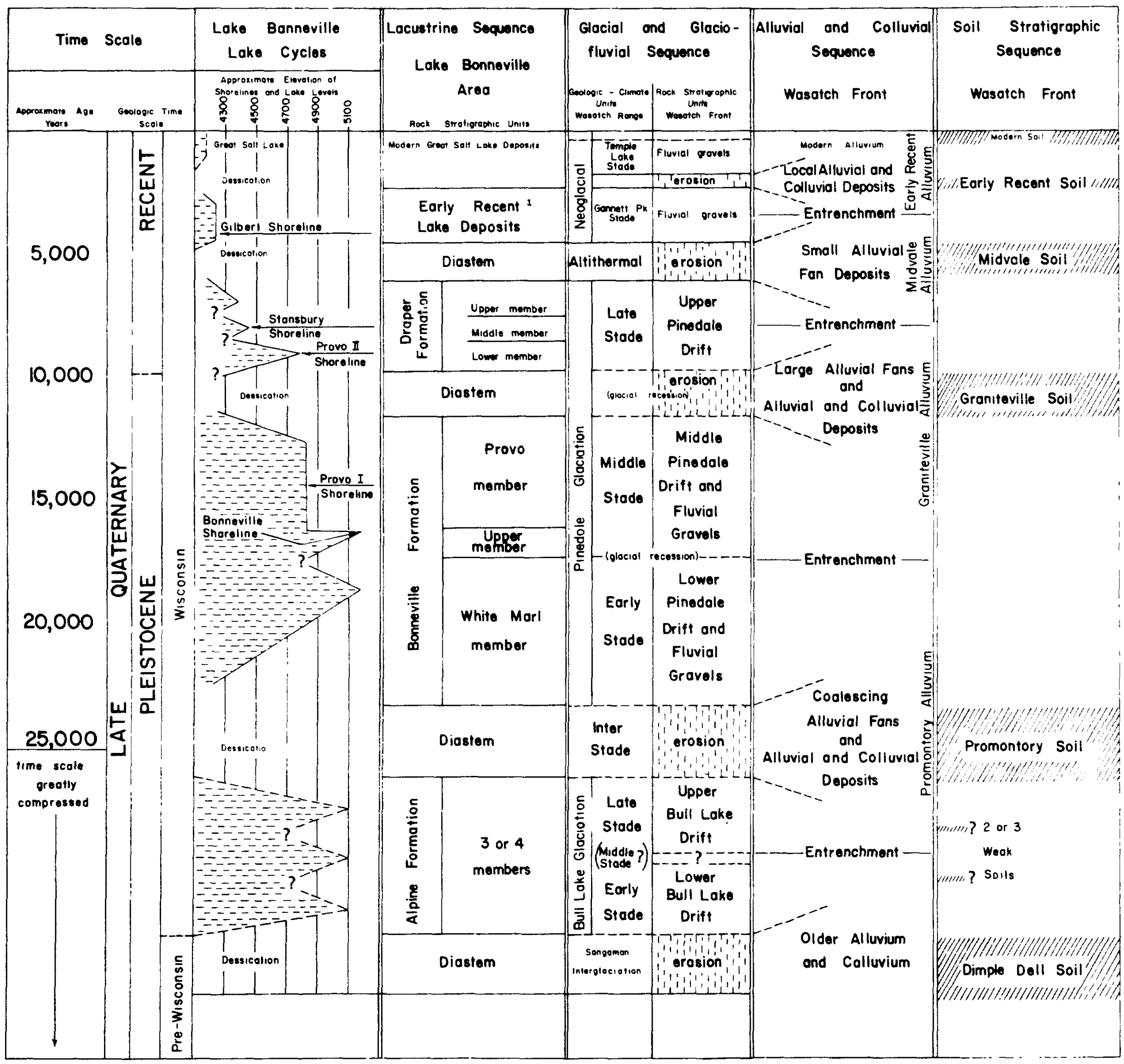
LOCATION AND SETTING OF THE KAYSVILLE SITE

The Kaysville site is located between Baer Creek and Shepard Creek, approximately 3 km 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 graben occurs along this segment of the Wasatch fault (Figure 3). In the northern part of the site area these graben are bounded by a prominent west-facing fault scarp (Figure 13a) on the east and by a series of en echelon antithetic fault scarps on the west (Figure 13b). The height of the main fault scarp decreases from 22 m in the central part of the site area to less than 10 m 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 m west of the main scarp (Figure 3). The antithetic fault scarps (Figure 15) vary in height from less than 1 m to 2.5 m.

Trenches and test pits were excavated across the southern end of a closed depression that occurs in the graben in the

CORRELATION CHART

Late Quaternary Stratigraphic Sequences — Wasatch Fault Region



Source: Woodward-Clyde Consultants, 1975
(Modified from Bissel, 1963; Morrison, 1965; and Richmond, 1964)

1 Proposed Ridgeland Formation - Van Horn, Personal Communication

Table 1 – STRATIGRAPHIC CORRELATIONS FOR WASATCH FAULT SYSTEM

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 ephemeral 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 m. It is below the Bonneville and Provo shorelines (Figures 3, 4, 12, and 13). Lacustrine sediments deposited during 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 surface down to the west across the main fault scarp and graben.

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 subdued nature of these features and man-made modifications such as roads and powerlines make it difficult to determine if these breaks in slope are faults or recessional shorelines.

The Wasatch Range along this segment of the fault rises steeply eastward to an elevation of over 2750 m in a horizontal distance of 3.2 km. 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 by Gary A. Carver and John C. Young during a previous 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 ground water 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 - Photogeologic interpretation and field mapping from Baer Creek to Shepard Creek 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.

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 m to 1100 m. 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 to 6 m 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 m in length and varying in depth from 2 to 6 m were excavated. Approximately 160 m of trench (excluding trench C) were logged in detail at a scale of 1:20 (5 cm = 1 m). Trench locations are shown on Figure 3; logs of these trenches shown at a reduced scale are presented 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 Pleistocene high stands of 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 m. Evidence for a lake rise 10,000 years ago to 1450 m (Provo II stage on Table 1) has been reevaluated by William E. Scott (1979) and it is unlikely that the

Kaysville site was inundated at that time. Therefore, the lake deposits at the site are probably older than approximately 12,000 y.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 m west from the mountain front (Figure 13). Adjacent to the main fault scarp on the upthrown block the alluvial fan deposits are 11 m thick. On the downthrown block immediately west of the graben they are 4.4 m thick, and they continue to thin westward to the edge of the fan where they are less than 2 m 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 y.b.p. (recession of Provo stage of Lake Bonneville). 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 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 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 m at the trench site to less than 10 m towards the apex of the fan. Subsequent faulting of the fan is evidenced by pronounced graben on the south flank and at the apex of the fan. These graben 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 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 ± 150 y.b.p. The silt layer containing the charcoal is 47 cm 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 m 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 cm 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 m) layer of clayey silt exposed in the middle of the sag in trench A (26 to 32 m 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 cm 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.

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. This unit has subsequently been buried by deposits that are historical in age.

Historical deposits (unit 8). Following settlement of this area after 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 cm thick A horizon overlying a 20 cm 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, personal communication). This suggests the soil began to form approximately 6000 years ago.

Alluviated soil (soil S2). A weakly developed cumulative transgressive 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 ground-water 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 to 10 cm) 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 m 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 m 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 m, Plate 2). In trench A the fault is a zone that strikes N2E and varies in dip from 74 to 55 degrees west. The zone widens from 10 cm near the base of the trench to 40 cm near the surface. The fault zone is bounded on the east by a well defined plane. The eastern part of the zone (4 to 30 cm wide) consists of poorly sorted, pebbly, fine to coarse sand containing 10 to 15 percent subangular and subrounded pebbles up to 3 cm 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 to 8 cm 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 and 3 m 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 to 50 cm 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 to 64 degrees west. The fault zone is bounded on the east by a well defined 1.5 cm-wide reddish brown sandy clay seam. Material within a 3 to 5 cm-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 cm-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 m 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 cm to an observed maximum of 25 cm. 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 cm) 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 distinctive gouge.

A fault oriented N5E, 78W occurs 3.5 m 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 cm 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 m 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 m 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 graben. 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 cm.

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 cm 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 graben 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 to 150 cm and in width from 10 to 86 cm. 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 m 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 m down to the east across this fault. A wedge of organic-rich material 15 to 25 cm 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 to 10 cm-wide zone of grayish black pebbly sand, displaces post-Provo alluvial fan deposits 44 cm down to the east. Fan deposits are also downdropped 9 cm across two small graben located 1 and 2 m 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 m 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 to 26 cm 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 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 m of the main scarp these deposits have been rotated as much as 8 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 to 6 degrees to the east across a zone that extends 38 m 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 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 ± 150 y.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 graben 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 m 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 to 11 m 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 m; 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 to 3.7 m 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 colluvial units. Geometrical relationships suggest that tectonic displacement during the most recent surface faulting event may have been approximately 2 m. 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 is 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 m. 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 m. Total displacement across the antithetic faults was 2.2 m 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 m.

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 m. 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 m.

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 to 11 m of tectonic displacement, tectonic displacement associated with the oldest event recognized at the site would have to be 5 to 8 m. 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.

The data indicate a range in values of between 1.7 and 3.7 m for the 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 suggest 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 to 11 m 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. The post-Provo alluvial fan surface is displaced approximately the same amount. This surface is older than soil S1; formation of this soil is estimated to have begun approximately 6000 years ago. These observations indicate that the 10 to 11 m of vertical tectonic displacement may have occurred within the past 6000 years.

A radiocarbon age of 1580 ± 150 y.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 m 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 y.b.p. less the time it took to deposit at least 1.6 m 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 cm-thick pond deposit (unit 7) and 35 to 40 cm of historical (post 1847) 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 to 11 m 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 km 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 to 11 m down to the west across the main fault scarp and graben. This unconformity has a maximum age of 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 ± 150 y.b.p. has been obtained on detrital charcoal from 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 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 graben 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.

ACKNOWLEDGMENTS

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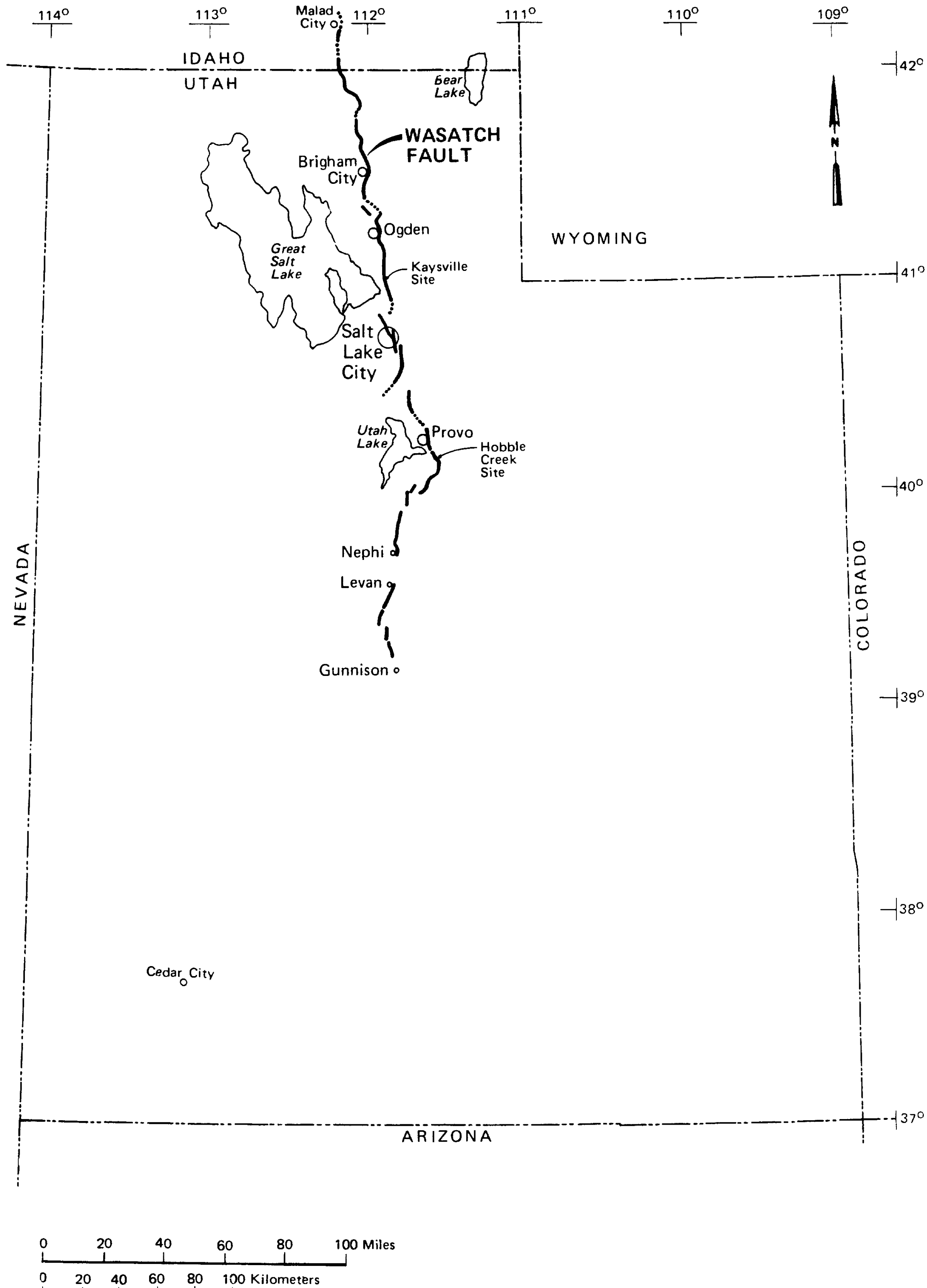
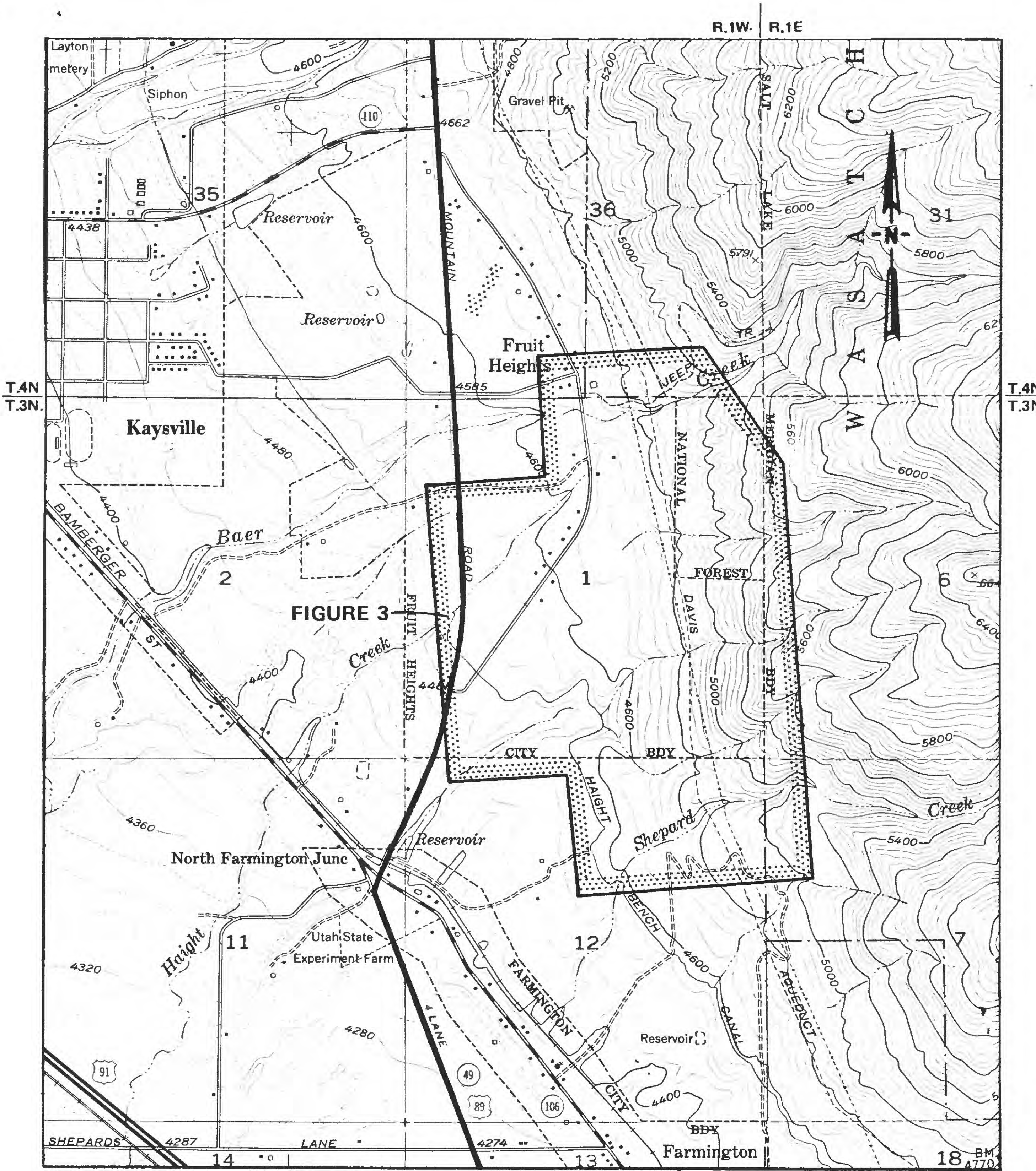


Figure 1 - REGIONAL LOCATION MAP



0 1 MILE

0 1 KILOMETER

Map source: USGS 7½' quadrangle, Kaysville, Utah

Figure 2 - LOCATION MAP OF KAYSVILLE SITE

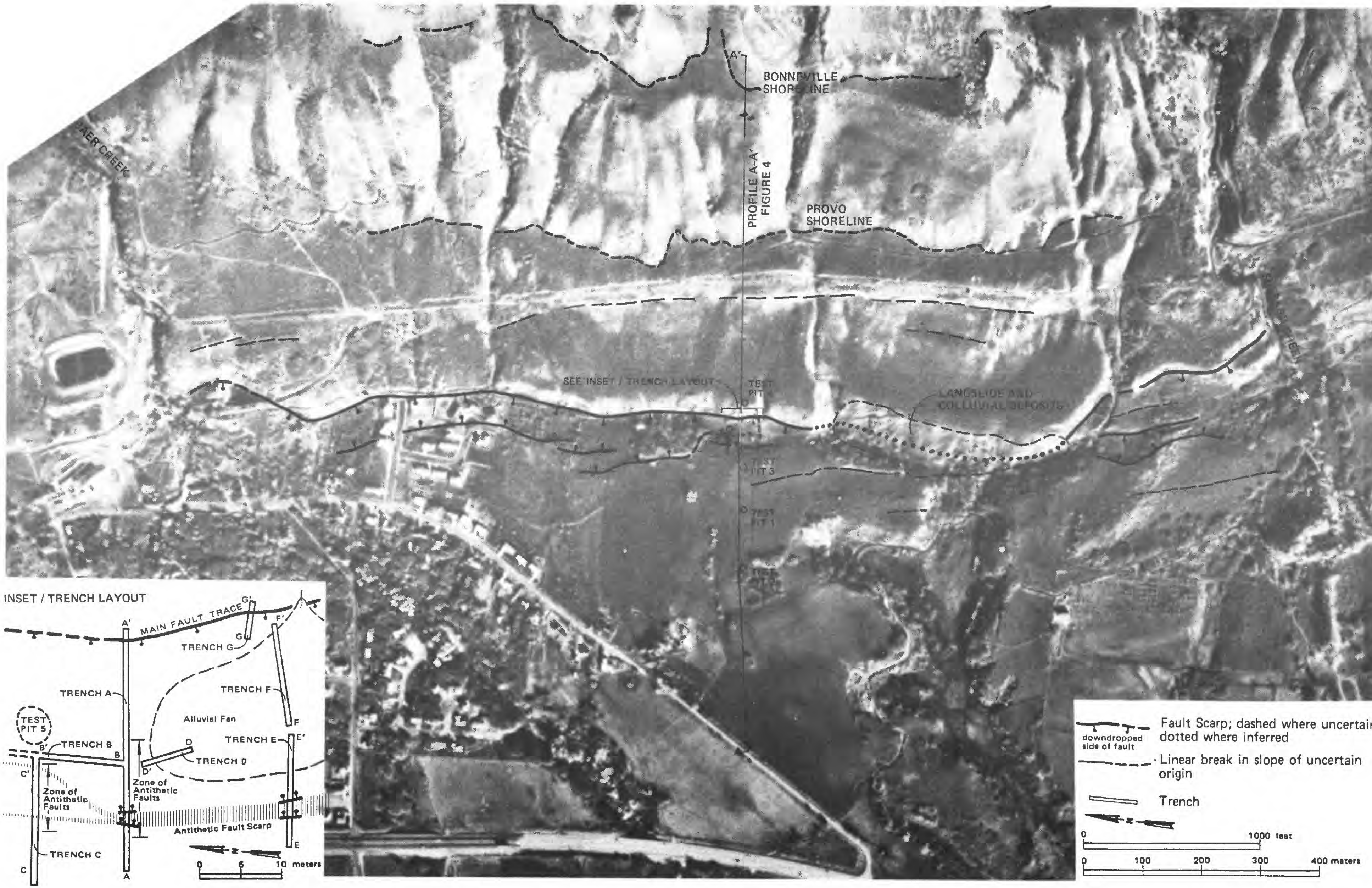


Figure 3 - PHOTOGEOLOGIC MAP OF THE KAYSVILLE SITE

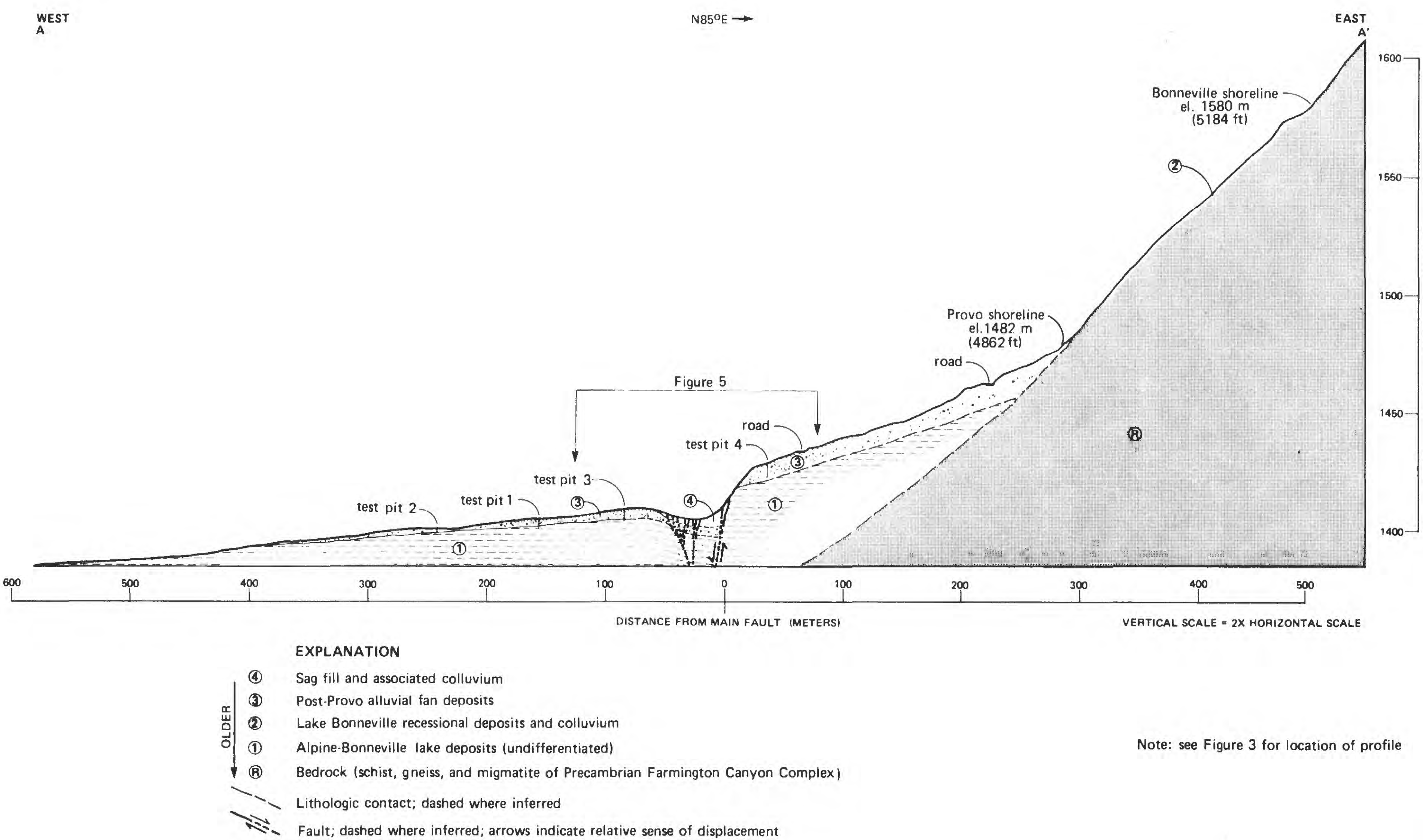
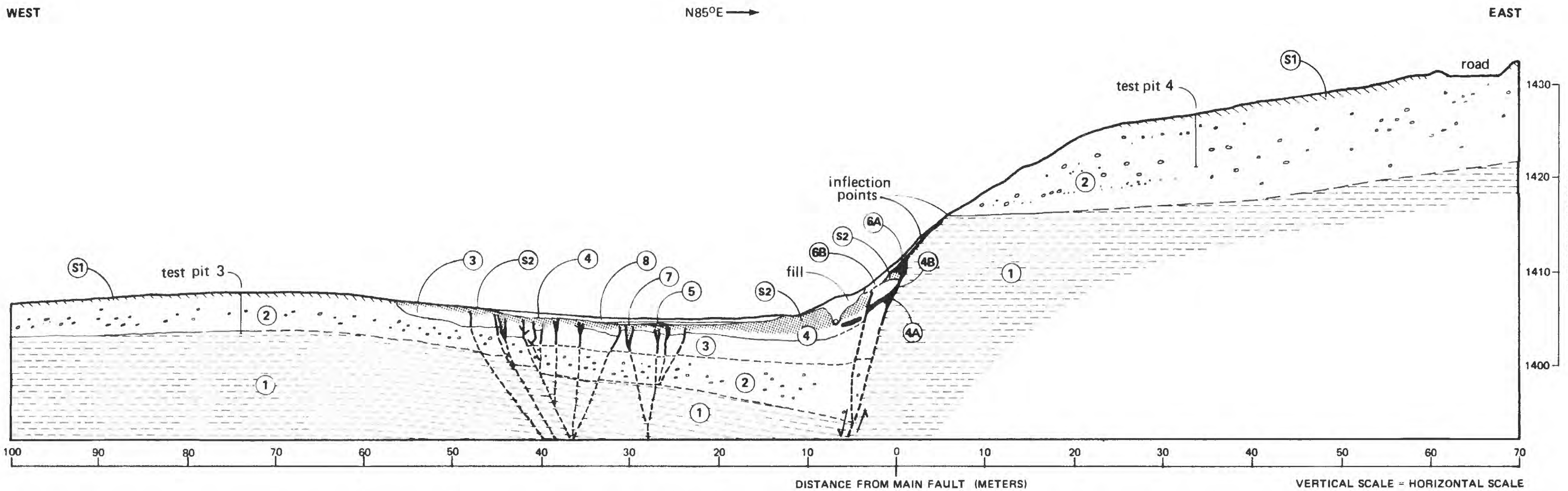


Figure 4 — GEOLOGIC CROSS SECTION OF KAYSVILLE SITE ALONG A–A'



EXPLANATION

LITHOLOGIC UNITS

(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)

OLDER

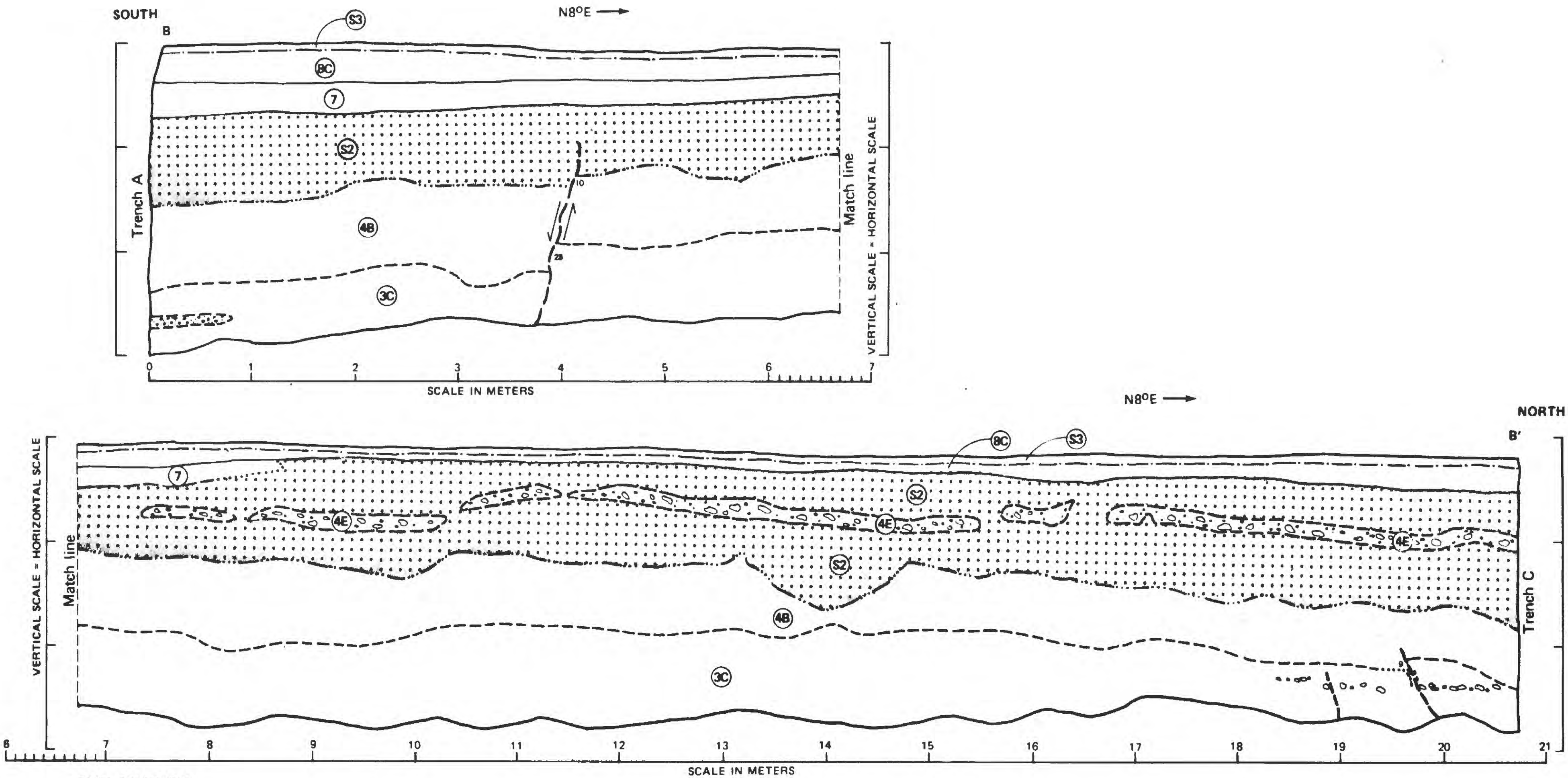
SOIL UNITS

(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

Figure 5 — GEOLOGIC CROSS SECTION OF GRABEN AT THE KAYSVILLE SITE



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

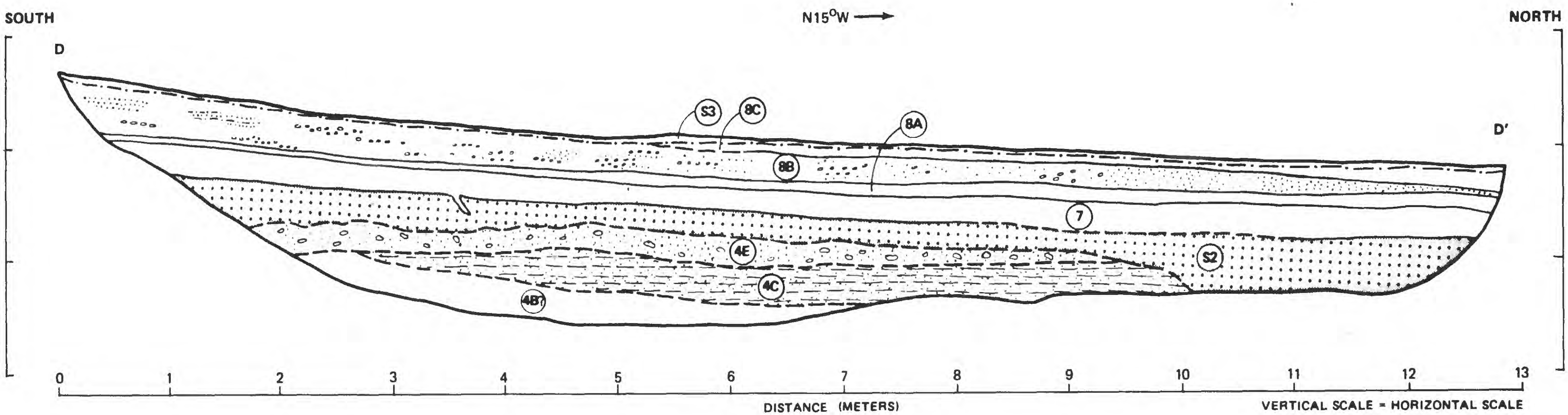
—··— Soil boundary; gradual, transition zone is between 6 and 12.5 cm thick

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

Figure 6 - LOG OF TRENCH B KAYSVILLE SITE



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

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

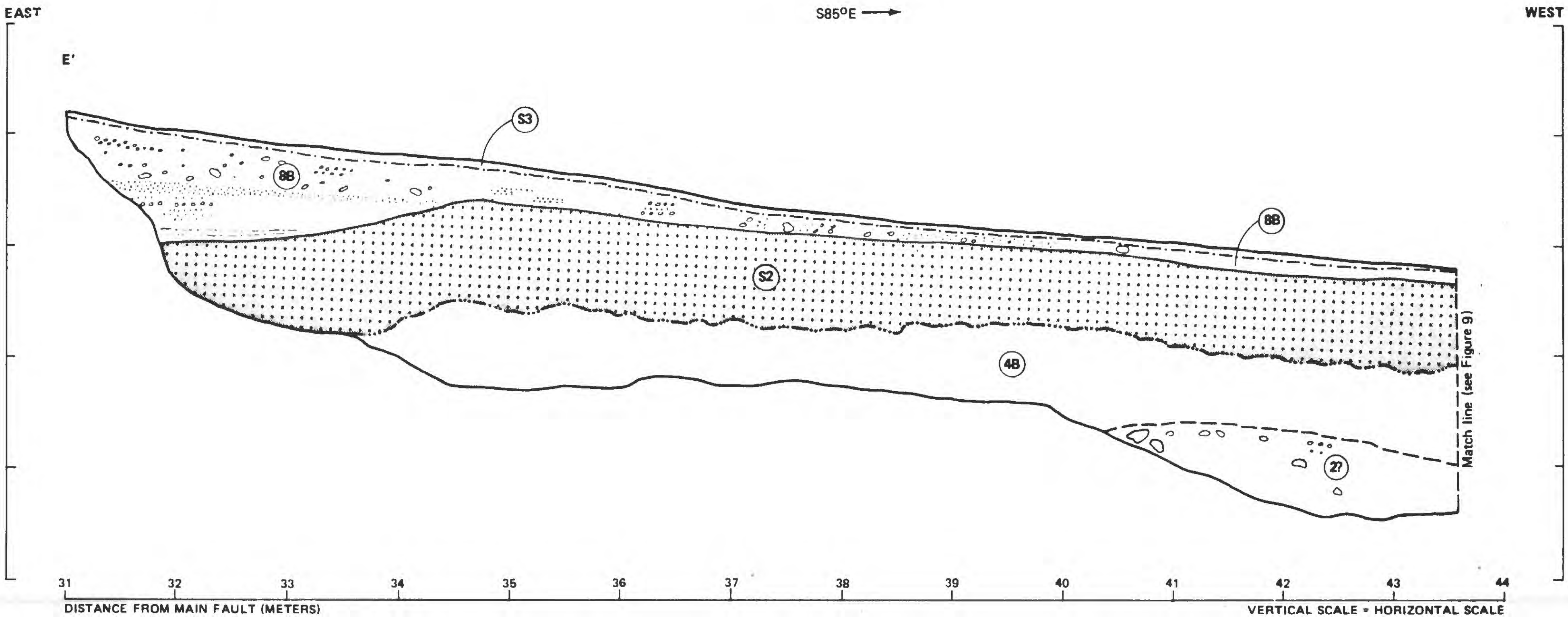
- (S3) Topsoil
- (S2) Alluviated soil

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

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

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

Figure 7 - LOG OF TRENCH D KAYSVILLE SITE



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

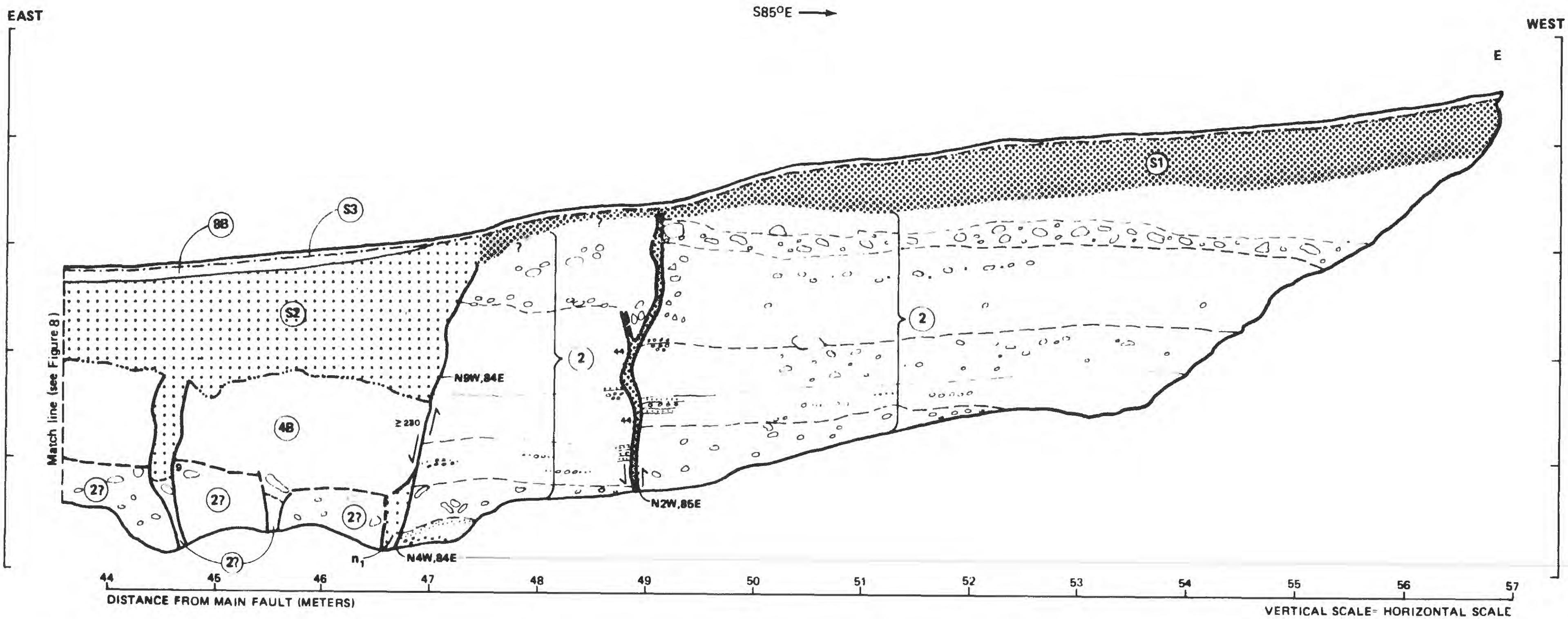
- Lithologic contact; dashed where less distinct
- Soil boundary; abrupt, transition zone is between 1mm and 2.5 cm thick
- Soil boundary; gradual, transition zone is between 6 and 12.5 cm thick
- Fault trace: solid line where well defined; dashed where less distinct; bold numbers indicate strike and dip of fault plane; small numbers indicate stratigraphic separation in cm; arrows indicate relative sense of displacement

N2E, 60W

6

Note:
n_1 Gravelly sand containing carbonacious material

Figure 8 - LOG OF TRENCH E KAYSVILLE SITE, SHEET 1



Note: See Figure 8 for Explanation

Figure 9 - LOG OF TRENCH E KAYSVILLE SITE, SHEET 2

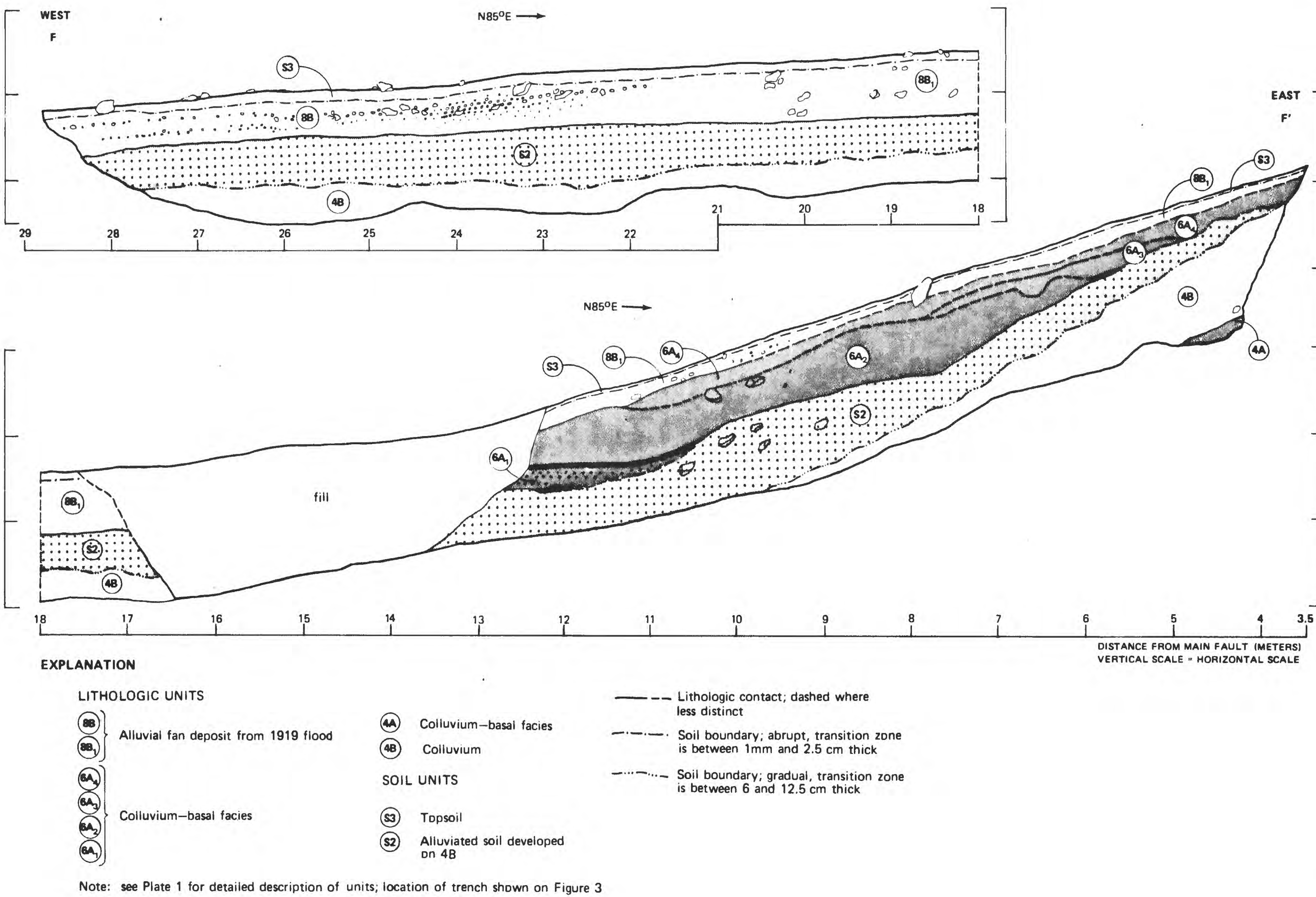


Figure 10 - LOG OF TRENCH F KAYSVILLE SITE

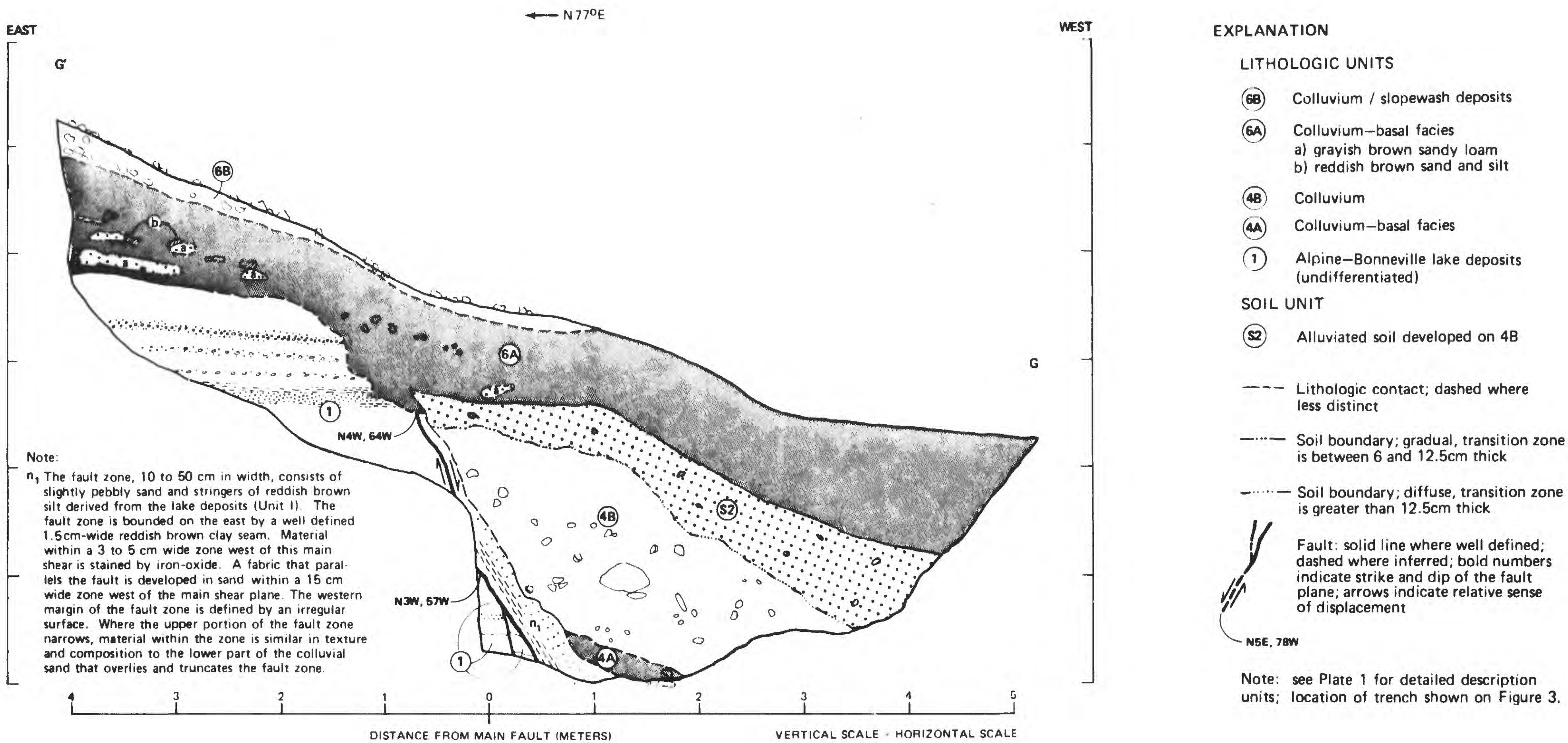
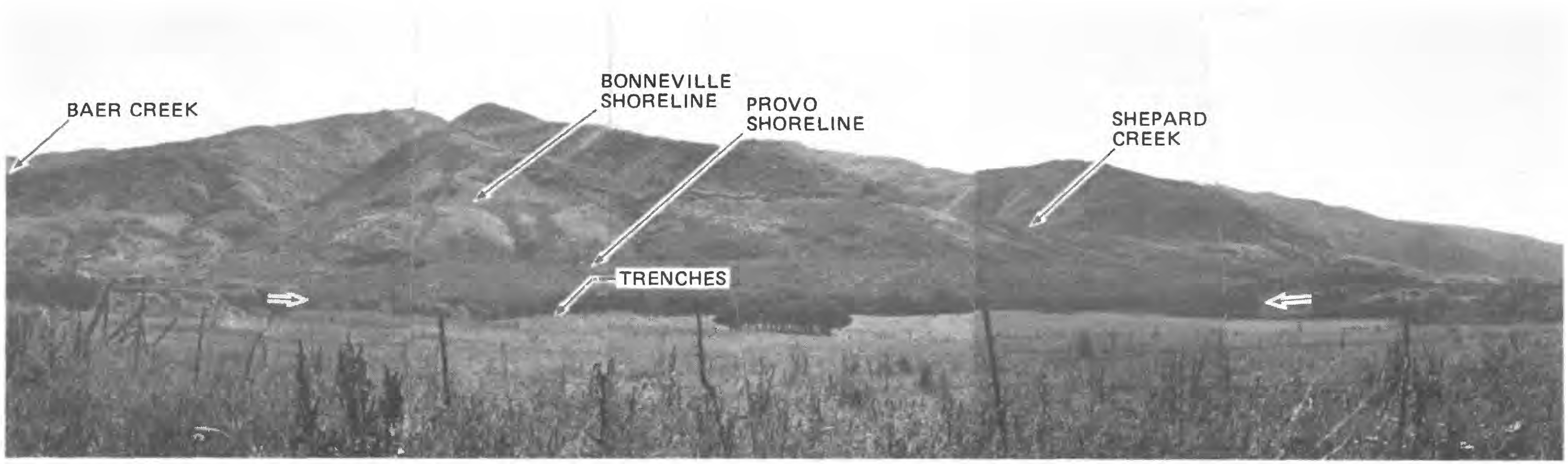


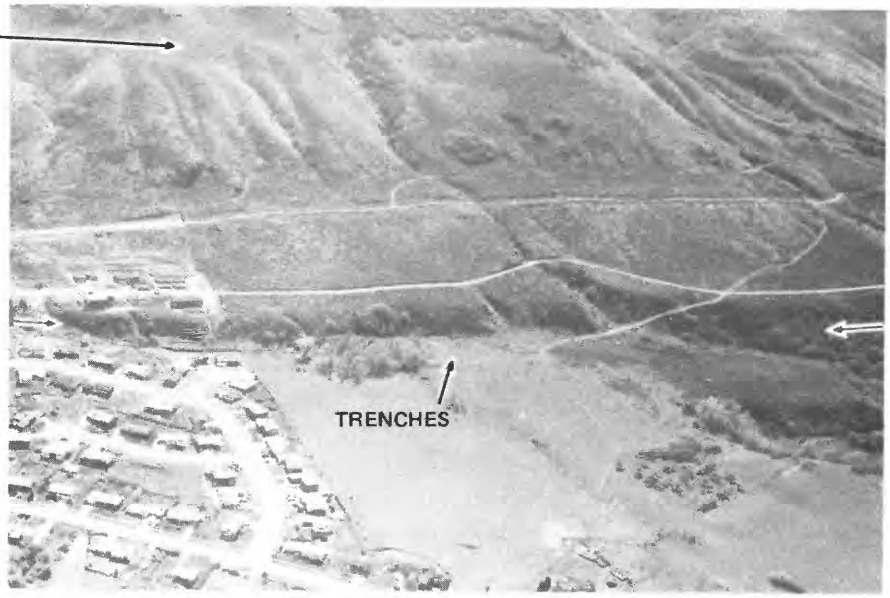
Figure 11 - LOG OF TRENCH G KAYSVILLE SITE



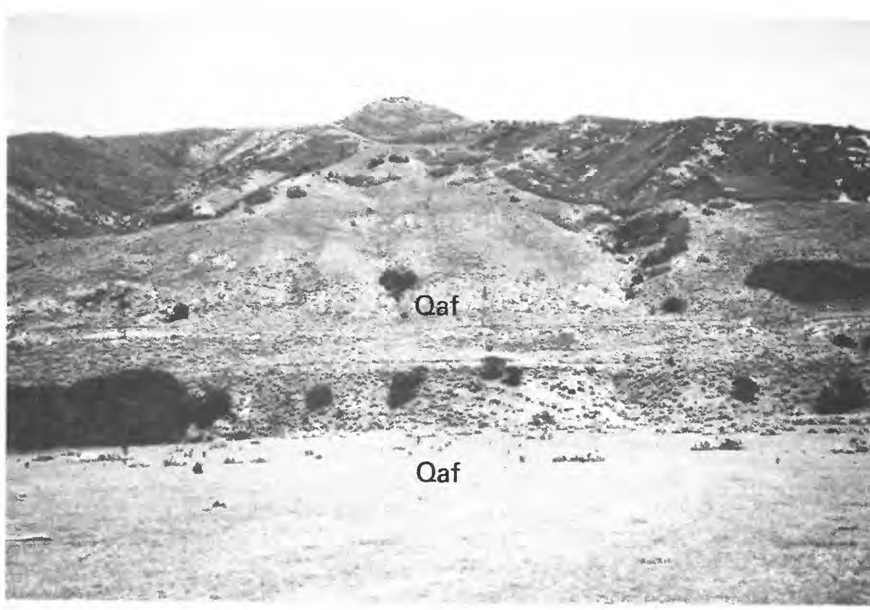
Panoramic view of Wasach Front between Baer Creek and Shepard Creek near Kaysville, Utah, showing the recent fault scarp (arrows) and location of trenches

Figure 12 - PHOTOGRAPH SHOWING WASATCH FRONT NEAR KAYSVILLE, UTAH

BONNEVILLE SHORELINE



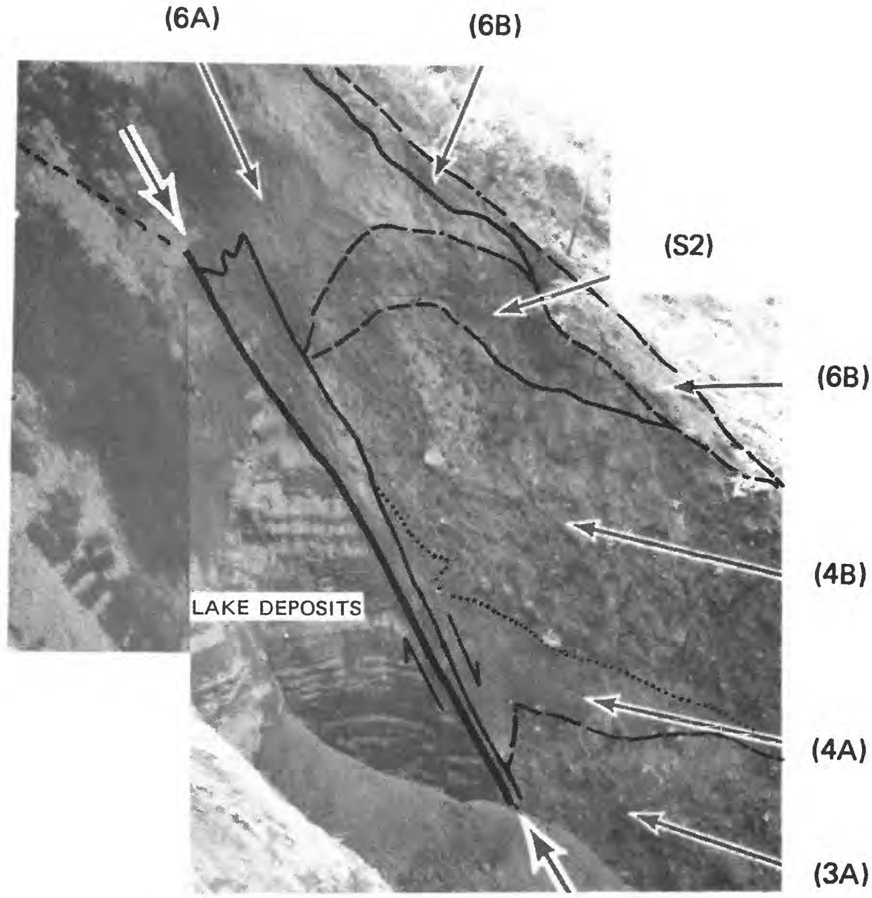
(a) Aerial view of main fault scarp, (arrows), and associated graben at Kaysville Site.



BONNEVILLE SHORELINE

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

Figure 13 - PHOTOGRAPHS SHOWING RECENT FAULT SCARP AT KAYSVILLE



Main fault, (arrows), exposed in the south wall of Trench A, Kaysville site. The two lower colluvial units, (3A and 4A-B), and a soil (S2), are in fault contact with well bedded lake deposits. The upper colluvial unit, (6A), which formed subsequent to the most recent displacement, is in depositional contact with the fault scarp. See Plates 1 and 2 for descriptions of these units.

Figure 14 - PHOTOGRAPH SHOWING MAIN FAULT EXPOSED AT KAYSVILLE SITE

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

Figure 15 - PHOTOGRAPH SHOWING ANTITHETIC FAULT SCARPS AT KAYSVILLE SITE