UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Map of fault scarps in unconsolidated sediments, Richfield 1° x 2° quadrangle, Utah

By

R. Ernest Anderson and R. C. Bucknam

Open-File Report 79-1236
1979

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

MAP OF FAULT SCARPS ON UNCONSOLIDATED SEDIMENTS,
RICHFIELD 1° x 2° QUADRANGLE, UTAH

by

R. Ernest Anderson and R. C. Bucknam

INTRODUCTION

As initially conceived this map was to have shown the locations of fault scarps formed on unconsolidated alluvium, colluvium, and lacustrine deposits in the Richfield 1° x 2° quadrangle, Utah. As it stands, the map represents two important departures from these compilation criteria. (1) Scarps formed on basaltic flows of known or inferred Quaternary age in the Cove Fort and Black Rock Desert areas are shown so as to partially depict the Quaternary geologic setting of scarps formed on sediments in adjacent areas such as the Beaver valley and northwest of White Sage Flat. (2) Scarps formed on sediments made cohesive by calcic soils are combined, without discrimination, with scarps formed on true unconsolidated sediments. Such calcic soils impart variable degrees of cohesion (ranging to a firm cementation) to surficial sediments; calcic soils are widespread on old faulted surfaces as well as on old scarp surfaces.

The surficial materials on which scarps in the quadrangle are formed consist mostly of pebble-, cobble-, and boulder-bearing deposits of three principal types: (1) fanglomerate, (2) terrace and pediment mantles, and (3) alluvium reworked by the waters of Lake Bonneville. All are inferred to have been deposited in Quaternary time as the last phase of basin-fill sedimentation. Time-dependant degradation of the fault scarps formed on these deposits serve as a guide to the frequency and location of relatively large earthquakes in the region as averaged over thousands of years. The scarps formed on Quaternary basaltic flows do not serve as such a guide because their durability precludes short-term variations in morphology.

The map is not a comprehensive map of Quaternary faults and thus does not show all faults that may produce earthquakes. Such a map would include all Quaternary faults in bedrock and at bedrock-alluvium contacts as well as Quaternary faults expressed in surficial deposits as lineaments. Also, the map does not show connecting fault traces between discontinuous segments of on-strike fault scarps.

Mapping was done by a systematic scanning of 1:60,000-scale aerial photographs for all possible fault-related offsets of geomorphic surfaces developed on surficial materials and selected lava flows. The search was followed by compilation of the traces of all identified surface discontinuities at a scale of 1:250,000. Additions were made to the compilation from an unpublished compilation of traces of young faults in the Black Mountains area in the south-central part of the quadrangle provided by P. D. Rowley (written commun., 1976). Fault scarps in basaltic flows in the Black Rock Desert and Cove Fort areas were adapted from maps by Hoover (1974) and Clark (1977). The combined compilation served as a guide for field studies that followed.

Field studies consisted of (1) mapping fault traces and deleting from the preliminary compilation features that could not be judged to be fault scarps or that show no surface offset (lineaments), (2) search for stratigraphic indicators of amount and/or age of displacements, and (3) measurements of surface profiles normal to the scarp trace according to procedures described by Bucknam and Anderson (1979a). For this type of study, profiles should be measured only at places where scarps are sufficiently continuous and unmodified by deposition or erosion at their base to be diagnostic of surface offset. Many scarps in the Richfield quadrangle are so old that it is not possible to identify unmodified portions of the downdropped original surface. This is especially true where the surface is downdropped into graben structures or is back-tilted into closely spaced faults. At such localities the downdropped original surface tends to be buried by post-fault sediments. In the measurement of profiles a judicious effort was made to avoid such localities. However, in some areas it was necessary to yield to the position that some data are better than none, and profiles were measured at localities where the downdropped surface could not be identified with certainty.

Profiles were not measured on all scarps and no profiles were measured in areas of basaltic flows. In the valley west of Beaver scarps are locally more abundant than shown on the map (pl. 1).

During field studies, and especially during periods of low sun angle, search was made for sites of surface offset that had not been identified by searching the aerial photographs. Of the few that were found, most represent surface offsets of less than one meter and are located in areas of, or along the projection of, other offsets that were identified from stereoscopic photo study. With the generally good-to-excellent-quality 1:60,000 aerial photography available, offsets with a vertical component of as little as one meter can be detected if they involve planar surfaces of considerable extent.

This map is one of a series of similar maps in western Utah that will form the basis for a 1:500,000 scale compilation of faulting in the region. The authors would appreciate comments, corrections, and additional data that could be utilized for compilation at the smaller scale.

GEOGRAPHIC AND GEOLOGIC SETTING

The Richfield quadrangle includes areas of highly contrasting physiography. In the east are the forested highlands of the deeply dissected western part of the High Plateaus and on the west the ranges and broad intervening alluviated valleys of the Great Basin. Large areas in the east are above 3,000 m elevation and the highest points in the Tushar Mountains are above 3,800 m. In the west, only a few peaks reach 3,000 m and large areas are below 1,800 m. The western part is semiarid and lacks permanent streams. In the eastern part, Beaver River carries waters from the Tushar Mountains westward through Beaver Valley and the Minersville area. The north-flowing Sevier River drains a large part of the High Plateaus in the eastern part of the quadrangle, and carries its waters to a sump in the Sevier Desert north of the quadrangle.

The Richfield quadrangle covers an area that bridges the boundary between the Basin and Range and Colorado Plateaus provinces. That boundary is marked approximately by the course of Interstate Highway 15 and its incomplete segments (U.S. Highway 91). Rocks of Paleozoic, Mesozoic, and Cenozoic age are found on both sides of the boundary, but Mesozoic and Cenozoic rocks predominate to the east and Precambrian, Paleozoic, and Cenozoic rocks predominate to the west (Hintze, 1963; Steven and others, 1978). Exposed Paleozoic rocks east of the boundary are restricted to the Pavant Range where they form the upper plates of east-directed thrust faults that were active during the Late Cretaceous Sevier orogeny. Upper Cretaceous and lower Tertiary sedimentary rocks that post-date the Sevier orogeny overlap the thrusts in the Pavant Range and occur widely scattered elsewhere in the quadrangle; they also may be present west of the province boundary as downfaulted strata in the basins of the Basin and Range. Aside from Paleogene sedimentary rocks in the Pavant Range, Tertiary strata east of the province boundary are mostly volcanic rocks and volcanigenic sedimentary rocks of the Marysvale volcanic pile and minor post-volcanic alluvium. West of the boundary Tertiary rocks include ash-flow tuffs and flows of the Great Basin volcanic province and intrusive rocks. In the Black Mountains in the south-central part of the quadrangle, the volcanic rocks of the Great Basin volcanic province and the Marysvale pile are interstratified (Anderson and Rowley, 1975).

Quaternary rocks and deposits are exposed over about 48 percent of the Richfield 1° x 2° quadrangle; that figure represents a rough estimate of the percentage of the quadrangle studied for fault scarps. The rocks and deposits consist of three main types: (1) mafic and siliceous lava flows, (2) alluvium, colluvium, and pediment gravels, and (3) lacustrine sediments deposited in Lake Bonneville or in other lakes that occupied closed basins. Sparse Quaternary volcanic rocks are found in the highlands (Steven and others, 1978) but, in general, rocks and deposits of Quaternary age accumulated in the topographically low sites of structural depressions that formed during late Cenozoic time by block faulting.

About 19 percent of the total area of the Richfield quadrangle was occupied by Pleistocene Lake Bonneville when it reached its maximum extent. Shoreline, including high-stand features and numerous other features at lower elevations, are well preserved below about 1,570 m (5,150 ft) in the northern part of the quadrangle, but are less well preserved and difficult to locate in the southern part along Escalante Valley (Anderson and Bucknam, 1979). The approximate position of the high-stand shoreline is shown on the map by a dotted line. No fault scarps that formed on Lake Bonneville deposits were identified in this study.

The age of the high stand of Lake Bonneville has not been unequivocally determined. "Landmark" dates chosen by Morrison and Frye (1965) after evaluating radiocarbon determinations of the lake chronology indicate that the high stand occurred sometime in the interval between 11,800 years ago and 15,400 years ago.

Quaternary volcanism of bimodal (silicic and mafic) composition was extensive from the Black Rock Desert southward to the Black Mountains. Pleistocene rhyolitic eruptions occurred in the Mineral Mountains between about 0.8 and 0.5 m.y. ago (Lipman and others, 1978). Rhyolitic volcanism occurred at White Mountain in the Black Rock Desert area as recently as about 0.4 m.y. ago (Lipman and others, 1978) and basaltic volcanism nearby in the Ice Springs volcanic field is inferred to be younger than 12,000 years (Hoover, 1974). Most of the young volcanic rocks are displaced by normal faults. The distribution of faults and the magnitude of separation on them have been studied recently and the results have been used to determine rates of extension (Hoover, 1974; Clark, 1977).

RESULTS

The scarps shown on plate 1 are divided into zones of two types: (1) zones that contain scarps that are probably coeval and therefore indicate the dimensions of an area that probably would be affected by surface rupture associated with a single large earthquake (solid boundary lines), and (2) zones that contain scarps that may or may not be coeval but are grouped together for convenience of discussion (dashed boundary lines). A few isolated scarps are found outside the boundaries shown on the map. Some of these isolated scarps were studied and found to be similar to those in nearby zones.

The chief goal of this study has been to rank fault scarps or groups of scarps according to their relative age and to determine the magnitude of displacement that produced them and the length along which the surface was displaced. The results are presented in table 1. Three factors are considered in the ranking procedure: (1) age relative to shoreline features produced by Lake Bonneville, (2) relative age determined quantitatively from scarp profiles, and (3) relative age determined qualitatively from scarp morphology data. Length of faults is measured from the map (pl. 1) and is listed in table 1 only for those zones bounded by solid lines. Magnitude of offset is measured from the scarp profile. In part A of table 1, scarps and the high stand of Lake Bonneville are assigned relative ages (oldest at the bottom) on the basis of a quantitative evaluation of data determined from scarp profiles, and in part B scarps and the high stand of Lake Bonneville are assigned relative ages on the basis of a general evaluation of scarp morphology. The regression equation of scarp-slope angle (θ) on the logarithm of scarp height (H) for the Bonneville shoreline as reported by Bucknam and Anderson (1979a) is θ=5.61+19.40 log H. Scarps that are inferred to be younger than the high stand of Lake Bonneville are found only at Red Canyon (part B).

In the paragraphs that follow elaboration is presented on the subjects of scarp profiles, surface offset, and length of faulting as they apply to this study, in the hope that the results presented in table 1 will be easily understood. Descriptions of selected aspects of individual scarps or zones of scarps are presented in a subsequent section.

Scarp profiles.--In general, the slope of a scarp decreases with increasing age, but Bucknam and Anderson (1979a) found that the slope of a scarp is strongly dependent on its height as well as its age. In order to make direct comparisons between maximum slope angles measured on different scarps, it is necessary to eliminate the effect of this dependence on scarp height. If profiles for each scarp or group of scarps are measured over a sufficiently broad range of scarp heights, the data can be normalized to an arbitrary scarp height. Data adequate for this type of normalization could not be collected in most zones owing to complications arising from the great age of the scarps or their development on initially steep surfaces. Maximum slope angles normalized to 3 m are given in table 1A, column 5.

A high scarp with a profile that shows a steep youthful-looking segment represents at least two periods of activity. The number of individual displacement events directly indicated by the morphology of the scarp is clearly a minimum. The profiles of some fault scarps consist of two distinct slope segments. The steeper of the two segments probably represents renewed movement on the fault and the more gentle part represents one or more earlier displacement events. Such two-stage or multi-stage scarps are interpreted as resulting from earthquakes and not from fault creep because the creep rates would have to vary dramatically over the displacement history in order to produce the observed scarp morphology. In addition, historic earthquakes have produced fault scarps at 11 locations in the Basin and Range province while no scarps in the province are known to have developed in historic time in a manner that would suggest fault creep.

Many scarps in western Utah, some of which are as much as 25 m high, show no evidence of compound slopes. These scarps, when compared to those produced by large, historic earthquakes, seem too high to have formed in a single event. It is assumed that most, or possibly all, of these very high scarps with smooth profiles were produced by several displacement events despite the fact that direct evidence for multiple events is lacking. This lack of direct evidence indicates that the time elapsed since the last event has been sufficiently long for erosional processes to produce a smooth profile.

Surface offset.--Surface offset is defined in figure 1 and is determined from the profile data. In the Richfield quadrangle only the Beaver zone (table 1a) involves offset of a well-preserved extensive surface; this is suggestive of a single fault event. That event probably represents renewed movement on faults that were active earlier during the late Quaternary. At Water Creek in the Annabella zone and at Amos Canyon in the Red Canyon zone (localities not shown on pl. 1) alluvial surfaces of very limited extent show well-preserved offset suggestive of a single event of renewed movement on faults that also show evidence of earlier activity during the late Quaternary. In the Cricket Mountains zone the original surfaces are completely modified by post-faulting erosion, but the persistence of the low scarp through an area of no obvious earlier fault scarps is suggestive of surface offset due to a single fault event. The number of fault events responsible for surface offsets in the other zones listed in table 1a and 1b are not known. For these old scarps, for which the number of individual events that produced the scarp is unknown, the value given for surface offset is the total surface offset, and that value obviously cannot be directly compared with magnitude/displacement relations.

Length.--The length of a fault scarp given in table 1 is measured in a straight line between the end point of observed surface offset and may or may not reliably reflect the length of the subsurface bedrock fault rupture associated with the earthquake that produced the scarp. In general, the length given in table 1 will be a minimum value for the length of the earthquake source zone. Determination of the total extent of the bedrock fault to be considered as a seismic source zone requires evaluation of additional data such as described by Slemmons (1977).

DESCRIPTIONS OF SCARPS OR ZONES OF SCARPS

As an adjunct to the data presented in table 1, descriptive data and observations that serve as additional justification for the rankings made in the table are presented here. The first two entries pertain to scarps in the Beaver area, the only area where significant amounts of profile data were collected.

Beaver Valley was probably a structural basin with interior drainage during Pliocene and early Pleistocene time. At some time during the Pleistocene the valley wall was breached in the topographically low area between the Black and Mineral Mountains and drainage was integrated with Escalante Valley and the Sevier Desert by the establishment of Beaver River as a through-going stream. Sediments deposited during the interior drainage phase have been incised by the downcutting of streams of the Beaver River system. Downcutting has produced a series of gravel-mantled fans, pediments, and stream terraces throughout Beaver Valley. Many of these surfaces have fault scarps formed on them. In general, old surfaces show greater

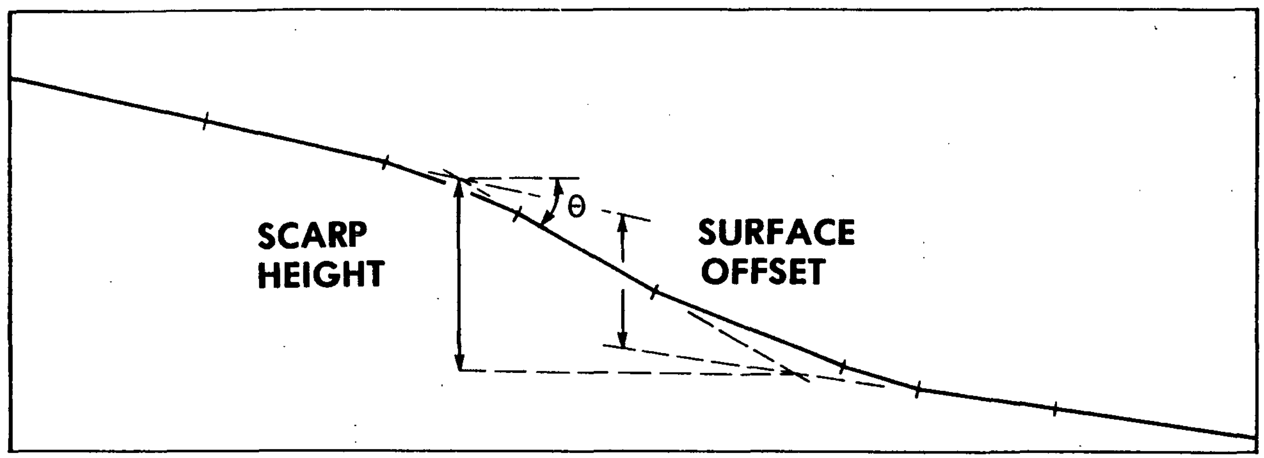


Figure 1.--Scarp profile showing definition of surface offset and scarp height. Tick marks on profile are the intervals measured in the field. θ = scarp-slope angle.

offset than young surfaces, thus providing a sequence of geomorphic surfaces that should be ideal for evaluating the history of faulting. For the present study, analysis was made only of scarps formed on the oldest and youngest of the surfaces. Those on the young surface are referred to as the Beaver fault zone because scarps pass through the town of Beaver, and those on the old surface are referred to as the Last Chance Bench fault zone because they are well preserved on that feature.

Regression lines and equations for profile data (scarp height and slope angle) for the Beaver and Last Chance Bench zones are given in figure 2. Regression lines from some zones of scarps outside the Richfield quadrangle are given for comparison.

1. Beaver

Beaver River and North Creek have constructed a broad alluvial surface that is as much as 6 km wide in the vicinity of Beaver. This is the youngest major surface that predates the modern stream channels. Much of this surface stands only 1 to 3 m above the modern channels of those streams and would probably serve as an active flood plain were it not for manmade alterations in drainage distribution. The alluvial surface is offset along scarps that are remarkably continuous except where they are crossed by the modern stream channels. The scarps range in surface offset from less than 1 m to 3.1 m. Some of these scarps are coextensive with older scarps that have as much as 25 m of indicated offset of older surfaces. The low scarps are inferred to have formed in a single fault event--the youngest of an unknown number of earlier events.

Profile data normalized to an arbitrary scarp height of 3 m suggest that the scarps in the Beaver zone are very close in age to the high stand of Lake Bonneville and therefore are pre-Holocene in age.

2. Last Chance Bench

Last Chance Bench is a gravel-mantled pediment surface that extends from the western base of the Tushar Mountains southwestward about 20 km to the vicinity of Minersville reservoir. It is beveled across faulted and tilted Pleistocene basin-fill strata that have dips as high as 30°. The surface is very uneven because it is cut by at least 50 northerly trending faults that have displacements ranging from 1 to 25 m. In addition to sharp back-tilting into the faults the entire surface has been tilted gently to the south-southeast, possibly contemporaneously with faulting. As a result of this gentle tilting, many minor post-fault drainages have been established at the base of and parallel to the fault scarps--features that preclude the collection of meaningful profile data over most of the area. There is widespread evidence that calcic soils formed prior to, during, and following the fault events that displace the old surface of Last Chance Bench. These calcic soils tend to consolidate and cement the surficial gravels and thereby retard the normal process of scarp modification. The extent to which retardation occurs relative to areas where noncalcic soils form is not known. Studies in southwestern Utah have shown that calcic soils affect essentially all old fault scarps and must be an important regional factor in the rate of scarp modification.

The results of measurement of 15 fault scarp profiles on Last Chance Bench and related surfaces are given in table 1. The data indicate a maximum slope of 9.5° normalized to a

Table 1.--Fault scarp parameters showing chronological implications Richfield 1° x 2° quadrangle, Utah

A. Chronology based on profile data

Locality and identification number	Maximum surface offset (m)		Length of zone of surface offset (km)	Maximum slope in degrees normalized to 3-m scarp height	Number of profiles measured	Number of periods of activity
	Total	Last event				
High stand of Lake Bonneville				15[1]	16	
1 Beaver	25	3.1	16	12.0	20	1
2 Last Chance Bench	--	---	--	9.5	15	2+

B. Chronology based on general evaluation of scarp morphology

Locality and identification number	Maximum surface offset(m)	Length of zone of surface offset (km)
3 Red Canyon	2.2	9.5
High stand of Lake Bonneville		
4 Annabella	5.2	13
5 Cricket Mountains	1.3	18
6 White Sage Flat	13.2	—
7 Marysvale-Circleville	12.2	—
8 Lund	5.5	19
9 Minersville	5.5	—
10 San Francisco Mountains	N.D.	13

1/ From measurements of the wavecut scarp in alluvial fans along the east flank of the Drum Mountains, Juab County, Utah

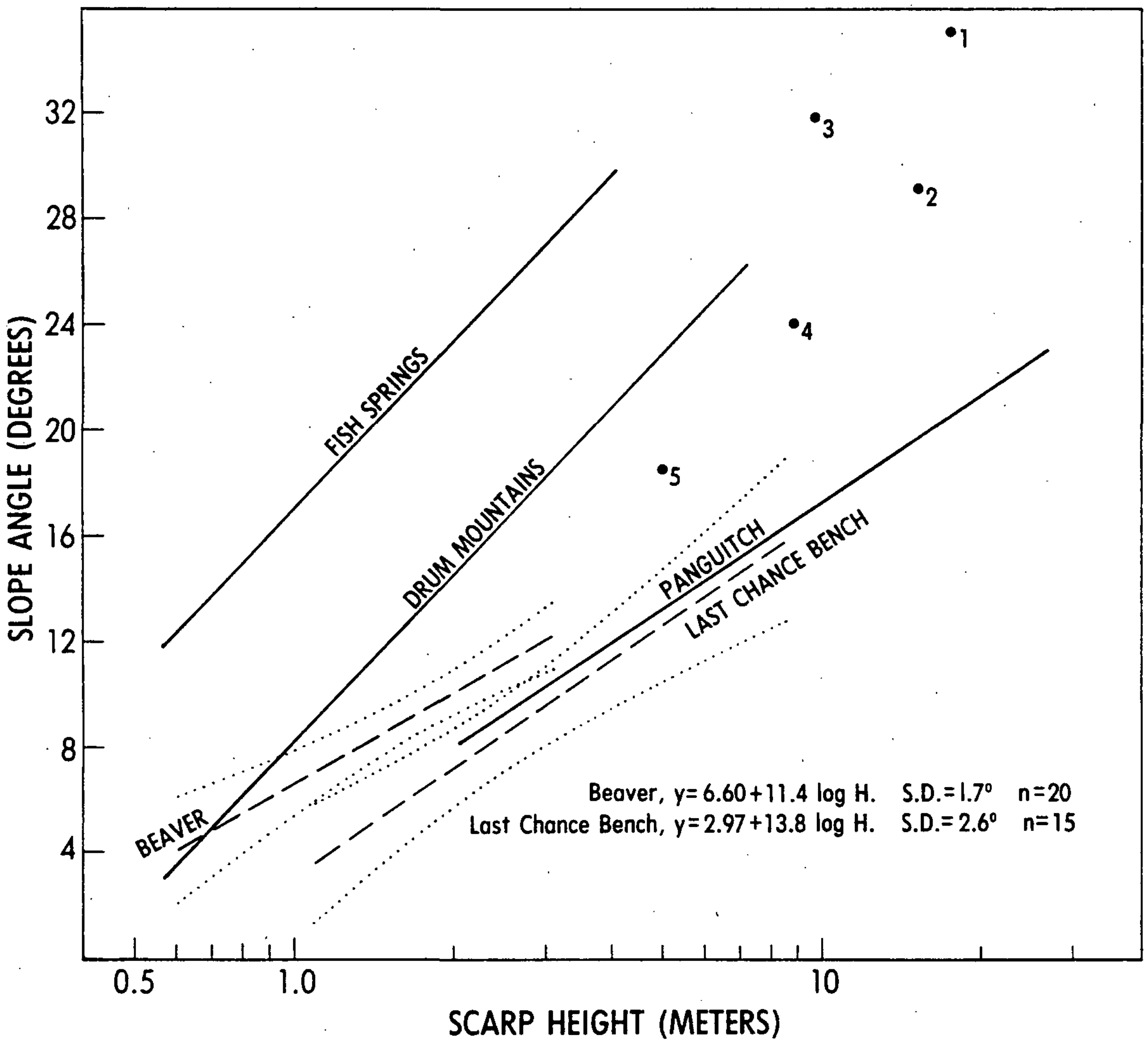


Figure 2.--Regression lines to fault-scarp profile data. Solid lines are for areas reported on by Bucknam and Anderson (1979a), dashed lines represent data collected from the vicinity of Beaver where scarps on an old alluvial surface (Last Chance Bench) are clearly older than scarps on a young alluvial surface (Beaver). Dotted lines define the 95% confidence envelope for the regression lines. Regression equations are given together with the standard deviation of the slope angle about the regression line; n equals number of observations.

scarp 3 m high. The significance of this value is difficult to measure because it represents scarps formed over a time interval of unknown length and because, as noted, the scarps are nonideal from the standpoint of soil development and erosional modification. The sites chosen for profiling, though generally not ideal, were in every case the best available. The time lapsed since scarps began to form on the Last Chance Bench is probably many times greater than the time lapsed since those of the Beaver zone formed despite the fact that they differ by only 2.5 degrees in maximum slope angle normalized to 3 m (table 1a).

3. Red Canyon

The scarps shown in the northeastern part of the quadrangle along the eastern flank of the Pavant Range form the southern part of a 60 km-long quasicontinuous zone of scarps of diverse age described by Bucknam and Anderson (1979b). Fault scarps with surface offsets of at least 2.7 m and of probable Holocene age are identified along a 6.2 km segment of the zone in Scipio Valley, and scarps probably of very latest Pleistocene age are identified along a 13.8 km segment of the zone in Little Valley, both areas in the Delta 2° quadrangle to the north (Bucknam and Anderson, 1979b).

In the Richfield quadrangle fault scarps indicate surface offset of 1.5 to 2.2 m. The offsets are of initially steep surfaces formed on either colluvium or bedrock that is mantled to partially mantled by a thin layer of colluvium. Slopes of 15° to 30° are common on these pre-fault surfaces, and the maximum slope angles of fault scarps formed on them are commonly 35° to 40°. These steep fault scarps are sparsely vegetated compared to adjacent areas, giving the scarp a youthful appearance. This youthful appearance may result from the difficulty seedlings experience in becoming rooted on the steep scarp surfaces. The steepness of the fault scarps may reflect the nearness of bedrock to the surface. In any case, these steep scarps cannot be used in a comparative evaluation with scarps formed on gently sloping fan or terrace surfaces. At one locality, 3.6 km south of the quadrangle boundary at Amos Canyon, the fault crosses a stream terrace whose surface is offset about 2.2 m. At this locality, which is the only one found to be suitable for profiling, the scarp has a maximum slope angle of about 17.5°, suggesting that the scarp is possibly of Holocene age (Bucknam and Anderson, 1979a,b).

4. Annabella

In the Annabella area southeast of Richfield, a zone of fault scarps extends from Thompson Creek northeastward for about 7 km to the eastern quadrangle boundary and for an additional 6 km into the adjacent Salina 1° x 2° quadrangle. The scarps are formed on a variety of materials including fan gravels, stream terrace deposits, and landslide deposits. These have not been mapped in detail; some may be of Tertiary age.

The area is rich in geomorphic evidence of relatively youthful tectonism. Numerous small closed basins and recently breached closed basins are perched on mountain flanks. Down-to-mountain displacements have produced youthful-looking alined inflections of parallel ridge crests, and major drainages appear to have been deflected by long-continued displacements on faults that intersect them. Much of the faulting is probably related to youthful growth of the southern end of the Sevier-San Pete anticline--a 110 km-long structure with thousands of meters of structural relief. The structure is known to have been active during Pliocene and/or Pleistocene time (Gilliland, 1963).

The Annabella zone of scarps is bounded on the east by a main fault that locally displays evidence of large separation. A scarp about 41 m high is formed where the fault crosses on old fan and only 9 m high where it crosses an adjacent younger stream terrace (Water Creek area, Salina 1° x 2° quadrangle). This relationship provides positive evidence of fault recurrence of probable late Quaternary age. Evidence for fault recurrence is also seen in the medial segment of the profile of a high scarp. The medial segment is steeper (35°) than the adjacent segments (27°). The eastern fault scarp of a small graben east of Annabella (pl. 1) is about 29 m high and its profile also has a medial segment that is steeper (29°) than other parts of the scarp (20°), suggesting fault recurrence.

Five profiles were measured on scarps in the Annabella zone. If only the effects of the youngest fault events are considered, the data suggest that the maximum slope angle of scarps in the Annabella zone is more dependent on scarp height than in other areas of western Utah (fig. 2). The reason for this strong dependency is not known. Scarps 1 and 2 (fig. 2) may be anomalously steep because they formed on existing moderately steep scarps and scarp 3 may be anomalously steep because bedrock is near the surface at that locality. In any case, this set of data cannot be compared directly with data sets from other areas (Bucknam and Anderson, 1979a). Only the profile across the faulted stream terrace at Water Creek (Salina quadrangle) (scarp 4, fig. 2) represents a scarp that probably formed in a single fault event and is uncomplicated by other factors. That profile indicates an age for the youngest event that may be close in age to the Bonneville shoreline. Scarps in the Annabella zone are mostly much older than Holocene, although the youngest fault event--exhibiting surface offset of at least 5.2 m--may have occurred close in time to the Pleistocene-Holocene boundary.

5. Cricket Mountains

Discontinuous low fault scarps on the western flank of the Cricket Mountains form a zone about 18 km long. The scarps are located in the area between the Bonneville and Provo 1 shorelines and are formed on fan gravels that are mantled locally by thin deposits of beach gravel. The fan surfaces have been delicately etched into a series of subdued beach terraces spaced a few tens of meters apart, and the fault scarps trend at a low angle across the traces of the beach terraces. The fault scarps are 1-2 m high and have a steeper maximum slope angle than the adjacent wave-etched scarps.

Despite the apparent steeper slope, the fault scarps are interpreted to be older than the adjacent wave-etched scarps because (1) at one locality a faint trace of a wave-etched bench can be seen on the fault scarp, (2) the fault scarps are only found in areas where there is negligible lacustrine sedimentation, and (3) the beach terraces show no apparent offset across the fault scarps. The shore features probably developed during the rise of Lake Bonneville waters to the Bonneville shore--a feature that has an estimated age between about 15,400 and 11,800 years (Morrison and Fry, 1965, Bucknam and Anderson, 1979a). They were probably not expressed as steep scarps when they were formed. The fault scarps were probably steep when they were formed and are older than the shore features.

A single profile across one of the scarps indicates an age similar to that of scarps in the area east of the Drum Mountains north of the quadrangle inferred by Bucknam and Anderson

(1979b) to be younger than the Bonneville shoreline. Additional studies, including profiling of fault and shore scarps, are planned for this area.

6. White Sage Flat

In the area northwest of White Sage Flat, about 15 km west-southwest of Kanosh, fault scarps are found above and below the level of the Bonneville shoreline. The scarps are part of a widespread system of north- to northeast-trending scarps formed on basaltic lavas and adjacent alluvium as mapped by Clark (1977). They are formed on fan gravels which, in the area below the Bonneville shoreline, are mantled locally by deposits of rounded beach gravels. In the area above the Bonneville shoreline the ancient fan surfaces were probably dissected prior to faulting and have been strongly dissected since that time. Drainage courses have been established along many of the fault scarps, thus rendering them unsuitable for profiling. Evidence is widespread that a mature carbonate soil had developed on the ancient fan surface and on surfaces that dissect it.

All scarps that extend to the Bonneville shoreline from the south and southwest are destroyed at the shoreline by the construction of a wave-cut bench, proving that faulting predates the shoreline. This age relationship is further substantiated in the area of the ancient lake bed by (1) the presence of barrier bars that terminate in depositional contacts against a fault scarp, (2) faint wave-cut benches formed on the upthrown fan gravels at some faults, and (3) the absence of scarps in areas where the ancient fan gravels are buried beneath lacustrine deposits. The fault scarps in the ancient lake basin had to have survived the advance and retreat of the waters of Lake Bonneville (as with those in the Cricket Mountains zone), though none survived the relatively long-term stillstand at the Bonneville level and some were probably completely buried by lacustrine sediments. Those that survived probably did so, in large part, because of the competency rendered to the alluvial gravels by pre-lake pedogenic carbonate cement.

The highest scarp in the area northwest of White Sage Flat is the one nearest the highway (pl. 1). It has a minimum surface offset of 13.2 m above the Bonneville shoreline and 4.3 m below the shoreline. On the basis of only four profiles, the estimated maximum slope angle normalized to a scarp height of 3 m is about 12°. Using 15° for the maximum slope angle of the Bonneville shoreline normalized to a height of 3 m (Bucknam and Anderson, 1979a) the fault scarps appear to be older than the shoreline, which is proven on the basis of crosscutting relationships as noted above.

7. Marysvale - Circleville

Widely scattered scarps along the valley of the Sevier River between Circleville and Marysvale are included in a single zone. The valley is, in general, a fault-bounded feature and most scarps occur near the major structural margins of the valley (Steven and others, 1978). Other scarps, in medial portions of the valley near Marysvale and south of Elbow Ranch, may be structurally analagous to those in the Beaver valley.

Eleven profiles were measured on scarps ranging in height from 1 to 15 m. Maximum slope angles range from 6° to 24°. When the height-slope angle data are compared with reference relationships for western Utah (Bucknam and Anderson, 1979a, fig. 5) an age similar to that of scarps in the Panguitch, Utah area (also in the Sevier River Valley) is indicated, although the data show more scatter than for the Panguitch area. The scarps in the Marysvale-Circleville area are associated with several different faults or fault zones and probably represent faulting of several different ages. This age diversity may be reflected in the scatter of the data, but it is not possible to evaluate because not enough is preserved of scarps associated with individual structures to permit detailed morphometric analysis. The data, together with data from Panguitch to the south and Annabella to the north, do provide evidence that the series of structures that are paralleled by the northerly trending valley of the Sevier River have experienced surface displacement during late Quaternary time but probably not during Holocene time.

8. Lund

The westernmost scarps in the quadrangle are found at the southern end of the Wah Wah Mountains. They form a 19 km zone that extends northeast from 3 km south of the quadrangle boundary. The scarps cross alluvial fans that were formed by streams that flowed to Escalante Desert from the Wah Wah Mountains. Surface offsets are down toward the basin to the east and southeast. A single profile west of Lund indicates at least 5.5 m of surface offset, but locally it is probably as much as 10 m. The scarps are above the level of the inferred high stand of Lake Bonneville (Anderson and Bucknam, 1979). They are so highly dissected by closely spaced washes that meaningful profile data could not be collected. The extent of erosional dissection is similar to that of scarps in the Minersville zone. At a locality 2.8 km northwest of Lund a poorly defined shoreline that appears to represent the high stand of Lake Bonneville is formed on alluvial materials that postdate formation of the fault scarp.

9. Minersville

A zone of highly dissected discontinuous scarps extends from south of Minersville 37 km northward along the western base of the Mineral Mountains. In the southern part the scarps indicate downthrow to the west. They are so highly dissected and modified that only one locality suitable for profiling was found. The scarp there has a surface offset of 5.5 m. In the northern part, the scarps reflect a band of discontinuous asymmetric grabens. Surficial materials on which those scarps are formed vary widely from boulder fanglomerate to coarse sandy gruss derived from a large Tertiary batholith exposed to the east in the central Mineral Mountains. Five profiles were measured on the graben scarps, but they are of limited value because of the uncertain effect of clast size on slope modification. Minimum scarp heights are as much as 7.3 m on the eastern faults of the grabens and 1-4 m on the western faults. The limited profile data suggest that scarps that formed on boulder and cobble conglomerate are slightly older than those on the Last Chance Bench in Beaver Valley, whereas those that formed on gruss have low slope angles and appear much older.

One of the faults, the northernmost one of the zone (pl. 1), has apparent offset down to the east and is an important structure in the Roosevelt Hot Springs thermal area because of its apparent influence on convective rise of hot water. Alluvial materials along the fault are highly modified by cementation with siliceous sinter and minor sulfur deposited by rising hot water. The cementation renders the materials unsuitable for profiling. Petersen (1973) shows strata of Holocene age to be offset by the fault, but a brief reconnaissance of the area failed to disclose criteria that could be used to verify such a young age. The scarp is as highly dissected as other scarps in the area, suggesting that it is as old as they are. According to the ranking in table 1 the scarps are pre-Holocene. They, like the scarps on Last Chance Bench, probably formed at an age many times older than that of the Pleistocene-Holocene boundary.

10. San Francisco Mountains

Aerial photographs show scattered short step-like discontinuities in old dissected fan surfaces on the western flank of the San Francisco Mountains. These discontinuities are probably fault scarps. They are alined as single down-to-the-west scarps, forming a zone 13 km long. No field studies were made of these scarps, but comparison with other scarps visible on aerial photos of the same scale suggest that the scarps are as much as 10 m high and are among the oldest that have been identified in unconsolidated sediments of the Richfield quadrangle.

11. Buckskin Valley

Subdued and dissected scarps near the axis of Buckskin Valley suggest faults that bound a narrow horst. Exposures of the materials that form the horst were not seen, but they are inferred to be unconsolidated boulder fanglomerate. The scarps are located along the northerly projection of a fault mapped in bedrock by Anderson (1971). Profiles were not measured, and the scarps are not included in table 1 because of an uncertainty as to whether the scarps reflect an offset surface or the flanks of an erosional rib produced by a raised block whose physical properties contrast with those of the adjacent downdropped blocks.

12. Parowan Valley

The few short fault scarps in Parowan Valley, along the southern border of the quadrangle, are at the northern end of a 25-km-long zone of scarps that parallels the valley axis. These scarps will be described in a subsequent report dealing with faulting in the Cedar City 1° x 2° quadrangle. They are not included on table 1.

REFERENCES CITED

Anderson, J. J., 1971, Geology of the southwestern High Plateaus of Utah--Bear Valley Formation, an Oligocene-Miocene volcanic arenite: Geological Society of America Bulletin, v. 82, p. 1179-1205.

Anderson, J. J., and Rowley, P. D., 1975, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 1-51.

Anderson, R. E., and Bucknam, R. C., 1979, Two areas of probable Holocene deformation in southwestern Utah: Tectonophysics, v. 52, p. 417-430.

Bucknam, R. C., and Anderson, R. E., 1979a, Estimation of fault-scarp ages from a scarp height-slope angle relationship: Geology, v. 7, p. 11-14.

______ 1979b, Map of fault scarps on unconsolidated sediments, Delta 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 79-366.

Clark, E. E., 1977, Late Cenozoic volcanic and tectonic activity along the eastern margin of the Great Basin, in the proximity of Cove Fort, Utah: Brigham Young University Geology Studies, v. 24, pt. 1, p. 87-114.

Gilliland, W. N., 1963, Sanpete-Sevier Valley anticline of central Utah: Geological Society of America Bulletin, v. 74, p. 15-124.

Hintze, L. F., compiler, 1963, Geologic map of southwestern Utah, in Geology of southwestern Utah, 1963: Intermountain Association of Petroleum Geologists Guidebook, 12th Annual Field Conference, Utah Geological and Mineralogical Survey, 232 p.

Hoover, J. D., 1974, Periodic Quaternary volcanism in the Black Rock Desert, Utah: Brigham Young University Geology Studies, v. 21, pt. 1, p. 3-72.

Lipman, P. W., Rowley, P. D., Mehnert, H. H., Evans, S. H., Jr., Nash, W. P., and Brown, F. H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah—Geothermal and archeological significance: U.S. Geological Survey Journal of Research, v. 6, no. 1, p. 133-147.

Morrison, R. B., and Frye, J. C., 1965, Correlation of the middle and late-Quaternary successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), southern Great Plains, and eastern Midwest areas: Nevada Bureau of Mines Report 9, 45 p.

Petersen, C. A., 1973, Roosevelt and Thermo hot springs, Beaver County, Utah, in Hintze, L. F., and Whelan, J. A., eds., Geology of the Milford area, 1973: Utah Geological Association Publication 3, p. 73-74.

Slemmons, D. B., 1977, State-of-the-art for assessing earthquake hazards in the United States; Report 6, Faults and earthquake magnitude: U.S. Army Waterways Experiment Stations, Miscellaneous Paper 5-73-1, 129 p.

Steven, T. A., Rowley, P. D., Hintze, L. F., Best, M. G., Nelson, M. G., and Cunningham, C. G., 1978, Preliminary geologic map of the Richfield 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 78-602.

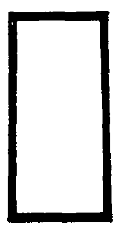
Department of the Interior
U.S. Geological Survey

Open-File Report 79-1236

Explanation for Plate 1

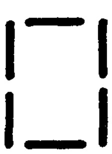
Fault scarps in unconsolidated sediments, dot on line indicates downthrown side of fault, where known

RED CANYON

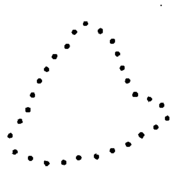


Zone of fault scarps and name of locality for scarps that are probably coeval

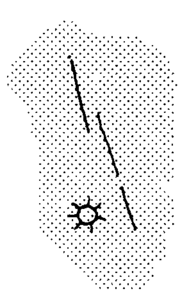
WHITE SAGE FLAT



Zone of fault scarps and name of locality for scarps that may not be coeval



Approximate location of the high stand of Lake Bonneville



Area of Quaternary basalt containing fault scarps; hachured circle marks locations of volcanic vents