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INTRODUCTION

There is abundant geomorphic and geologic evidence that indicates large earthquakes have occurred repeatedly along the Wasatch fault zone throughout the late Pleistocene and Holocene (Gilbert, 1890; Cluff and others, 1970, 1973, 1974, 1975). However, no earthquakes associated with surface fault rupture are known to have occurred along the Wasatch fault during historical time (Cook, 1972; Cook and Smith, 1967; Smith and others, 1978). Detailed geologic mapping and subsurface investigations are being conducted at selected sites along the Wasatch fault zone to measure fault displacements in strata that can be dated or correlated with dated units, and to obtain data regarding the amount of displacement per event and the number of faulting events on individual segments along the fault zone. These data are used to estimate the magnitude and frequency of recurrence of earthquakes associated with surface faulting along this segment of the Wasatch fault zone.

During the spring of 1978, detailed geologic mapping and subsurface investigations were completed at the Kaysville site, which is located 30 km north of Salt Lake City (Figure 1). The results of the investigations at the Kaysville site are described by Swan and others (1978). Based on stratigraphic and structural evidence observed in the trenches excavated across the main fault scarp and associated graben, the interval between surface faulting events along that segment of the fault is estimated to be between 500 and 1000 years. At least some of the events produced earthquakes of magnitude 7 or larger.

Detailed geologic mapping, topographic profiling, and subsurface investigations were conducted at a second site, the Hobble Creek site, during October, 1978 (Figure 1). This report presents the findings, interpretations, and conclusions of the investigations at the Hobble Creek site.

LOCATION AND SETTING OF THE HOBBLE CREEK SITE

The Hobble Creek site is 4.8 km east of the town of Springville in Utah County, Utah (Figures 1 and 2). It is located on the eastern margin of Utah Valley where the west-flowing Hobble Creek leaves the Wasatch Range.

In this area the Wasatch fault zone is characterized by a prominent fault scarp associated with the main trace of the fault, several small graben, and wide zones of back-tilting of the downthrown block towards the main fault scarp (Figure 10).

Sediments deposited during high stands of Lake Bonneville are exposed in the fault scarp and terrace escarpments. Geomorphic surfaces associated with these deposits are displaced down-to-the-west across the fault zone; cumulative tectonic displacements of these surfaces and deposits are progressively greater with increasing age (Figure 10b). Complex alluvial fans that consist of several fan segments occur in several places along the range front. The segmentation of these fans is the result of repeated slip along the fault.

Three trenches were excavated across the main fault trace and an associated graben 0.96 km northwest of the mouth of Hobble Creek (Figures 2 and 3). The graben at this location is 50 to 65 m wide. It is bounded on the northeast by the main fault scarp and on the southwest by a series of antithetic fault scarps. The graben cuts deposits of a large alluvial fan complex at the mouth of Deadmans Hollow. The main fault scarp has been partly buried by younger fan deposits, and the height of the scarp decreases southeastward from 15 m to 11.8 m near the apex of the young fan segment. The main antithetic fault scarp at this location is approximately 140 m long and progressively decreases in height from a maximum of 1.5 m to less than 0.5 m before it dies out to the southeast (Figure 11).

Paleozoic rocks of the Oquirrh Formation crop out along the mountain front. These rocks consist primarily of calcareous to quartzitic sandstone and contain some beds of limestone and cherty limestone. Soils developed on sediments derived from these formations tend to be more calcareous than soils on similar surfaces elsewhere along the Wasatch Front having less calcareous parent material.

PREVIOUS WORK

Possible active traces of the Wasatch fault in the vicinity of Hobble Creek 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 an investigation for the U.S. Geological Survey, in which the Hobble Creek site was selected for more detailed investigation (Woodward-Clyde Consultants, 1975).

The Quaternary deposits of the northern part of Utah Valley were mapped by Hunt and others (1953). The southern part of Utah Valley was mapped by Bissell (1963). The soils in the central part of Utah County have been mapped by the U.S. Department of Agriculture (1972).

METHODS OF STUDY

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

1. Detailed Surface Mapping - Based on photogeologic interpretation and field studies, late Quaternary stratigraphic units and selected geomorphic surfaces were mapped along and adjacent to the fault zone in the vicinity of Hobble Creek Canyon at a scale of approximately 1:7000. This mapping provided data on the location of possible faults, and the relative age and correlation of stratigraphic units and geomorphic surfaces. Mapping was also used as a guide to locate trench sites and was, in turn, supplemented and refined by data from the trenches. The photogeologic map is shown at a reduced scale on Figure 3; descriptions of map units and a correlation chart of map and trench units are presented on Plate 1.

2. Topographic Profiling - Longitudinal topographic profiles across the main fault scarp, antithetic fault scarps, and adjacent geomorphic surfaces were measured using hand level, Brunton compass, and tape. The profiles, in conjunction with trenching and mapping data, are used to assess cumulative displacements of different age surfaces across the fault zone; to examine the amount and extent of back-tilting; and to examine the relationship between faulting and scarp morphology. In addition, several transverse profiles were made at the mouth of Hobble Creek Canyon to assess the number and origin of a series of strath terraces on the upthrown block east of the main fault. The topographic profiles are presented on Figures 4, 5, and 6; the locations of the profiles are shown on Figure 2.

3. Trenching - Three trenches totaling 175 m were excavated using a backhoe to expose the structural and stratigraphic relationships along the fault scarp and graben (Figures 2 and 3). Trench HC-1 extended across the main fault and associated graben; it was 150 m long and varied in depth from 3 to 5 m. Trench HC-1 was logged at a scale of 1:20 (5 cm = 1 m); the part of the trench extending from the main fault scarp to the main antithetic fault scarp is shown at a reduced scale on Plate 2. Descriptions of the trench units and correlations of these units with the map units are on Plate 1. Two shorter trenches, trenches HC-2 and HC-3, were excavated across the main fault and antithetic fault scarps, respectively. These trenches exposed relationships similar to the ones exposed in trench HC-1.

RESULTS OF MAPPING AND SUBSURFACE INVESTIGATIONS

QUATERNARY STRATIGRAPHY

The Quaternary deposits mapped at the Hobble Creek site consist of lake, fan-delta, and nearshore sediments deposited during late Pleistocene high stands of Lake Bonneville; loess and reworked loess sediments; alluvial fan deposits; and Holocene alluvium and colluvium. The areal distribution of these deposits is shown on the photogeologic map of the Hobble Creek site (Figure 3). The trenches were excavated across the fault contact between Provo fan-delta deposits and Holocene fan deposits along the northwest margin of the Deadmans Hollow fan complex. The stratigraphic and structural relationships of the deposits at the Hobble Creek site are shown on geologic cross sections J-J' and K-K' (Figures 4 and 5) and the log of trench HC-1 (Plate 2). Correlations and detailed descriptions of lithologic units shown on the photogeologic map and the log of trench HC-1 are given on Plate 1. The major stratigraphic units mapped at the Hobble Creek site and observed in the trenches are discussed below.

Lithologic Units on Photogeologic Map

Alpine-Bonneville Lake Deposits (undifferentiated) (Qab) and Bonneville Lake Deposits (Qb). The oldest Quaternary deposits mapped at the Hobble Creek site consist of lake sediments deposited during the last major Pleistocene high stand of Lake Bonneville. In the northern half of Utah Valley, Hunt (Hunt and others, 1953) divided these sediments into three formations: the Alpine Formation (oldest), the Bonneville Formation, and the Provo Formation (youngest). Together, these formations are referred to as the Bonneville Group. As defined by Hunt, these formations are lithostratigraphic units. Bissell (1963) modified Hunt's definitions of these formations slightly and extended the mapping to the southern half of Utah Valley. As defined by Bissell, these formations are chronostratigraphic units.

Chronostratigraphic units are more useful for assessing recurrence intervals along faults. However, Bissell's nomenclature has not been completely adopted because his evidence for a major interval between deposits that he mapped as Alpine Formation and Bonneville Formation in the vicinity of Hobble Creek is equivocal.

In the Hobble Creek area Bissell (1963) measured a section of Alpine and Bonneville deposits over 100 m thick. The Alpine sediments consist predominantly of thinly bedded, laminated silt and clay; gravel and sand are common locally. These deposits are well sorted and stratified. These deposits extend to a maximum elevation of approximately 1555 m, which marks the high stand of the Alpine age lake according to

Bissell. The prominent bench at this elevation (Bonneville shoreline) is interpreted by Bissell (1968) to have been formed during the Alpine lake cycle and only occupied briefly during the later Bonneville lake cycle. This bench is generally underlain by cobble and boulder gravel that is coarser and less well-sorted than the underlying lake deposits. These gravel deposits are generally thin (less than 11 m) and occur as discontinuous remnants along the Bonneville shoreline at an elevation of approximately 1566 m. Bissell (1963) maps the well-sorted lake deposits as Alpine Formation and these coarser gravels as Bonneville Formation.

Bissell (1963) states that, locally, the Alpine and Bonneville Formations are separated by a disconformity, subaerial deposits, and a submature soil. Stratigraphic relationships between these deposits are well exposed in the sides of gullies that are eroded into the Alpine-Bonneville bench between Hobble Creek and Maple Canyon; these relationships are shown on geologic cross section K-K' (Figure 5). Evidence for a major disconformity between the Alpine sediments and Bonneville gravel is not apparent in these exposures. It might be argued, therefore, that rather than representing separate lake cycles, the Bonneville and Alpine Formations may be deep water (Alpine) and shallow water (Bonneville) facies of a single lake cycle. Scott (1979) suggests that this situation may exist at many places along the Wasatch Front.

These different interpretations affect the ages that would be assigned to these deposits. Therefore, an informal nomenclature has been adopted for this report: the thick sequence of well-sorted lake deposits that predate Provo-age deposits are referred to as Alpine-Bonneville lake deposits (undifferentiated) [Qab on Figure 3], which reflects the uncertainty in their age, and the coarser poorly sorted gravels that overlie these lake deposits and underlie the Bonneville bench are referred to as Bonneville gravel (Qb on Figure 3).

The ages of the Alpine and Bonneville Formations are uncertain. Morrison and Frye (1965) summarized significant dates to outline the major events in Alpine-Bonneville time as follows: 20,600 ± 500 and 20,800 ± 300 y.b.p. are C14 dates for the transgression of the white marl member of the Bonneville Formation at Little Valley, Promontory Point; and 15,300 ± 300 is a C14 date for the transgression of the later cycle of Bonneville Formation time, i.e., the lake cycle that rose to the Bonneville shoreline. Radiometric dates from the upper part of the Alpine Formation (Morrison, 1965) suggest these deposits are early Wisconsinan (approximately 70,000 y.b.p. to about 28,000 y.b.p.). Subsequent correlations proposed by Morrison (1975) suggest the Alpine Formation is pre-Wisconsinan in age; this interpretation is not consistent with the radiometric dates cited in his earlier paper (1965).

Provo Fan-Delta Deposits (Qp). Gravel deposits of Provo-age crop out in places along the main fault scarp and along terrace escarpments that parallel Hobble Creek. The deposits consist primarily of interbedded sandy gravel, gravelly sand, and gravel. Most of the gravel is coarse, containing numerous cobbles and boulders, but layers of pebble sand and fine sand occur locally. Individual beds vary from well sorted to poorly sorted; layers of pebble gravel and pebbly coarse sand are generally better sorted than the sandy cobble and boulder gravel. Beds of open-work gravel occur in places. The deposits vary from crudely stratified to well bedded and graded bedding occurs locally. The pebbles, cobbles, and boulders are generally rounded to well rounded.

At least two distinct beds of massive to finely laminated silt and fine sand are intercalated in the predominantly gravel sequence. Thicknesses of these silt layers vary from less than 10 cm to more than 1 m. Lenses of fine cross-bedded sand occur in places.

The Provo gravel deposits are mapped by Bissell (1963) as a composite delta built by Hobble Creek, Spring Creek, and nearby smaller streams. Bissell states that the shape of the delta, internal structure, and textural distribution indicate strong northwestward flowing littoral currents. Between the mouth of Hobble Creek Canyon and the trench site, steep fore-set bedding characteristic of deltaic deposits are not observed. The structure of these gravel beds is more typical of alluvial terrace deposits, and it appears that the increased sediment load of Hobble Creek was deposited in an alluvial fan-delta complex rather than a typical deltaic environment. A slowly receeding lake environment would be conducive for formation of such a fan-delta complex. Inter-bedded lacustrine silts within the gravel deposits indicate that although there was a net lowering of the lake, there were temporary fluctuations that resulted in higher lake levels at times.

Radiocarbon dates from post-Provo material near Delta, Utah and from Danger Cave indicate that recession of Lake Bonneville from the Provo level occurred prior to approxi-mately 12,000 y.b.p. (Morrison and Frye, 1965; Jennings, 1957). A moderately developed relict paleosol (A/B/Cca profile) has formed on the Provo fan-delta surface (Table 1).

Strath Terraces (t_b; t_g; t_k; t_p). There is a sequence of three paired strath terraces and one unpaired terrace that are eroded into the Provo fan-delta deposits near the mouth of Hobble Creek Canyon east of the main trace of the Wasatch fault (Figure 3). The terraces are below the Provo terrace, which is 25 to 28 m above Hobble Creek, and above a terrace underlain by post-Provo pre-Utah Lake alluvium (Qal_1), which is 4.5 to 5.5 m above Hobble Creek. Two transverse valley profiles that show these terraces are presented in Figure 8.

Table 1

Profile of Bingham gravelly loam, which is representative of soils formed on Provo age terraces (modified from U.S. Department of Agriculture, Soil Conservation Service, 1972).

HORIZON	THICKNESS (cm)	DESCRIPTION
Ap	15	Dark grayish-brown (10 YR 4/2; 3/2 moist) gravelly light loam; weak, medium, subangular blocky structure that parts to moderate, fine, granular; slightly hard, friable, slightly sticky, and plastic; many fine roots; common fine pores; clear, smooth boundary.
B21t	15	Brown (10 YR 4/3; 3/3 moist) gravelly sandy clay loam; moderate, medium, subangular blocky structure that parts to moderate, fine, granular; hard, firm, sticky, and plastic; common medium and fine roots; few fine pores; thin patchy clay films; gradual, wavy boundary.
B22t	16	Brown (7.5 YR 4/3; 3/3 moist) gravelly heavy fine sandy loam; moderate, medium and fine, subangular blocky structure; very hard, firm, sticky, and plastic; few fine roots; common medium and fine pores; thin patchy clay films; gradual, wavy boundary.
$IIB3_{ca}$	22	Brown (7.5 YR 4/3; 3/3 moist) very gravelly sandy loam; massive; soft, friable, slightly sticky, and slightly plastic; few fine roots; few interstitial pores; thin, occasional clay films; lime coating on gravel; gradual, wavy boundary.
IIC_{ca}	32	Dark-brown (10 YR 6/3; 4/3 moist) very gravelly sand; single grain; loose; nonsticky and nonplastic; few fine roots; interstitial pores; strongly calcareous; lime is disseminated and also appears as coatings on gravel.

From highest to lowest, these strath terraces are t_b, t_g, t_k, and t_p. Terrace t_b occurs on the south side of Hobble Creek 17.5 to 19 m above the thalweg of the creek. It is the only unpaired terrace in this sequence. Terrace t_g is 13.6 m above the creek. It is mapped only on the south side of Hobble Creek (Figure 3) because it is buried by thin alluvial fan deposits (Qf_1?) on the north side of the creek. Terraces t_k and t_p are 10.5 to 11.5 m and 8 to 8.5 m above the thalweg of Hobble Creek, respectively.

The paired terraces, and possibly even the unpaired terrace, are believed to be tectonic in origin. They only occur on the upthrown side of the fault. Each terrace probably represents incision of Hobble Creek into the upthrown block following a faulting event. The ages of the individual strath terraces are not known; however, the sequence of terraces is post-Provo and pre-Qal_1 in age (i.e., post about 12,000 y.b.p. and pre-middle Holocene or about 6,000 y.b.p.).

Post-Provo Pre-Utah Lake Deposits (Qal_1). Recession of Lake Bonneville below the Provo stage resulted in incision of the Provo fan-delta surface by Hobble Creek. The eroded material was subsequently redeposited as an alluvial fill and large alluvial fan (Qal_1) on which Springville is located. Bissell (1963) reports that the fan has a maximum thickness of about 12 m in its central part. He describes the fan gravel as poorly sorted boulder, cobble, and pebble gravel characterized by lenticular bedding. Redola loam and Pleasant View fine sandy loam are the predominant soil types occurring on the terraces and fan surfaces underlain by post-Provo pre-Utah Lake alluvium. These soils are not as well developed as the soils on the Provo terraces; they are characterized by A/C soil profiles (no textural B horizon) and they contain small amounts of carbonate compared to the soils on the Provo terraces. A representative profile of Redola loam is presented in Table 2.

Table 2

Profile of Redola loam, which is representative of soils formed on terraces underlain by post-Provo pre-Utah Lake alluvium along Hobble Creek (modified from U.S. Department of Agriculture, Soil Conservation Service, 1972).

HORIZON	THICKNESS (cm)	DESCRIPTION
Ap	20	Grayish-brown (10 YR 5/2; 3/2 moist) loam; weak, thin, platy structure in the uppermost inch or two, and weak, medium, subangular blocky below; hard, friable, slightly sticky, and slightly plastic; few, medium, fine and very fine roots; few, medium, fine and very fine, discontinuous pores; strongly calcareous; lime is disseminated; clear, smooth boundary.
C1	30	Grayish-brown (10 YR 5/2; 3/2 moist) loam, massive; hard, friable, slightly sticky, and slightly plastic; few, medium, fine and very fine roots; few fine and common very fine pores; moderately calcareous; lime is disseminated; gradual, smooth boundary.
C2	25	Grayish-brown (10 YR 5/2; 3/2 moist) light loam; massive; slightly hard, friable, slightly sticky, and slightly plastic; few, medium, fine and very fine roots; few, fine and common, very fine, discontinuous pores; moderately calcareous; lime is disseminated; gradual, wavy boundary.
C3	51	Grayish-brown (10 YR 5/2; 3/2 moist) very fine sandy loam stratified with thin lenses of coarse sand or gravelly coarse sand; massive; slightly hard, friable, slightly sticky, and slightly plastic; few fine and very fine roots; few fine and common very fine pores; moderately calcareous; lime is disseminated; clear, smooth boundary.
IIC4	25	Light brownish-gray (10 YR 6/2; 4/2 moist) gravelly coarse sand; single grain; loose, nonsticky, and nonplastic; few fine and very fine roots; slightly calcareous.

The terraces underlain by these deposits (Qal_1) are not generally subject to flooding. However, historical floods from Hobble Creek Canyon have inundated the Qal_1 terrace, and the surface has been modified in places by erosion and/or deposition.

The post-Provo pre-Utah Lake alluvium is probably correlative with deposits that are mapped as Draper Formation by Morrison in Salt Lake Valley, which he estimated to have been deposited between 10,000 and 6,000 years ago (Morrison, 1965, Figure 2). The Redola and Pleasant View soils series are somewhat less well developed than Morrison's Midvale soil. This is probably due to the fact that the post-Provo pre-Utah Lake terraces are still subject to occasional flooding. The alluvial fan deposits mapped as Qf_1 (Figure 3) grade to these terraces and appear to be the same age; a soil comparable to Morrison's Midvale soil is developed on this fan surface (see Table 3 and description of soil unit 2S exposed in trench HC-1).

Flood-Plain Deposits (Qal_2). Alluvium that consists of poorly sorted, lenticular bedded gravel and sand, with some silt and clay, occurs along the present flood plain of Hobble Creek which grades to Utah Lake. The flood plain and, locally, the post-Provo pre-Utah Lake terrace surface (Qal_1) are veneered with sediment from a major flood that occurred in 1952. The channel of Hobble Creek, particularly on the upthrown block, has been extensively modified as a result of this flood and subsequent flood control measures.

Fan Deposits (Qf). Numerous small fans that consist primarily of poorly sorted gravelly-silty-fine-sand and silty-sandy-gravel debris-flow deposits occur at the mouths of intermittent streams and gullies along the mountain front. A few small fans grade to the Bonneville bench on the upthrown block east of the main fault. Most of the fans, however, are inset below the Alpine-Bonneville deposits and unconformably overlie Provo-age and younger deposits on both the upthrown and downthrown sides of the fault.

Slip along the Wasatch fault has repeatedly beheaded many of these fans, producing fan segments of different ages. Remnants of displaced fan segments are preserved on the upthrown block south of Hobble Creek at the mouths of Ether Hollow and the next major intermittent stream to the south, and north of Hobble Creek at the mouth of Deadmans Hollow. In many places the fault scarp is breached by younger fan segments that do not appear to be faulted. Individual fan segments are not differentiated on Figure 3, except for the fan complex at the mouth of Deadmans Hollow.

The Deadmans Hollow fan complex is composed of four segments. The oldest segment, Qf_1 (equivalent to unit 2, trench HC-1), buries Provo-age gravel and grades to a terrace underlain by post-Provo pre-Utah Lake alluvium. At the trenching site these fan deposits are inset at least 5 m below the Provo fan-delta deposits in the upthrown block east of the main fault. A relict soil occurs on the Qf_1 fan surface, which is tentatively correlated with Morrison's (1965) Midvale soil (Table 3). This soil is buried by the younger fan deposits (Qf_2 and Qf_3). Based on its geomorphic position, this soil is believed to be younger than the post-Provo pre-Utah Lake alluvium (post about 6,000 y.b.p.). Morrison (1965) maintains that formation of the Midvale soil may have begun as recently as about 4,500 years ago during the later part of the altithermal.

Fan segment Qf_2 (equivalent to unit 3C, trench HC-1) consists of debris flow deposits that partly fill the graben on the northwest flank of the fan complex. Deposits of fan segment Qf_2 are exposed at the ground surface in the western end of

Table 3

Soil developed on alluvial fan and loess deposits, unit 2, exposed in trench HC-1 130 m southwest of the main fault scarp.

HORIZON*	THICKNESS (cm)	DESCRIPTION
A11	10 to 20	Dark grayish brown (10 YR 4/2; 3/2, moist) plastic, nonsticky slightly sandy silt loam that generally contains less than 5 percent angular pebblesand cobbles; fine to medium angular blocky structure; numerous roots; abrupt smooth lower boundary.
A12	10 to 30	Brown (10 YR 5/2; 4/2) slightly plastic, nonsticky, slightly sandy silt loam; massive; lower part mottled and transitional into C1; common roots; gradual smooth lower boundary.
C1	25 to 50	Light yellowish brown (10 YR 6/4; 5/5 moist) gravelly silt loam, contains 30 to 40 percent angular gravel, mode 2 to 4 cm, maximum size 20 cm; medium angular blocky structure; common roots; gradual wavy lower boundary.
$C2_{ca}$	45 to 55	Very pale brown (10 YR 8/4, 6/6 moist) silt, contains some lenses of gravel and sand; massive; contains approximately 5 percent filamentous stage I carbonate, rinds $\leq$ 1 mm thick on bottom of gravel clasts; few roots; gradual to diffuse smooth lower boundary.
$C3_{ca}$	30 to 50	Light brown (7.5 YR 6/4; 5/4 moist) silt; locally contains layers, lenses, and some stringers of fine sand and gravelly fine sandy silt; weakly cemented with approximately 1 to 2 percent filamentous, stage I carbonate; gradual to diffuse lower boundary.
C4	>100	Light brown (7.5 YR 6/4, 5/4 moist) sand and silt; contains layers and stringers of pebble and cobble gravelly sand; calcareous (reacts to hydrochloric acid, but carbonate is not apparent).

*Horizons A11 and A12 correspond to unit 2S on Plate 2; horizons C1, $C2_{ca}$, $C3_{ca}$, and C4 are included in unit 2 on Plate 2.

the graben; however, they are buried in most places by fan segment Qf_3 (equivalent to unit 5C, trench HC-1). Fan segment Qf_3 occupies the area at the apex of the fan complex. This segment has a steeper gradient than the older fans and exhibits typical cone-shape fan morphology. Qf_3 deposits partly bury the main fault scarp, which decreases in height towards the apex of the fan. A lobe of this fan segment extends into the graben. The most recent faulting has beheaded this fan along the main trace of the fault; a remnant of the fan segment is preserved on the upthrown block. The channel of the intermittent stream presently occupying Deadmans Hollow is incised below this segment; this stream breaches the fault scarp and is the source for fan segment Qf_4, which is located on the east flank of the fan complex. The most recent fan sediments consist of a series of fresh mudflow lobes near the apex of fan segment Qf_4. Fan segments Qf_2, Qf_3, and Qf_4 post-date the soil developed on Qf_1.

Eolian Deposits (Qe). Windblown deposits of silt and fine sand (Qe) mantle Bonneville gravel on the Bonneville bench and Alpine-Bonneville lake deposits at Murdock Mountain (Figure 3). Only a weak A/Cca soil profile is developed on these eolian deposits. The deposits are above the Provo shoreline and could represent eolian deposition during and shortly following late Bonneville time. However, because the slopes between the Bonneville and Provo shorelines are steep, only small areas of lakebeds were exposed after Lake Bonneville receded to the Provo level. On the other hand, large expanses of the gently sloping lakebed were exposed after the lake receded from the Provo level, providing an ample source of sand and silt. Bissell (1963) reports that windblown sand and silt overlie the Provo Formation elsewhere, and it is likely that the eolian deposits are mostly post-Provo in age.

Lithologic and Soil Units--Trench HC-1

Trench HC-1 was excavated across the graben on the northwest flank of the Deadmans Hollow fan complex and exposed the stratigraphic and structural relationships between Provo-age gravels and the deposits related to the individual fan segments. These relationships are shown on the log of trench HC-1 (Plate 2). Descriptions of the lithologic and soil units exposed in this trench and the correlations between these units and the units shown on the photogeologic map (Figure 3) are presented on Plate 1.

Provo Fan-Delta Deposits (unit 1). The oldest deposits exposed in the trenches at the Hobble Creek site are Provo fan-delta deposits. These deposits were exposed in the foot-wall on the upthrown side of the fault and in a deep test pit excavated in the floor of trench HC-1 on the downthrown side of the fault (3.5 m below the ground surface and 125 m south of the main fault scarp).

These deposits, which consist primarily of sandy gravel, gravelly sand, and gravel (see description of map unit Qp), are juxtaposed against a sequence of scarp-derived colluvium across the main fault.

Alluvial Fan and Loess Deposits (unit 2). Adjacent to the steep mountain front, the alluvial fan (Qf_1) that grades to the post-Provo pre-Utah Lake surface (Qal_1) consists primarily of coarse mudflow debris consisting of gravelly silt and silty cobble and boulder gravel. Most of the clasts within the mudflow deposits are subangular and angular. Locally, individual mudflows are separated by weakly developed soils characterized by slightly darker zones of organic accumulation. These soils are generally difficult to trace laterally.

With increasing distance from the mountain front, these deposits contain greater amounts of reworked loess and may contain some primary loess. The loess component of the fan deposits increases gradually away from the apex of the fan. It is the predominant component of the alluvial fan west of the main antithetic fault (station 67, Plate 2) where unit 2 consists mainly of massive, slightly calcareous silt that locally contains layers, lenses, and some stringers of fine sand and gravelly fine sandy silt.

Post-Unit 2 Soil (unit 2S). A moderately developed soil having a weak textural B horizon and stage I carbonate accumulation in a Cca horizon has formed on these fan deposits. A profile of this soil is described in Table 3. This soil is tentatively correlated with Morrison's Midvale soil. It is displaced across the antithetic main fault and buried by younger mudflow deposits (unit 3C). North of station 55 in trench HC-1 the buried soil S2 is less distinct and is characterized only by a weakly developed zone of organic staining.

Fan Deposits and Associated Colluvium (unit 3). Deposits of a lobe of fan segment Qf_2 observed in trench HC-1 consist primarily of a sequence of individual mudflow units (unit 3C) separated by weakly developed soils (unit 3S) characterized by A/C profiles that formed on the individual mudflow units. Burial of these soils at frequent intervals prohibited significant soil profile development. These buried soil horizons (paleo-entisols) are characterized by only small accumulations of organic material. They range in thickness from less than 3 cm to as much as 20 cm. Individual mudflow units vary from 0.1 to 0.8 m in thickness.

These deposits were observed only in the graben and appear to have been deposited against a preexisting antithetic fault scarp. These deposits are presently in fault contact with loess and alluvial fan deposits (unit 2) across the main antithetic fault scarp, and are displaced across numerous minor faults within the graben.

The sequence of mudflow deposits (unit 3C) grades laterally into an alluvial facies (unit 3B) at the northeastern margin of the graben, which in turn grades into a colluvial facies (unit 3A) adjacent to the main fault scarp. The colluvial deposit consists of pebbly sandy silt containing numerous angular and subangular pebbles; this deposit was probably derived primarily from nearby gully fill rather than the rounded gravels of the adjacent Provo fan-delta deposits.

Colluvium (unit 4). Reddish yellow colluvium that infills a wedge-shaped depression at the toe of the fault scarp is in fault contact with the Provo fan-delta deposits. Similar wedge-shaped infillings were observed in trenches across the main fault scarp at the Kaysville site (Swan and others, 1978). These features are interpreted to be infillings of fissures that form at the top of the debris slope near the base of the fault scarp during a surface faulting event. The colluvium, a poorly sorted sandy gravel, contains abundant rounded to well rounded clasts derived primarily from Provo fan-delta gravel deposits in the upthrown block. The intertonguing relationship of this colluvium and the underlying colluvium unit (unit 3A) observed in trench HC-1 (Plate 2, stations 7 to 10) appears to be the result of slumping and deformation of these deposits, which probably occurred during or shortly after deposition of unit 4. A weak soil having some carbonate accumulation in a Cca horizon (unit 4S on Plate 2; horizon IIca on Table 5) developed on this colluvium; the upper part of the soil was subsequently truncated prior to and/or during deposition of the overlying colluvium (unit 6A) and alluvium (unit 5A).

Channel and Fan Deposits (unit 5). Alluvial deposits (unit 5A) consisting of stratified, poorly sorted to moderately well sorted sand, gravelly sand, and minor amounts of fine gravel occupy a buried channel at the base of the main fault scarp. The contact of these deposits with underlying colluvium (unit 4) is defined, in part, by a cobble and boulder lag. The channel deposits are overlain by poorly sorted, sandy gravel debris flow deposits (unit 5B); these fan deposits are similar in texture and morphology to unit 3C. The topsoil developed on the debris flow deposits at the ground surface is an entisol that exhibits only minor accumulation of organic matter (Table 4). This soil is comparable in degree of profile development to paleo-entisols within the mudflow sequence (unit 3C).

Young Scarp Colluvium and Associated Channel Deposit (unit 6). The youngest colluvial unit on the main fault scarp, unit 6A, consists of pebbly silty sand. This unit overlies the main fault and is in depositional, rather than fault, contact with the underlying Provo fan-delta deposits (unit 1) and older fault scarp derived colluvium (unit 4). This unit was deposited immediately after the most recent surface faulting event. Unlike the older colluvium derived from the fault scarp (unit 4), this unit does not occupy a wedge-shaped fissure at the base of the scarp. The deposit contains a mixture of rounded, subangular, and angular clasts suggesting that it was derived from both Provo fan-delta deposits and alluvial fan or gully fill sediments. The weakly developed A/Cca soil profile on this unit is described in Table 5. The colluvium grades into silty coarse sand and gravelly silt (unit 6B) that occupy a small channel at the base of the main fault scarp. The basal contact of this unit is defined in part by a lense of cobble and boulder gravel. Stratigraphic relationships in this zone are obscured in places by numerous large tree roots. The colluvium is buried by loose debris

Table 4

Soil developed on mudflow deposits, unit 5B, exposed in trench HC-1 (station 25, Plate 2).

HORIZON*	THICKNESS (cm)	DESCRIPTION
A11	5 to 10	Root mat; similar to A12, contains abundant roots.
A12	5 to 20	Grayish brown to brown (10 YR 5/2.5; 3/2 moist) plastic, slightly sticky, pebbly silt loam, contains 5 to 20 percent subangular and angular pebbles, mode $\leq$ 1 cm; locally the texture is a pebbly silty sandy loam; numerous roots; clear wavy to smooth lower boundary.
C		Pale brown (10 YR 6/4; 3/3 moist) gravelly silt and silty gravel, contains 30 percent to greater than 50 percent locally subangular and angular pebbles and some cobbles and boulders, mode 2 to 3 cm; calcareous (reacts to hydrochloric acid, but carbonate is generally not apparent); poorly sorted; moderately dense.

*Horizons A11 and A12 are included in unit 5S on Plate 2; horizon C is equivalent to unit 5B on Plate 2.

Table 5

Soil developed on youngest scarp-derived colluvium and slope wash (unit 6A); buried in places by fill from road construction; upper surface slopes 40 degrees to the southwest; profile measured at station 3, trench HC-1.

HORIZON*	THICKNESS (cm)	DESCRIPTION
A11	13	Grayish brown to brown (10 YR 5/2.5; 3/3 moist) pebbly sandy loam, contains less than 5 to 10 percent angular and rounded pebbles, mode 2 to 3 cm, 5 cm common; massive to weak fine-coarse crumb structure; loose to very friable; poorly sorted; calcareous; numerous roots; clear to gradual smooth lower boundary.
A12	37	Pale brown to light yellowish brown (10 YR 6/3.5; 4/3 moist) pebbly sandy loam, contains approximately 20 percent rounded, subangular and angular pebblesin roughly equal proportions, mode 3 to 5 cm, maximum size 18 cm; weak coarse to very coarse crumb structure, readily crumbles to loose sandy loam; clear wavy lower boundary.
C1	32	Pink (7.5 YR 8/4; 5.5/6 moist) pebbly silty sand, contains 10 to 30 percent rounded, subangular, and some angular pebbles; thin (< 1 mm) film carbonate coatings on the bottom part of some of the pebbles, calcareous matrix; friable; long axes of pebbles parallel slope creating a pronounced fabric; some roots; clear smooth lower contact.
C2	18	Gravel, sandy gravel, and gravelly sand; predominantly well rounded pebbles and cobbles, mode 3 to 8 cm, maximum size 25 cm; loose; crudely stratified parallel to slope; calcareous, thin carbonate films (< 1 mm) on the bottoms of most pebbles; clear smooth lower contact.
IICca	31	Very pale brown (10 YR 7/3.5; 5/3.5 moist) silty gravelly sand, contains approximately 20 percentangular, subangular, and rounded pebbles, mode 3 to 5cm, maximum size 15 to 20 cm; medium granular to medium angular blocky structure; vesicular; weakly cementedby calcium carbonate; abrupt to clear wavy lower boundary with unit 4.

*Horizons A11, A12, C1, and C2 are incuded in unit 6A on Plate 2; horizon IIC_{ca} is included in unit 4S on Plate 2.

resulting from the construction of a farm access road higher up on the fault scarp.

FAULTING AND DEFORMATION AT THE HOBBLE CREEK SITE

Faulting and Deformation Observed in Exploratory Trenches

Faulting Associated with the Main Scarp. Trenches HC-1 and HC-2 were excavated across the main fault scarp and exposed the faults associated with this scarp. HC-1 traversed the entire scarp and HC-2 crossed the lower part of the scarp. Faults observed in these trenches are described below.

Faulting on the upthrown block occurs completely within Provo-age gravel and sand, and has produced horsts and grabens across a zone extending 3 1/2 m northeast of the main fault plane. Trench HC-1 extended an additional 10 m to the northeast (not shown on Plate 1); no other faults were observed in this interval. Faults strike between N20W and N40W, generally parallel to the main fault, and dip steeply east and west. Displacements vary from as little as 0.5 cm on faults in sand and silt immediately northeast of the main fault to as much as 54 cm on the northeasternmost fault in the zone. The faults that form the boundaries of the grabens are defined by zones 3 to 6 cm wide of aligned pebbles; locally, the alignment of pebbles is strongly developed.

The main fault is oriented N36W, 58W. It juxtaposes Provo-age gravel and sand in the footwall against colluvium derived from the fault scarp. Cumulative stratigraphic separation across the main fault is greater than the height of exposures in the trench (approximately 15 m). In the lower part of trench HC-1, the fault is defined by a deformed zone up to 7 cm wide. In the fine sandy Provo deposits, the fault is a reddish brown zone 3 cm wide that is bounded on the east by a sharp contact with stratified Provo deposits. In the colluvium the fault is defined by a zone up to 4 cm wide of pebbles oriented parallel to the contact with the lake deposits; the degree of pebble alignment varies locally from very strong to weak. In the upper part of the trench, where Provo gravel is in contact with colluvial gravel, the fault is a zone varying in width from 5 to 7 cm. Within the Provo gravels the fault is a 3 to 4 cm wide zone of rotated gravel; in the colluvium, pebbles have been rotated across a 2 to 3 cm wide zone. The preferred orientation of pebbles varies locally from well developed to weak. Locally, roots have worked themselves down along the main fault.

Antithetic Faulting and Back-Tilting. The graben on the downthrown side of the main fault at the trench site (Figure 3) was crossed completely by trench HC-1 (Plate 1), and the northeast facing antithetic scarp that forms the southwestern boundary of the graben was crossed at a second location by trench HC-3. The fan deposits exposed in these trenches are faulted and tilted back towards the main fault scarp.

The zone of faulting within the graben in trench HC-1 contains 16 faults. The faults vary in strike from N29W to N66W; most strike between N40W and N58W. Faults dip steeply to the northeast and southwest as much as 72 degrees, producing series of horsts and graben (Plate 1). Most of the faults are straight to curvilinear planes or thin zones, but some splay or anastomose upwards to produce a series of small steps or minor horsts and graben (station 33). At stations 36, 39, 46.5, and 52 irregularly shaped fault bounded zones containing softer unbedded sediment and a higher concentration of organic material than the surrounding sediment are observed; these may represent infillings of fissures by the overlying soil or illuvial organic material deposited by surface water percolating down along faults and fractures.

Displacements on individual faults within the graben range from 3 to 36 cm. Most of the faults appear to extend into, and displace the base of, unit 5B. Displacements on many of these faults are the same on successively younger stratigraphic units, indicating that they formed during the most recent surface faulting event. However, some faults appear to die out before extending into unit 5B. At station 22.5 the contact between units 2 and 3C is displaced 16 cm down to the northeast by a northeast-dipping fault. The fault splays upward and displaces a gravel layer within 3C by the same amount, but no displacement of the contact between units 3C and 5B is observed. At station 26 an east-dipping fault displaces the contact between units 2 and 3B and a soil horizon within unit 3B 16 cm down to the northeast; the contact between units 3C and 5B is not clearly displaced, but does appear to be warped across the fault. A fault within unit 2 at station 47 displaces a sand-gravel contact 20 cm down to the northeast; this fault cannot be traced above, and does not appear to displace, the contact between units 2 and 3C.

The expression of individual faults within the graben in trench HC-1 is variable and depends, in part, on the type of material through which the fault passes. In the well-layered mudflows, gravels, and sands of units 3C and 5B, faults are thin (up to 2 cm wide) zones of disturbed sediment that contain rotated pebbles in places; no well-defined planar surfaces are observed. In the massive mudflow deposits in unit 2, expression of faults is subtle in most places and it is difficult to trace some faults to the bottom of the trench (dashed faults, Plate 1). Within this massive unit faults are defined by discontinous hairline fractures, discontinuous color changes and, in a few places, by oriented pebbles. If the layered sequences 3C and 5B were not present, some of the faults in unit 2 might go undetected.

The main antithetic fault (station 67) is defined in the lower part of the trench (unit 2) by a sharp linear color change and/or by a 3 to 5 mm wide light tan zone having sharp boundaries. Within the lower part of unit 3C the fault is a sharp linear color change; the long axes of two pebbles are parallel to the color change, but a fabric is not developed in the sand. The upper 60 cm of the fault is a slightly irregular color change that is sharp locally; irregularities result in places from the many angular pebbles that occur along this portion of the fault. The cumulative vertical displacement of soil unit 2S is approximately 2 1/2 m, based on a projection of this soil on the southwestern side of the fault across the antithetic scarp to the fault plane. In trench HC-3, 110 m to the southeast, the displacement of unit 2 across this fault is 1.3 m.

The fan deposits on the downthrown side of the main fault are tilted towards the main fault over a wide zone that extends for approximately 120 m from the main fault scarp. The tilt of the beds is greatest adjacent to the main fault and rapidly decreases away from the fault. Between stations 15 and 20 in trench HC-1 (Plate 2), units 3 and 2 dip 12 degrees and 16 degrees towards the fault scarp, respectively. At station 50 the dip of unit 2 is less than 4 degrees towards the fault. At station 63 the dip of unit 2 is about 2 degrees; shallow dips towards the main fault scarp gradually decrease for another 56 m. The actual amount of rotation of these fan deposits is difficult to determine because the initial dips of these units are not known. The effects of back-tilting on the assessment of the net tectonic displacement are discussed in the following sections.

Cumulative Displacements Based on Scarp Profiles

Surface faulting throughout late Quaternary time is indicated by the progressively smaller cumulative displacements that are observed in the successively younger datums measured. Scarp heights are lower and vertical stratigraphic separation is less with decreasing age of the faulted sediments. Earlier studies at the Kaysville site (Swan and others, 1978) and the data from the Hobble Creek site show that back-tilting and antithetic faulting can significantly increase the apparent cumulative vertical separation across the main fault relative to the true tectonic displacement across the entire deformed zone. If this factor is considered, corrected values of the cumulative net tectonic displacement can be calculated. Measurements of scarp heights and back-tilting, and the cumulative net vertical tectonic displacements of different age deposits, are discussed below.

Scarp Heights and Vertical Stratigraphic Separation. The vertical heights of the fault scarps in Bonneville-Alpine lake deposits, Provo fan-delta deposits, and post-Provo pre-Utah Lake alluvium are 60 m, 28.5 m, and 12.5 m, respectively (Figure 6). These heights include the effects of back-tilting and graben formation. In addition, the fault scarp in the Alpine-Bonneville lake deposits has been significantly modified by erosion and by deposition of younger eolian deposits (Figure 5). Consequently, the scarp height (60 m) may not accurately reflect the post Alpine-Bonneville displacement on the main fault. The top of a gravel unit in these lake deposits is exposed in the sides of gullies eroded into the upthrown block east of the main fault and in the west end of a canal cut through Murdock Mountain on the downthrown block west of the fault (Figures 5 and 6). The vertical stratigraphic separation of this gravel marker is 56 m.

Back-tilting. Topographic profiling of the post-Provo pre-Utah Lake terrace and the Provo terrace show measurable tilting of each terrace surface back toward the main fault scarp (Figure 6). West of the deformed zone, the post-Provo pre-Utah Lake terrace surface dips 1/2 degree to the west. This surface rotated an average of 1/2 degree toward the main scarp across a zone that extends 200 m from the scarp. The initial dip of the Provo terrace surface is approximately 1 degree toward the west. This surface has subsequently been rotated an average of 1 1/2 degrees eastward across a zone extending 385 m from the main scarp. Near the main fault this surface dips as much as 3 degrees to the east.

Due to erosion and subsequent deposition, the amount of rotation associated with the Alpine-Bonneville lake deposits (profile K-K', Figures 5 and 6) cannot be measured. Presumably these deposits are affected to the same degree, or possibly to an even greater degree, as the Provo-age deposits.

Cumulative Net Vertical Tectonic Displacement. Back-tilting and formation of antithetic faults affect the fault scarp height and increase the vertical stratigraphic separation across the main fault relative to the true tectonic displacement (the cumulative net vertical displacement across the deformed zone). The cumulative net vertical tectonic displacement can be calculated by projecting the measured datum (terrace surface or stratigraphic horizon) on both sides of the fault plane from outside the deformed zone to the projected trace of the fault (Figure 6). The vertical distance between the intersections of the projected datum with the projected trace of the fault is the cumulative net vertical tectonic displacement. Small errors in the angle of the projection of the surfaces across the wide zones of deformation can produce differences in the calculated values for the net vertical tectonic displacement. Consequently, these calculated displacements are usually more accurately expressed as a range of values. The cumulative vertical tectonic displacement of the post-Provo pre-Utah Lake terrace is calculated to be 7 to 8.5 m; the calculated value for the Provo terrace is 11.5 to 13.5 m (Figure 6).

The cumulative net vertical tectonic displacement on the Alpine-Bonneville marker horizon is uncertain (Figure 6) because the effect of back-tilting on the deposits is not known. A maximum value can be estimated by subtracting the amount of post-Provo subsidence due to back-tilting from the measured vertical stratigraphic separation. The Provo surface along profile L-L' (Figure 6) has subsided about 6 m at a distance of 220 m from the fault scarp, which is the approximate distance from the fault scarp to the exposure of the Alpine-Bonneville marker horizon on the downthrown side of the fault. This suggests a maximum tectonic displacement of 50 m. A minimum value for the cumulative net vertical tectonic displacement is estimated by assuming an average rotation of 3 degrees (two times the post-Provo rotation) on the Alpine-Bonneville marker horizon over a distance of 500 m. If these assumptions are valid, the marker horizon could have subsided as much as 26 m due to back-tilting, and the cumulative net vertical displacement could be as little as 30 m or one-half the scarp height. This seems to be a reasonable value because a 1:2 ratio between true tectonic displacement and scarp height occurs to the north on this segment of the fault (profile L-L' in Figure 6) and also along the segment of the Wasatch fault at the Kaysville site.

SLIP RATE; DISPLACEMENT PER EVENT AND EARTHQUAKE MAGNITUDE; AND RECURRENCE OF SURFACE FAULTING AT THE HOBBLE CREEK SITE

Slip rate, the displacement per event, and the recurrence interval between surface faulting events are all factors that can be used to assess the potential for earthquake hazards. These factors are discussed below.

SLIP RATE

Figure 7 is a graph showing the relationship between cumulative net vertical tectonic displacement (ordinate) and age of the displaced datum (abscissa). Uncertainties in the calculated values for the tectonic displacement and in the ages assigned to the displaced datum are shown by the boxes on Figure 7. Because of these uncertainties, a range of values for the slip rate (slope of line between two points on the graph) is represented by the shaded area on Figure 7.

The data for Holocene (i.e., post-Provo) displacements are reasonably well constrained. The best fit line for these data (solid line on Figure 7) indicate the average Holocene slip rate is 1.1 mm per year. The late Pleistocene slip rate is not well constrained because of the uncertainties in the amount of displacement and age on the Alpine-Bonneville lake deposits. Using the range of values for displacements and ages of the Provo terrace and Alpine-Bonneville lake deposits shown on Table 6, the late Pleistocene slip rate could be between 0.7 and 12.8 mm per year. The available stratigraphic evidence suggests the lake deposits faulted at Murdock Mountain are Bonneville and not Alpine in age. Also, the cumulative net vertical tectonic displacement of the lake deposits is probably closer to 30 m than to the maximum value of 50 m. If these interpretations are correct, the late

DATUM	APPROXIMATE AGE (yrs B.P.)	CUMULATIVE VERTICAL TECTONIC DISPLACEMENT POST DATUM (m)	CUMULATIVE VERTICAL TECTONIC DISPLACEMENT DURING INTERVAL (m)	NUMBER OF EVENTS DURING INTERVAL	AVERAGE DISPLACEMENT PER SURFACE FAULTING EVENT (m)	AVERAGE RECURRANCE INTERVAL FOR SURFACE FAULTING EVENTS (yrs.)
ALPINE-BONNEVILLE LAKE DEPOSITS	>15,000 to <35,000	30 – 50	–	–	–	
	–	–	16.5 – 38.5	?	?	
PROVO TERRACE	12,000	11.5 – 13.5	–	–	–	
	–	–	3 – 6.5	3 – 4	0.8 – 2.2	1500 – 2400
MIDDLE HOLOCENE TERRACE	6,000	7 – 8.5	–	–	–	
	–	–	7 – 8.5	3	2.3 – 2.8	
PRESENT FLOOD PLAIN	0	0	–	–	–	

Table 6 - SUMMARY OF DATA ON FAULT DISPLACEMENTS AT THE HOBBLE CREEK SITE

Pleistocene slip rate is 2 to 6 mm per year. These data suggest that there was a decrease in the slip rate along this segment of the fault between the late Pleistocene and the Holocene, and that the Holocene slip rate has been uniform.

DISPLACEMENT PER EVENT AND EARTHQUAKE MAGNITUDE

Displacements for individual surface faulting events at the Kaysville site are estimated to be between 1.7 and 3.7 m on the basis of the colluvial stratigraphy and structural relationships observed in trenches (Swan and others, 1978). These relationships are not as clearly defined at the Hobble Creek site; therefore, an average displacement per event has been calculated. The average displacement per event is equal to the cumulative displacement divided by the number of surface faulting events. Table 6 summarizes the data for cumulative vertical tectonic displacement, number of faulting events, and calculated average net tectonic displacement per event during different intervals. Values for the average vertical displacement per event range from 0.8 m to 2.8 m per event during the Holocene.

The empirical relation between the logarithm of maximum displacement and earthquake magnitude can be used to estimate the size of the earthquakes (Slemmons, 1977). According to Slemmons' curve for normal-slip faults, displacements of 0.8 to 2.8 m are associated with magnitude 6.7 to 7.2 earthquakes. Slemmons' curves, however, are based on the maximum resultant displacements observed during historical surface faulting events, and the reported values include both fault slip (net tectonic displacement) and distortion (exaggerated scarp heights due to back-tilting and graben formation). Back-tilting and graben formation may increase the net tectonic displacement by as much as a factor of two along this segment of the Wasatch fault. If this factor is taken into account, the average resultant displacement per event could be as high as 5.6 m, which gives a magnitude of 7.5 on Slemmons' curve.

Estimates of earthquake magnitude should be based on as many parameters as possible. Average displacement data will not necessarily define the maximum earthquake that has occurred. More rigorous analysis is required to assess the maximum size earthquake that can occur along this segment of the Wasatch fault zone. Nonetheless, it seems reasonable that surface faulting events associated with earthquakes in the magnitude range of 6.5 to 7.5 have occurred repeatedly along this segment of the fault.

RECURRENCE OF SURFACE FAULTING

A primary objective of this study is to assess the recurrence for surface faulting events along this segment of the Wasatch fault zone. The recurrence interval is a function of the number of events that have occurrred and their distribution in time.

The structural and stratigraphic relationships indicate that at least six, and possibly seven, surface faulting events have occurred in post-Provo time along the segment of the fault at Hobble Creek. Three, and possibly four, of these events occurred during early Holocene time and are indicated by pre-middle Holocene strath terraces that are eroded into Provo gravels on the upthrown side of the fault. Three additional events during late Holocene time are indicated by the segmented alluvial fan and the faulted fan deposits observed in the trenches at the mouth of Deadmans Hollow. The available data do not permit absolute dating of individual events and calculation of the actual intervals between successive events. However, the average recurrence interval between these events can be calculated.

Figure 12 summarizes possible average recurrence intervals for six and seven surface faulting events during the past 12,000 years. The recurrence interval depends, in part, on when the first and last events occurred during the 12,000 year interval. If the first identified event occurred immediately after formation of the Provo terrace (case 1 in Figure 12), the average recurrence interval would be 2400 years. If a period less than the recurrence interval elapsed before the first identified faulting event (case 2), the average recurrence interval would be 2000 years. If a surface faulting event occurred immediately before the formation of the Provo terrace and a period equal to the recurrence interval elapsed before the first identified event, the average recurrence interval would be a minimum of 1700 years for six events. Similarly, given seven surface faulting events in the past 12,000 years, the average recurrence interval would be between 1500 and 2000 years (cases 4, 5, and 6, Figure 12).

The average recurrence interval between surface faulting events at the Hobble Creek site is between 1500 and 2400 years. The actual intervals between successive events may have varied from these mean values.

SUMMARY AND CONCLUSIONS

The following sequence of events is inferred from the stratigraphic and structural relationships observed during mapping and exploratory trenching at the Hobble Creek site:

1. During late Pleistocene time the Hobble Creek site was repeatedly inundated by Lake Bonneville. The earliest evidence of this lake at the Hobble Creek site is a thick sequence of relatively fine grained lacustrine deposits capped by nearshore gravels that were deposited as the lake surface was attaining an altitude of approximately 1566 m. The deep water lacustrine deposits are interpreted by Bissell (1963) to have been deposited during the Alpine stage of Lake Bonneville, which suggests they are a few to several tens of thousands of years old. However, no major unconformity was observed at the Hobble Creek site between the deep water lacustrine sediments and the nearshore gravel deposits, and it is possible that both were deposited during the Bonneville stage which ended approximately 15,000 years ago.

2. During the late Pleistocene, repeated surface faulting events along this trace of the Wasatch fault produced 16.5 to 38.5 m of net vertical tectonic displacement of the Alpine-Bonneville lake deposits. The number of events and the duration of the intervals between these events are not known. The average slip rate was between a maximum of 12.8 mm per year and a minimum of 0.7 mm per year. The available data suggest the actual rate was probably 2 to 6 mm per year.

3. Approximately 15,000 years ago Lake Bonneville spilled over into Red Rock Pass, and incision of the spillway lowered Lake Bonneville until it stabilized at the Provo stage. A large fan-delta complex built out from the mouth of Hobble Creek Canyon as the lake slowly receded. Lacustrine deposits interbedded with topset alluvial gravels indicate that the lake level fluctuated during the Provo stage. The lake receded from the Provo level about 12,000 years ago.

4. Following recession of the Provo-age lake, the Provo delta-fan surface was incised by Hobble Creek. On the upthrown block east of the fault, one unpaired and three paired strath terraces were eroded into the Provo gravels beneath the Provo terrace and above the post-Provo pre-Utah Lake terrace, which is middle-Holocene in age (about 6,000 y.b.p.). The proximity of these terraces to the fault scarp and the fact that similar terraces are not present on the downthrown block west of the fault suggests that they are tectonic in origin. The terraces probably represent at least three, and possibly four, faulting events that produced a cumulative net vertical tectonic displacement of 3 to 6.5 m in the interval between about 12,000 y.b.p. and 6,000 y.b.p.

5. Continued downcutting followed by alluviation along Hobble Creek during middle-Holocene time is represented by the post-Provo pre-Utah Lake alluvium (Qal_1) that underlies a low terrace above Hobble Creek. The main fault scarp was incised at least 5 m by an intermittent stream flowing from Deadmans Hollow, and built a large alluvial fan (Qf_1) that grades to the pre-Utah Lake alluvium (Qal_1). A soil (unit 2S on Plate 2) that is estimated to be about 6,000 years old began to form on this fan surface.

6. Surface faulting occurred. This event produced a graben at the trench site and created a fault scarp across the apex of fan Qf_1.

7. The fault scarp crossing Qf_1 was breached by erosion, and the graben was partly filled by a sequence of mudflows and colluvium from the main fault scarp (Qf_2 on Figures 3 and 4; unit 3 on Plate 2).

8. Surface faulting occurred. This resulted in rejuvenation of the main fault scarp across the Deadmans Hollow fan complex, and produced a fissure at the top of the debris slope that had formed at the base of the old scarp. Colluvium was deposited at the base of the fault scarp and filled the fissure (unit 4). A weakly developed carbonate soil formed on this scarp-derived colluvium.

9. The fault scarp was subsequently breached and fan Qf_3 formed, partly burying older fan segments Qf_1 and Qf_2. A thin veneer of channel and mudflow deposits (unit 5) were deposited in the graben.

10. Surface faulting occurred. Renewed uplift on the main fault was accompanied by renewed displacement on the main antithetic fault and development of new faults within the graben. Fan segment Qf_3 was beheaded as a result of this faulting. Erosion of the main fault scarp following this surface faulting event resulted in the deposition of a scarp-derived colluvium (unit 6A) that grades into alluvial sediments deposited in a small channel at the base of the scarp.

11. Subsequent to this most recent faulting event, the main fault scarp was breached and fan segment Qf_4 was formed.

The geological investigations at the Hobble Creek site indicate there have been six or seven surface faulting events along this segment of the Wasatch fault zone during the past 12,000 years. The average net tectonic displacement per event is from 0.8 to 2.8 m. The earthquakes produced by these events are estimated to be in the magnitude range of 6.5 to 7.5. The average recurrence interval for these events is calculated to be between 1500 and 2400 years.

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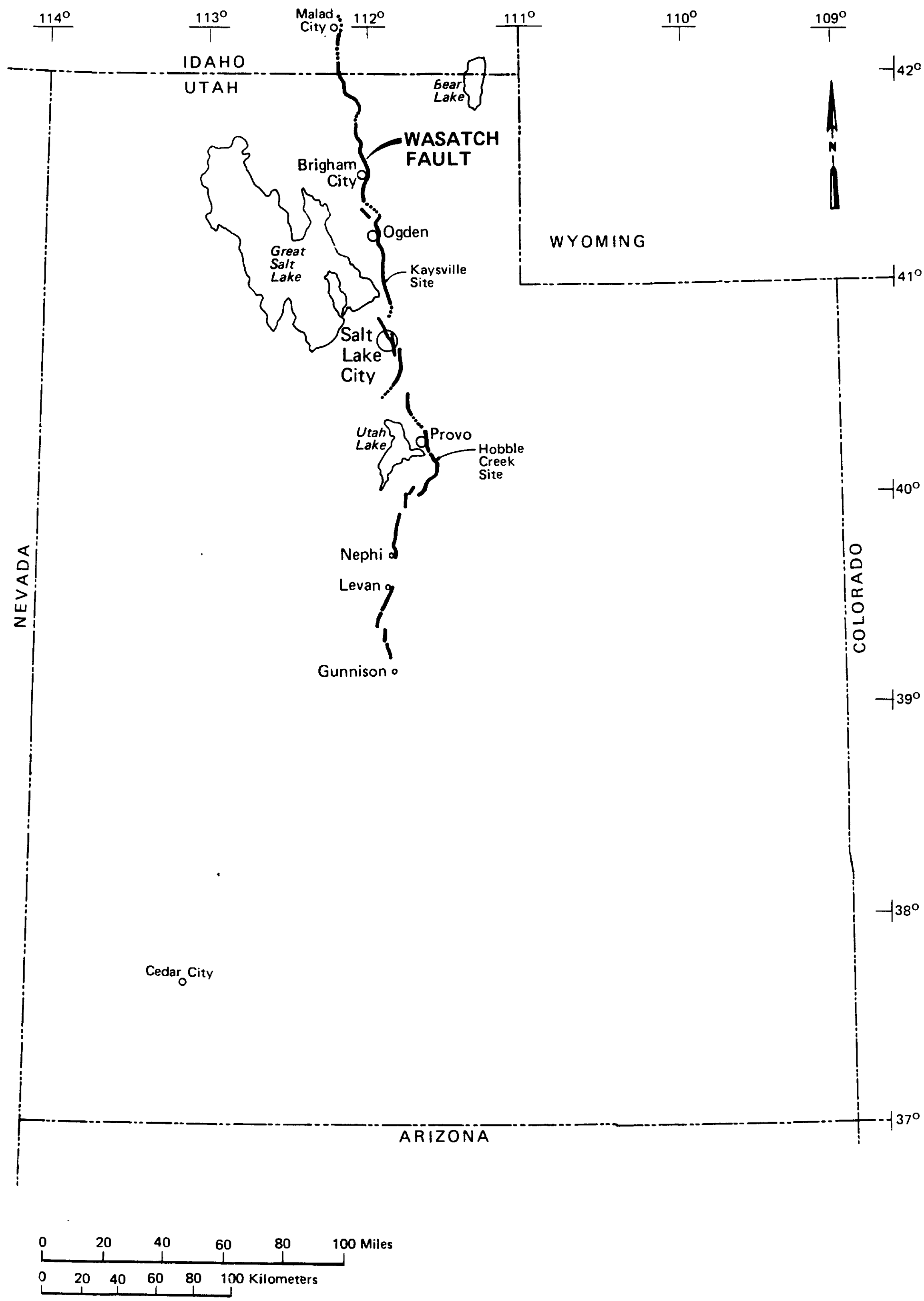
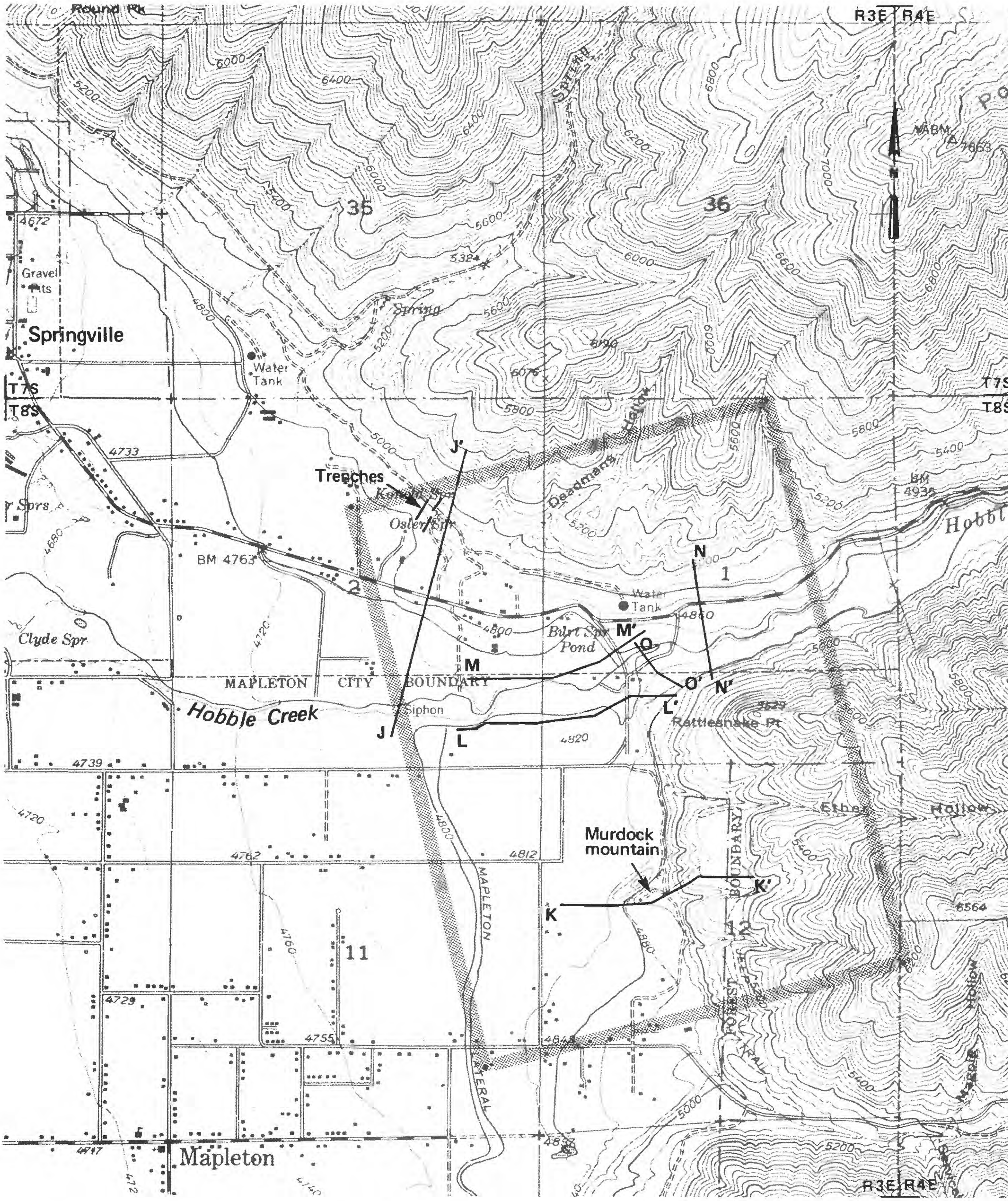


Figure 1 - REGIONAL LOCATION MAP



Map source: USGS 7½′ quadrangle, Springville, Utah

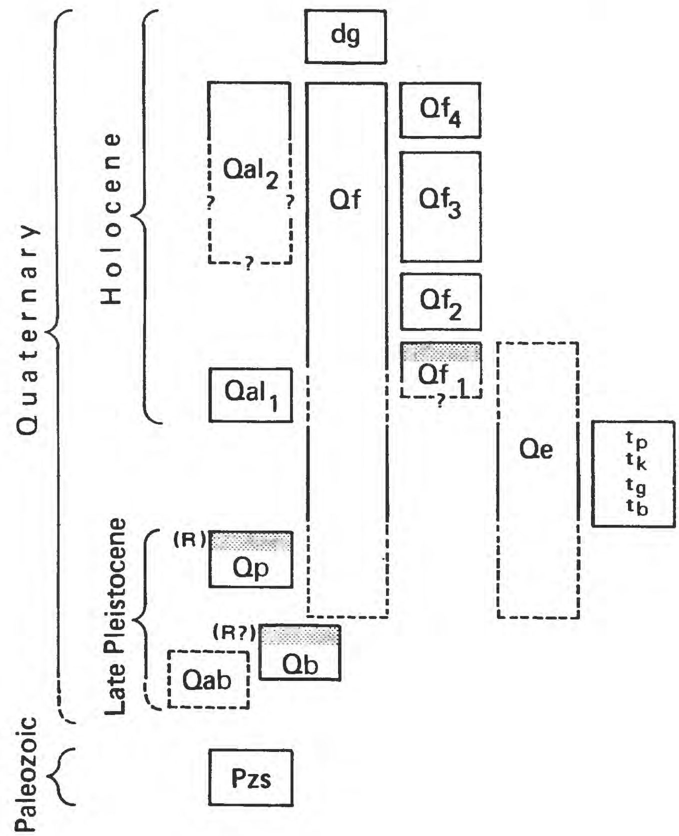
APPROXIMATE AREA OF PHOTO-GEOLOGIC MAP (Figure 3)

N —— N′ LOCATION OF TOPOGRAPHIC PROFILES

Scale: 0 — ½ — 1 Mile; 0 — 0.5 — 1 Kilometer

Figure 2 - LOCATION MAP OF HOBBLE CREEK SITE

CORRELATION OF MAP UNITS



MAP SYMBOLS:

- Lithologic contact
- Gradational lithologic contact
- Lithologic contact approximately located
- Terrace scarp
- Fault; dashed where less well defined; dotted where buried; balls on downthrown side.
- Linear break in slope; possibly of tectonic origin; circles on lower side.

LITHOLOGIC UNITS:

MAN- MADE DEPOSITS

- **dg** Disturbed ground

FAN DEPOSITS

- **Qf** Fan deposits (Undifferentiated)

Deadmans Hollow fan complex:

- **Qf_4** Fan segment 4 (youngest)
- **Qf_3** Fan segment 3
- **Qf_2** Fan segment 2
- **Qf_1** Fan segment 1 (oldest)

HOLOCENE ALLUVIUM

- **Qal_2** Utah Lake age alluvium
- **Qal_1** Post-Provo Pre-Utah Lake alluvium

EOLIAN DEPOSITS

- **Qe** Eolian fine sand and silt

STRATH TERRACES

- **t_p** lowest
- **t_k**
- **t_g**
- **t_b** highest

} Strath terraces

BONNEVILLE GROUP

- **Qp** Provo fan-delta deposits
- **Qb** Bonneville gravel
- **Qab** Alpine-Bonneville lake deposits (Undifferentiated)

BEDROCK

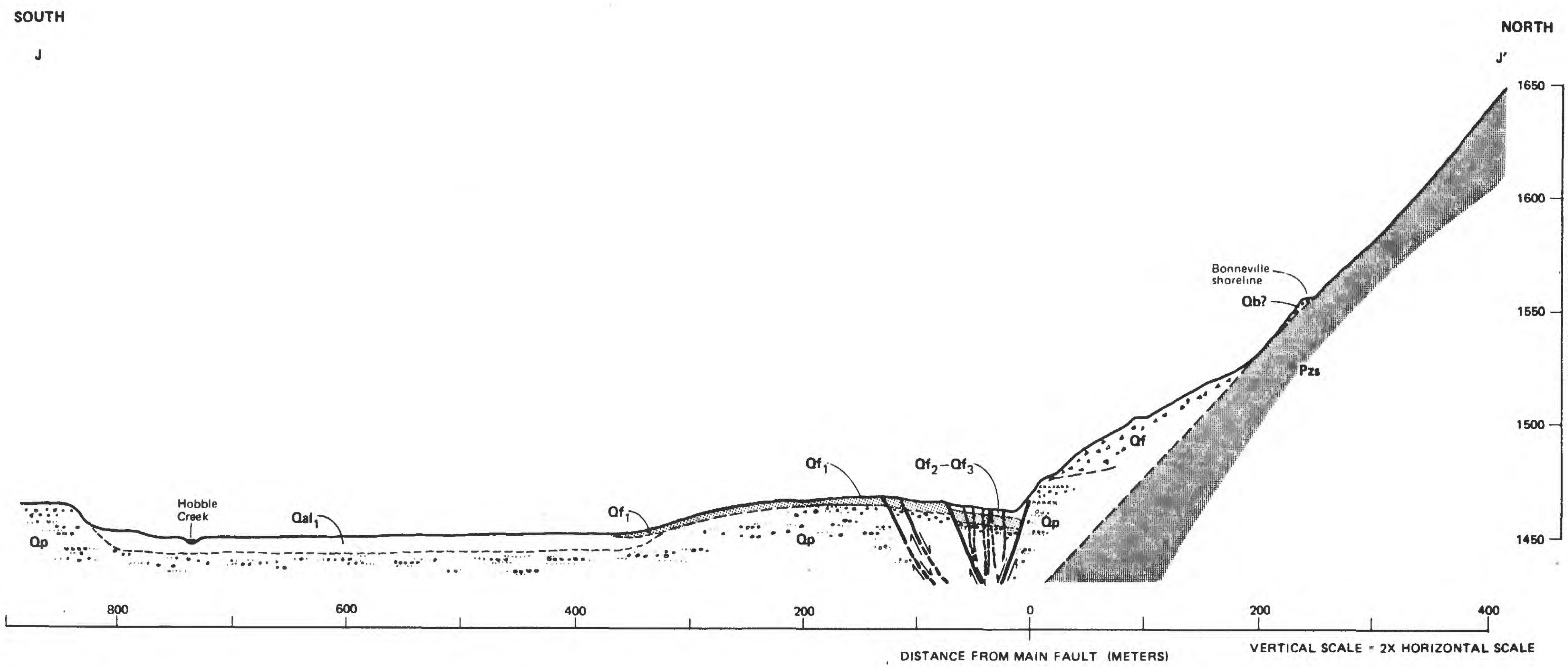
- **Pzs** Paleozoic sedimentary rocks

NOTE: See Plate 1 for detailed description of lithologic units.

Figure 3a- PHOTOGEOLOGIC MAP EXPLANATION
HOBBLE CREEK SITE

NOTE: map explanation is given on Figure 3a

Figure 3b - PHOTOGEOLOGIC MAP OF THE HOBBLE CREEK SITE



EXPLANATION

Qf_2–Qf_3	Fan deposits and associated colluvium
Qf_1	Fan deposits
Qf	Fan deposits (undifferentiated)
Qal_1	Post-Provo pre-Utah Lake alluvium
Qp	Provo fan-delta deposits
Qb	Bonneville gravel
Pzs	Paleozoic sedimentary rock

Lithologic contact; dashed where inferred

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

NOTES: Description and correlation of units on Plate 1 location of cross section shown on Figure 2

Figure 4 – GEOLOGIC CROSS SECTION ALONG PROFILE J–J' AT THE HOBBLE CREEK SITE

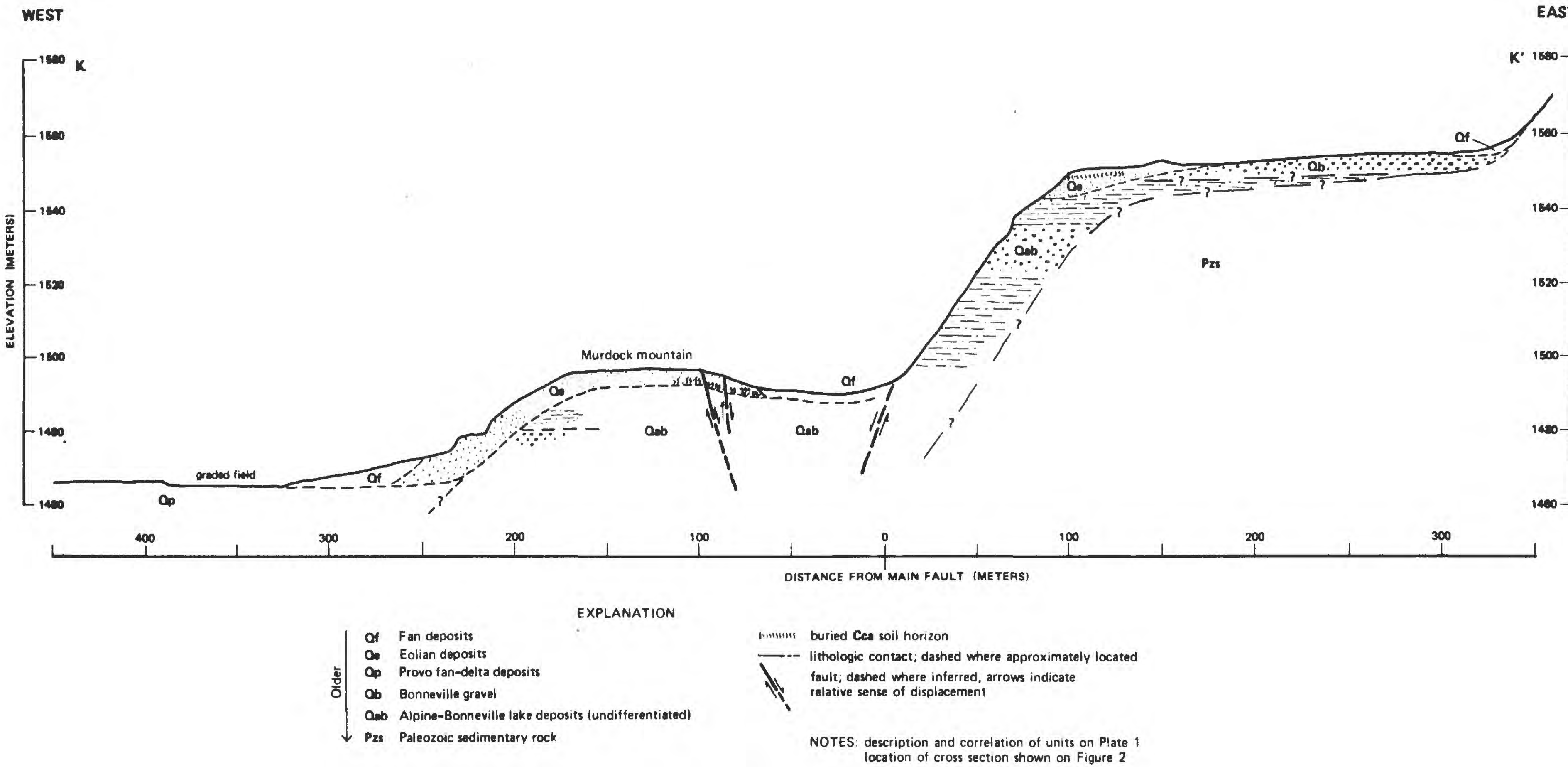


Figure 5 - GEOLOGIC CROSS SECTION K–K' AT THE HOBBLE CREEK SITE

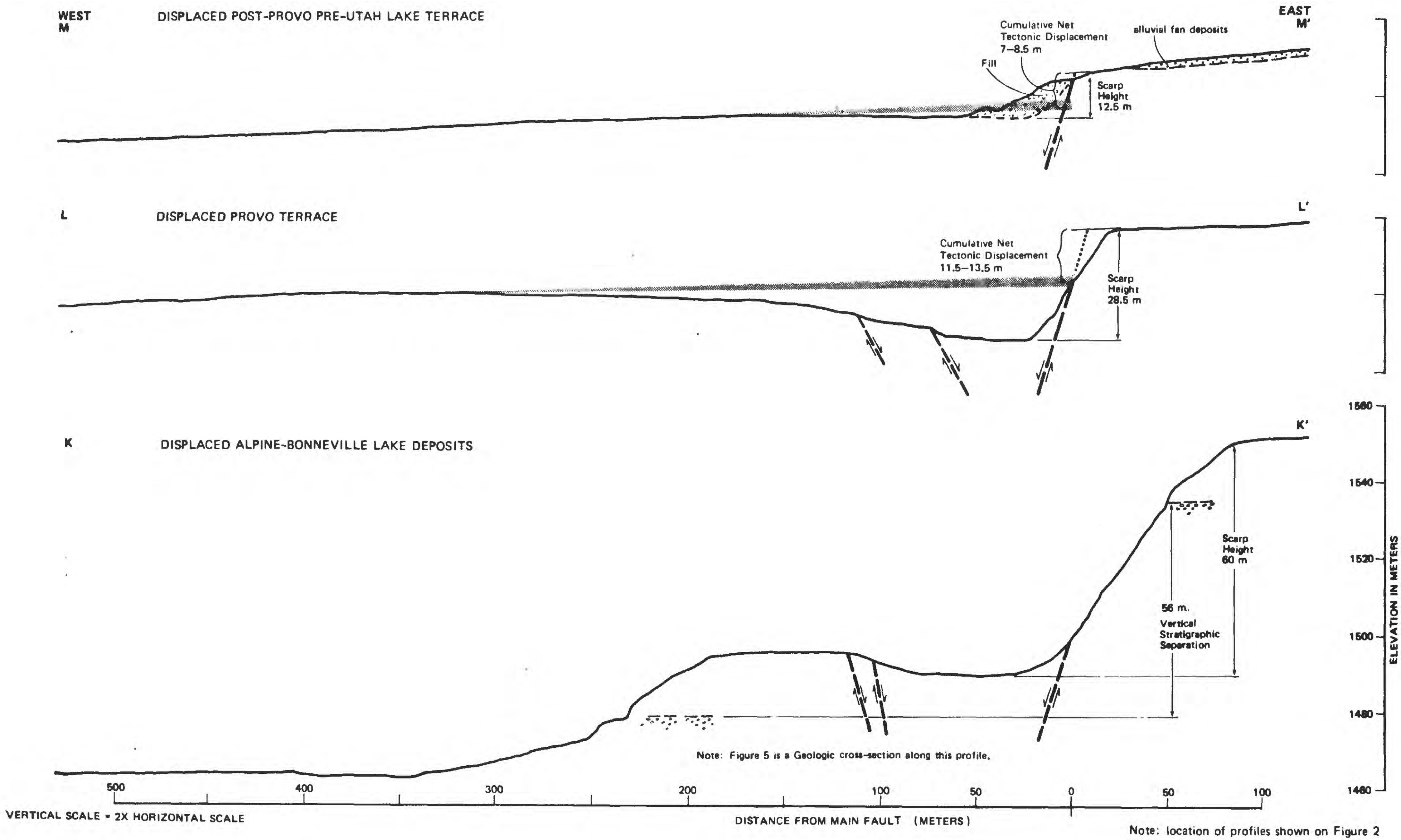


Figure 6 - LONGITUDINAL PROFILES SHOWING FAULTED TERRACES AND LAKE DEPOSITS AT THE HOBBLE CREEK SITE

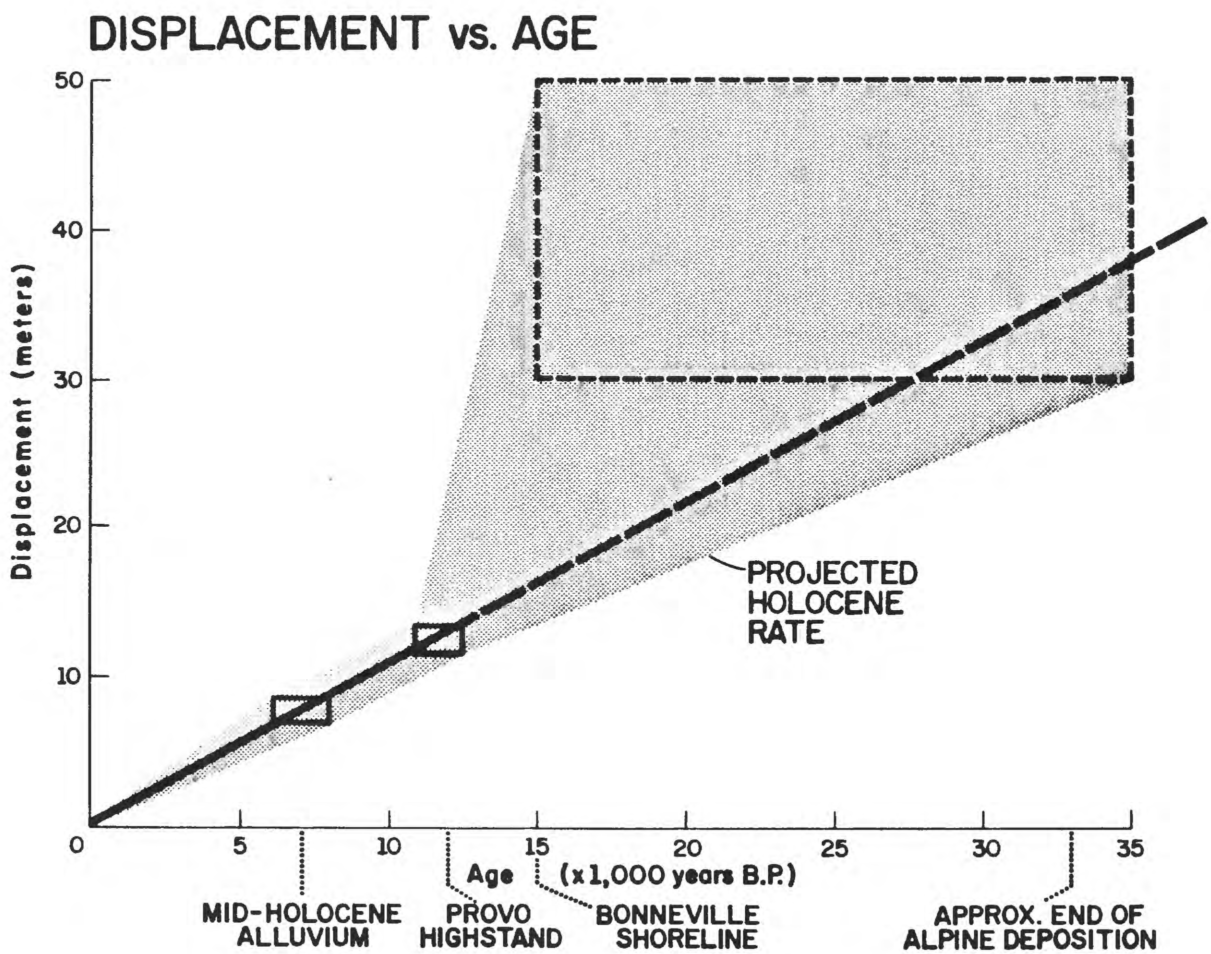


Figure 7 - GRAPH SHOWING RELATIONSHIP BETWEEN CUMULATIVE TECTONIC DISPLACEMENT AND TIME

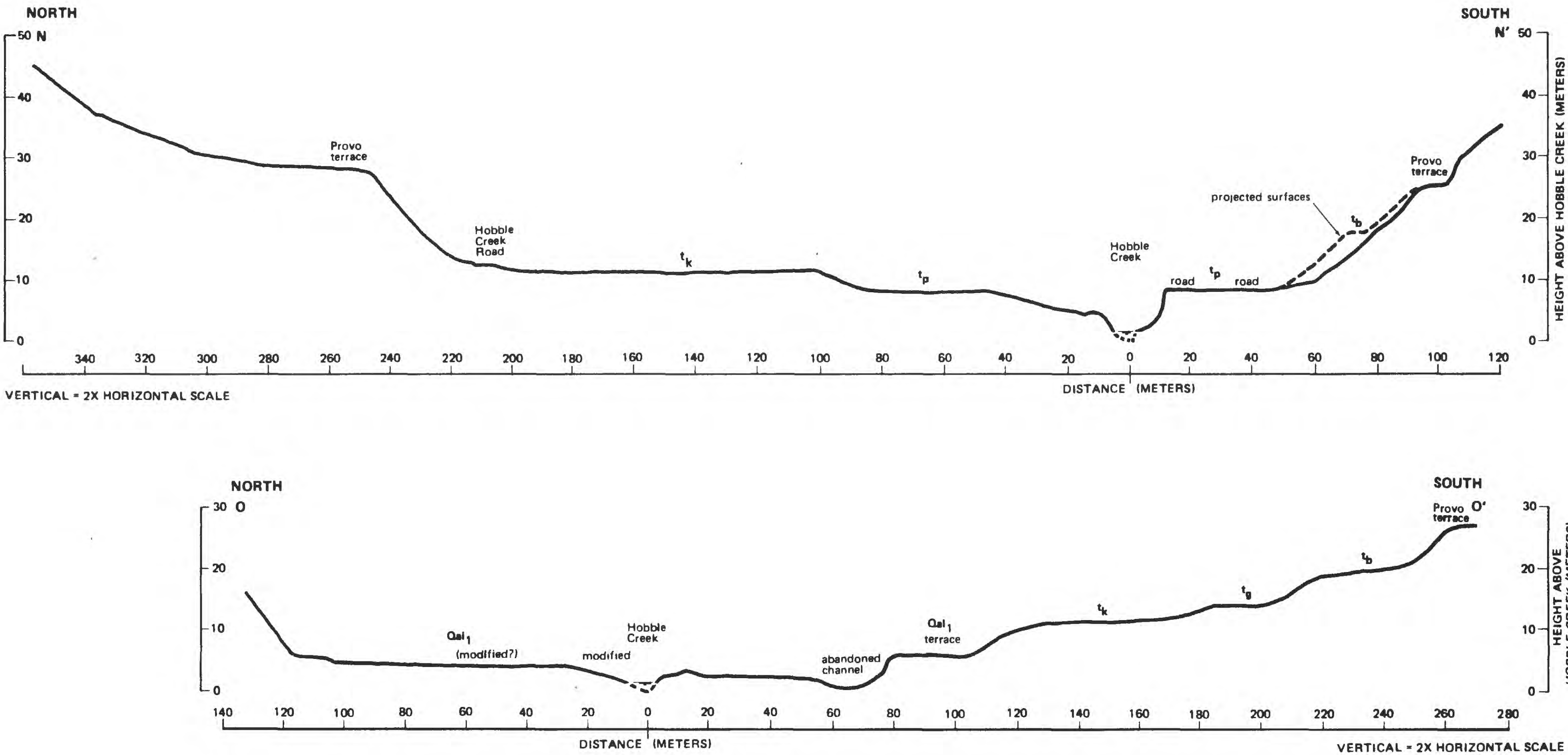
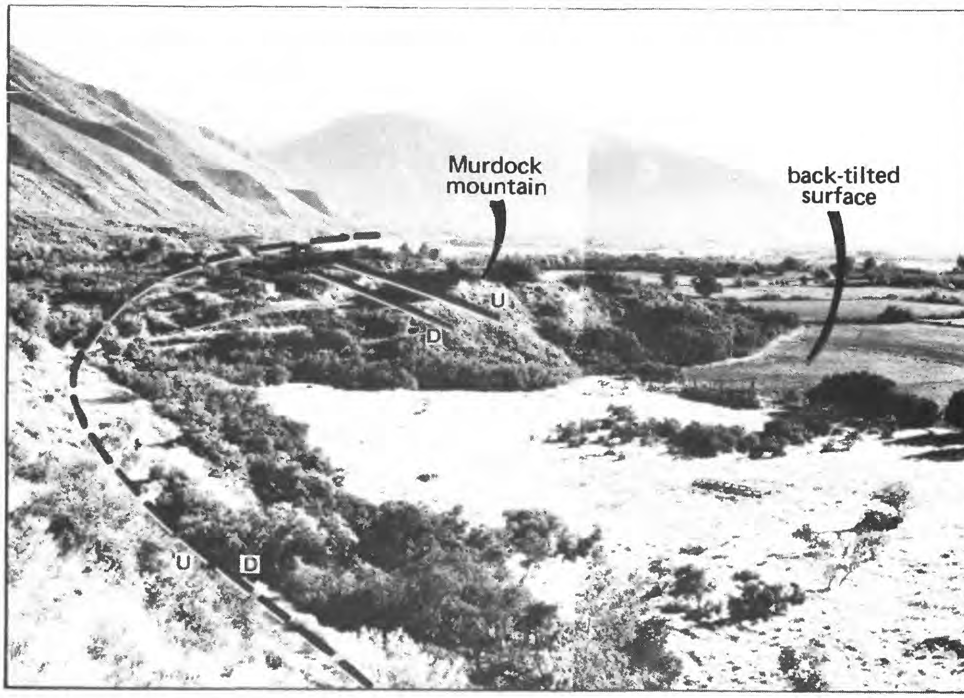
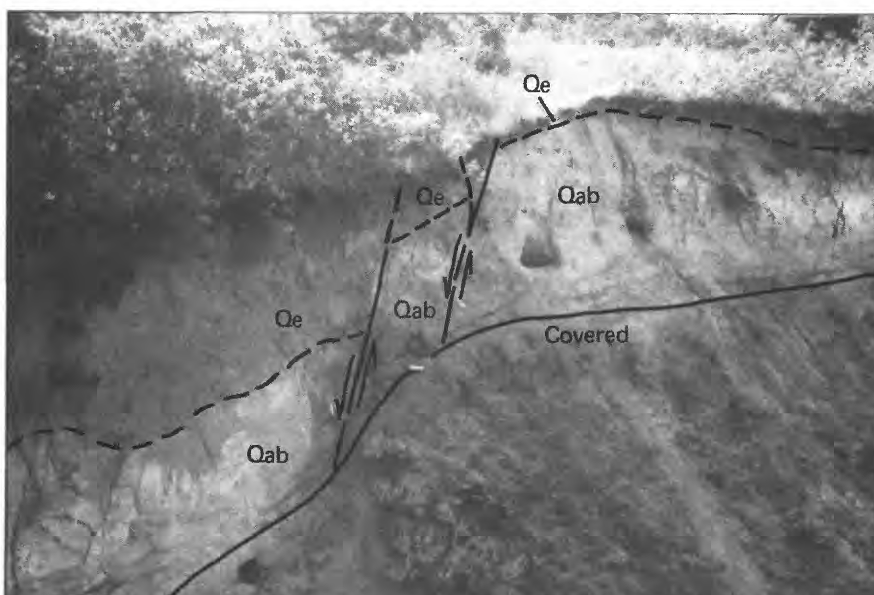


Figure 8 - TOPOGRAPHIC PROFILES SHOWING TERRACES ALONG HOBBLE CREEK

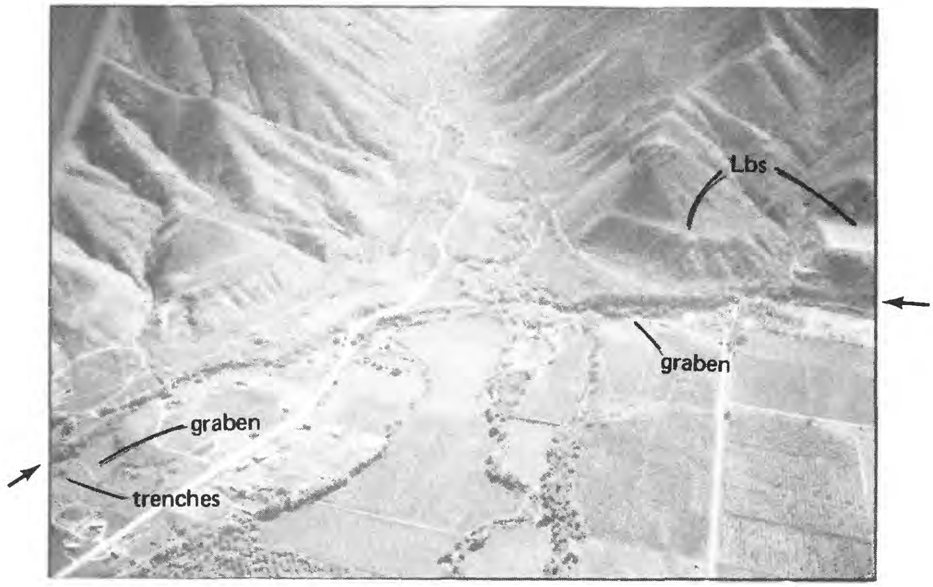


(a) View south along trace of the main fault (dashed line) towards Murdock mountain showing location of antithetic faults (solid lines) and back-tilted surface.

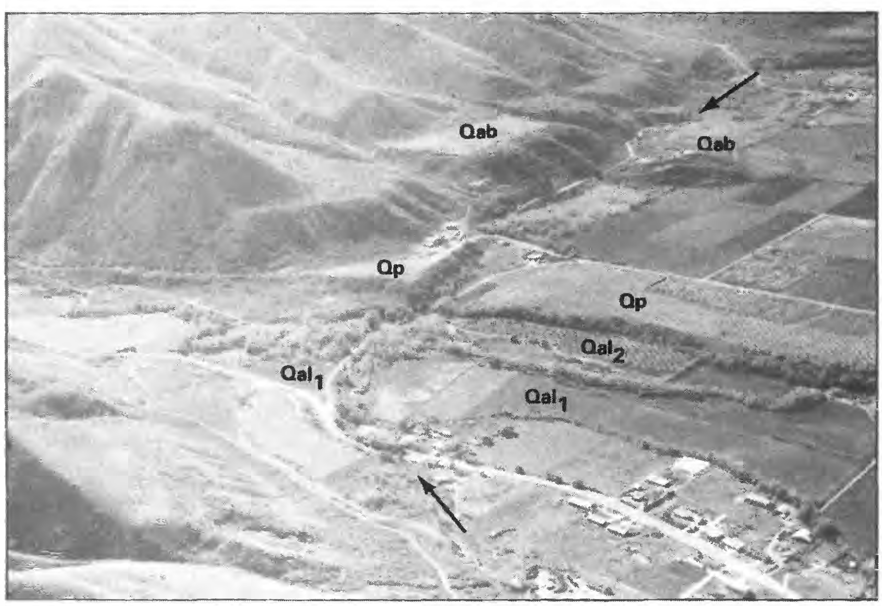


(b) Antithetic faults displacing Alpine-Bonneville lake deposits **(Qab)** and eolian deposits **(Qe)** exposed in canal cut through Murdock mountain. The unconformity between the lake deposits and the windblown sand is displaced approximately two meters vertically down-to the-east.

Figure 9. PHOTOGRAPHS SHOWING ANTICHETIC FAULTS AT MURDOCK MOUNTAIN



(a) View is east towards mouth of Hobble Creek Canyon showing main fault scarp (arrows), grabens, shoreline of Lake Bonneville (Lbs), and trenches.



(b) View is towards the southeast along the main fault scarp (arrows) and shows the progressively lower scraps associated with the successively younger Quarternary deposits. From oldest to youngest, the deposits and related scrap scarp heights are: Alpine–Bonneville lake deposits, (**Qab**), 60 m; Provo fan–delta deposits (**Qp**), 28.5 m; post-Provo-pre-Utah Lake deposits (**Qal_1**), 12.5 m; and the modern flood plain deposits (**Qal_2**), which show no detectable displacement.

Figure 10 – OBLIQUE AERIAL PHOTOGRAPHS OF HOBBLE CREEK SITE

Antithetic fault scarp (arrows) viewed from crest of the main fault scarp before excavation of Trench HC-1 (dashed line). Height of the antithetic fault scarp varies from less than 0.5 to 1.5 m. View is south towards Maple Canyon.

Figure 11- PHOTOGRAPH OF ANTITHETIC FAULT SCARP
AT TRENCH HC-1
HOBBLE CREEK SITE

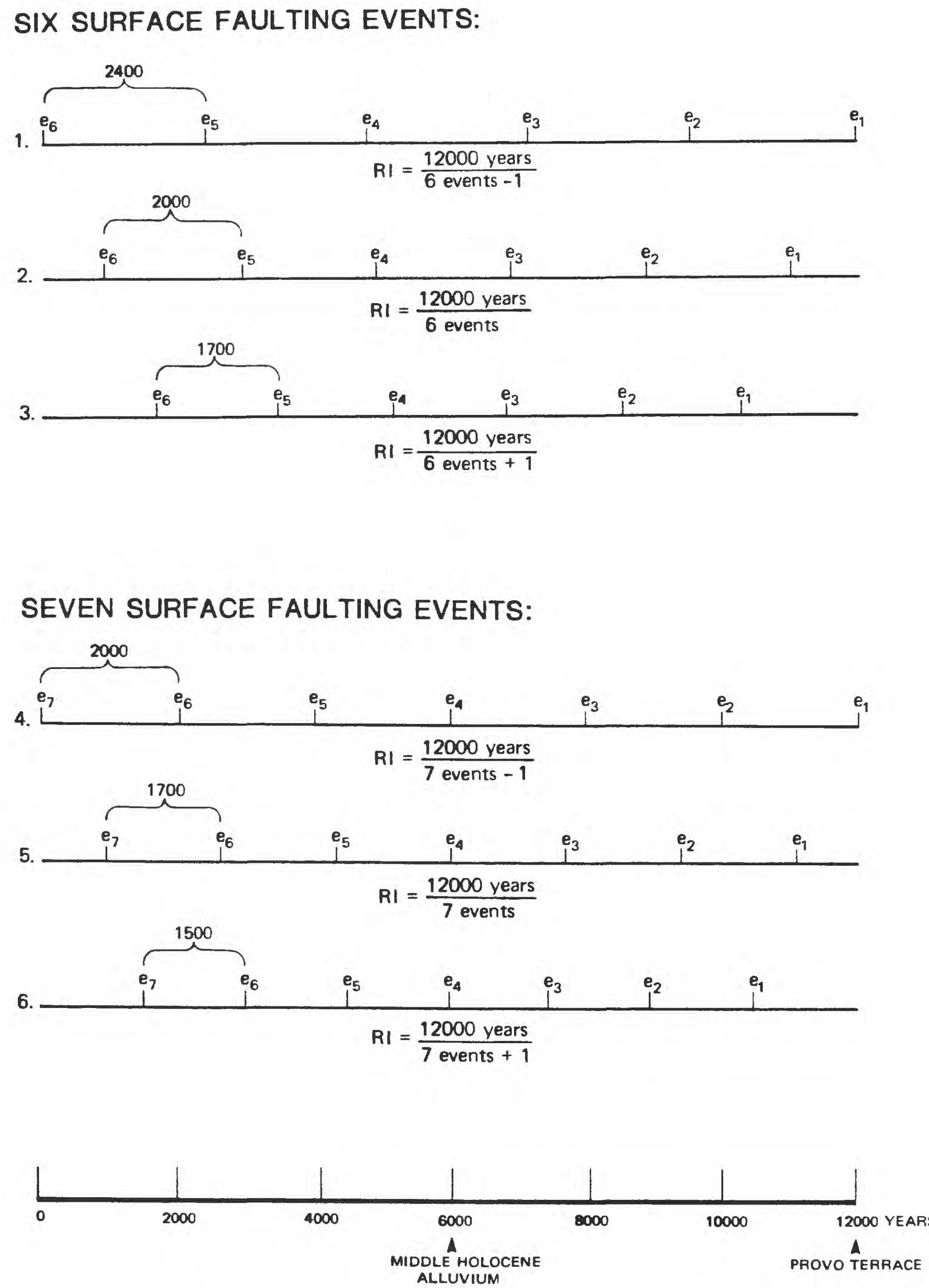


Figure 12 - AVERAGE RECURRENCE INTERVALS (RI) FOR SURFACE FAULTING EVENTS (e) AT THE HOBBLE CREEK SITE