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GEOLOGICAL SURVEY

Map of Fault Scarps on Unconsolidated Sediments, Delta 1° x 2° Quadrangle, Utah

By

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INTRODUCTION

The accompanying map (pl. 1) shows the locations of fault scarps developed on deposits of unconsolidated to weakly consolidated alluvium and colluvium and selected mafic lavas in the Delta 1° by 2° quadrangle, Utah. The surficial deposits on which most scarps in the Delta quadrangle are formed consist of pebble-cobble-bearing and boulder-bearing fan gravel inferred to have been deposited in late Quaternary time as the last phase of basin-fill sedimentation. The fault scarps formed on these deposits offer a guide to the frequency and location of relatively large earthquakes in the region as averaged over thousands of years.

The map is highly restrictive in that it only shows the traces of fault scarps preserved on unconsolidated materials and selected mafic lavas of Quaternary age. It 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. In addition, the map shows only fault traces where unconsolidated materials are affected, and not those localities where only bedrock is affected.

Aerial photographs at the scale 1:60,000 were systematically scanned for all possible fault-related offsets of geomorphic surfaces developed on surficial materials and selected lavas. The photoreconnaissance was followed by compilation of the traces of all identified surface discontinuities at a scale of 1:250,000. This preliminary compilation served as a guide for the field studies that followed.

Field studies had three objectives: (1) Fault traces were mapped and deleted from the preliminary compilation of features if it was judged not to be a fault scarp or showed no surface offset (lineaments); (2) stratigraphic indicators of amount and (or) age of displacements were sought; and (3) surface profiles normal to the scarp trace were measured according to the procedures described in Bucknam and Anderson (1979). Profiles were measured only at places where scarps are sufficiently continuous and unmodified by deposition and erosional channels at their base to be diagnostic of surface offset. Profiles were not measured on all scarps.

While in the field, especially during periods of low sun angle, sites of surface offset that had not been identified on the aerial photographs were sought. 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 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.

The authors would appreciate comments, corrections, and additional data about this and adjacent areas in western Utah.

GEOLOGIC SETTING

The quadrangle is located in the eastern Great Basin, Utah, and includes the southern extreme of the Great Salt Lake Desert and the northern part of the Sevier Desert. The Sevier and Beaver Rivers, which drain a large part of the western Colorado Plateau province, flow into the southeastern part of the quadrangle and terminate at Sevier Lake which is the sump for drainage in the Sevier Desert.

The mapped area is primarily within the Basin and Range structural province; a small area in the southeastern part of the mapped area is within the northern part of the Pavant Range and the eastern part of the Valley Mountains. The Pavant Range and the Valley Mountains are generally considered to be uplifted blocks belonging to the western faulted margin of the Colorado Plateau province. The boundary between the provinces is defined approximately by the course of Highway 91.

Bedrock is exposed over only about 30 percent of the quadrangle and consists of rocks ranging from Precambrian through Cenozoic age. The remainder of the area is underlain by alluvial, eolian, and lacustrine deposits generally known or inferred to be of Quaternary age. Most ranges were formed during Cenozoic time by block faulting or volcanotectonic processes. Those exposing old rocks commonly contain evidence of earlier compressional tectonics of the Sevier orogeny of Late Cretaceous - early Tertiary age.

In Pleistocene time, Lake Bonneville occupied as much as 60 percent of the total area of the Delta quadrangle. Shoreline features, including the high-stand features and numerous others at lower elevations, are extensively preserved at and below about 5140 ft (1600 m) elevation. The approximate position of the high-stand shoreline is shown on the map by a dotted line.

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.

An ancestral version of the Sevier River drained into Lake Bonneville and constructed a large delta from which the town of Delta and the quadrangle take their names. Because the delta is deeply entrenched by the modern Sevier River, the river banks provide excellent exposures of Quaternary sediments, locally faulted, that were deposited in Lake Bonneville. These sediments were studied by Gilbert (1890) and, more recently, by Varnes and Van Horn (1961) and D. J. Varnes (U.S. Geological Survey, unpub. data).

Quaternary volcanism of predominantly mafic composition was extensive in the eastern part of the quadrangle. Lavas have been dated by the K-Ar method at 0.88 m.y. from Fumarole Butte northwest of Delta, 0.31 m.y. at Smelter Knoll west of Delta (Peterson and others, 1978), and between 0.03 and 0.13 m.y. in the vicinity of Pavant Butte south of Delta (Hoover, 1974). Volcanism in these areas represents the northern part of a belt of Quaternary mafic and minor siliceous volcanism that continues for 70 km south of the quadrangle boundary. Most of the volcanic rocks are locally 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).

In some areas volcanic materials are interstratified with or form important constituents of lacustrine sedimentary rocks deposited in Lake Bonneville (Hoover, 1974; Varnes, oral commun., 1977). According to Varnes (oral commun., 1977), two basaltic tephra layers in lacustrine deposits near Delta suggest that rises in lake level coincided with ash eruptions and may indicate a cause and effect relationship.

RESULTS

The chief goal of this study has been to map fault scarps in unconsolidated materials, to rank the fault scarps or groups of scarps according to their relative age and to determine the magnitude of displacement that produced them, as well as the length along which the surface was displaced. At no fault site in the Delta quadrangle were we successful in acquiring datable materials from faulted beds. For ranking according to age we have relied on (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 faulting was measured on the map (pl. 1), and magnitude of offset was measured from the scarp profile. The results are presented in tables 1 and 2. In table 1 four scarp zones are assigned relative ages on the basis of a quantitative evaluation of data determined from scarp profiles, and in table 2 other scarp zones are assigned relative ages on the basis of a general evaluation of scarp morphology. Scarps that are inferred to be younger than the high stand of Lake Bonneville are found in both parts.

In the following sections, we elaborate 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 also follow.

Scarp profiles.--In general, the slope of a scarp would be expected to decrease with increasing age, but in addition Bucknam and

Anderson (1979) 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. Maximum slope angles normalized to 3 m are given in Table 1.

Between the upper convex and lower concave parts of a fault scarp, 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. We interpret such two-stage or multi-stage scarps as resulting from earthquakes and not from 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.

Table 1.--Fault scarp parameters, ranked on profile data, Delta 1° x 2° quadrangle, Utah.

[Zones of scarps are arranged by inferred age with young zones above old zones]

Name of fault scarp zone	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[1]				
1 Fish Springs	3.3	3.3	12.1	27	38	1
2 Scipio Valley	>11.1	2.7	6.2	25	15	2
3 Drum Mountains	6.7	6.7	36.0	18	49	1
High stand of Lake Bonneville----------				[2]15	16	--
4 Little Valley	8.2	---	13.8	15	11	1

[1] Last event displacement given only for youthful fault scarps where field observations indicate that it represents a single event.

[2] From measurements of the wavecut scarp in alluvial fans along the east flank of the Drum Mountains.

Table 2.--Fault scarp parameters, ranked on general evaluation of scarp morphology, Delta 1° x 2° quadrangle, Utah

Name of fault scarp zone	Maximum surface offset (m)	Length of zone of surface offset (km)
Clear Lake	2	20
House Range	1	5
Pavant Range	7	32
Inferred relative position of time of high stand of Lake Bonneville		
Scipio	N.D.	6.9
Sheeprock	>2.4	10.9
Maple Grove	12	4.5
Cricket Mountains	15	1
Deep Creek	N.D.	5.5
Tintic	N.D.	4

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. We infer 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. A high scarp with a youthful-looking steep scarp segment at its base represents at least two periods of activity. The number of individual displacement events directly indicated by the morphology of a scarp is clearly a minimum.

Surface offset.--Surface offset is shown in figure 1 and is determined from the profile data. For some very youthful scarps, the well-preserved details of the faulted surfaces seem most consistent with a scarp resulting from a single event. Accordingly, the offsets listed in the tables are measures of the ground surface displacement resulting from single events. For older scarps where the number of individual events that produced the scarp is unknown, only the total surface offset is given, and that value obviously cannot be directly compared with magnitude/displacement relations.

Length.--The length of the zone of offset given in tables 1 and 2 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).

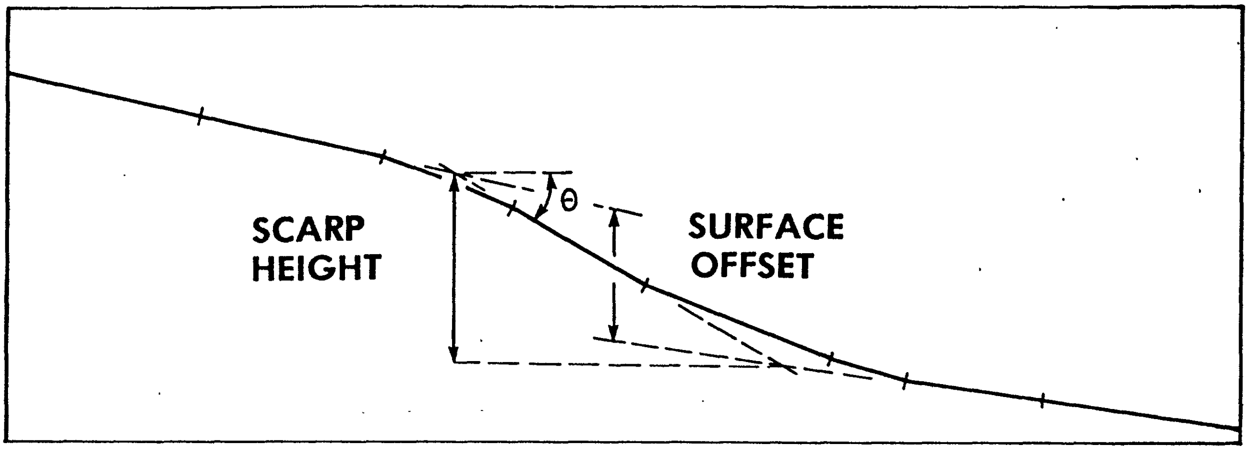


Figure 1.--Scarp profile showing definition of surface offset. Tick marks on profile are the intervals measured in the field. Θ = scarp-slope angle.

DESCRIPTIONS OF SCARPS OR ZONES OF SCARPS

As an adjunct to the data presented in table 1 we present here descriptive data and observations that will serve as additional justification for the rankings made in table 1. Two areas, Fish Springs and Drum Mountains, are described in Bucknam and Anderson (1979).

The first five descriptions pertain to a 60 km-long quasicontinuous zone of scarps of diverse age east of the Canyon and Pavant ranges (pl. 1). A few short scarps that appear to be part of this zone are found outside of the locality boundaries delineated on the map. These have not been studied in detail and are not described below, but their general appearance suggests that all are older than the high stand of Lake Bonneville. Although details of their relationship to the history of the zone are not known, they attest to the relatively high rate of activity along the zone.

1. Little Valley

   The morphology of the scarps, based on profile measurements, indicates that the scarps are approximately the same age as the high-stand shoreline; field evidence shows that the scarps are truncated by the shoreline and are thus older.

2. Scipio Valley

   The scarp in this section is notable because of the evidence of two periods of fault movement, one pre-Holocene and one Holocene. Along much of its length the younger scarp forms a steeper slope segment on the face of the older scarp. The alluvium, in the bottom of broad washes in smoothly rounded cross sections that dissect the older scarp, has been offset by the younger event. Several major active drainages have obliterated the young scarp with no evidence of a knickpoint in the stream profile, but erosion of the young scarp by other smaller drainages has produced steep-sided gullies that have migrated headward from the scarp only a few meters. The steepness of slope for a given height, the relatively unrounded upper limit of the scarp, and its moderate degree of dissection closely resemble the features along the Fish Springs scarp.

In addition to the fault scarps in Scipio Valley shown on plate 1, northeasterly trending zones of elongate sinkholes are conspicuous features affecting unconsolidated sediments of the segment in an area generally southeast of the mapped scarps. Many of the sinkholes are youthful, having formed within the last decade. They have been described by Bjorklund and Robinson (1968) as resulting from collapse of solution cavities developed along faults in the bedrock below the alluvium of the valley. Most of the sinkholes are elongate; maximum reported dimensions are 9 m wide, 75 m long, and 8 m deep. There was no vertical displacement across any of the sinkholes examined by us.

The zone of scarps at Little Valley and the older scarps in the Scipio segment are separated by a distance of about 4 km, as well as, a possible structural divide at the Low Hills. The profile data are insufficient to define the age of the pre-Holocene scarps in Scipio Valley to determine if it is the same approximate age as the Little Valley and Scipio Valley scarps and thus both might be considered as having resulted from a single event. It is clear, however, that the younger event in the Scipio segment did not extend northward to the Little Valley segment.

3. Scipio

A zone of faulting producing a well-defined graben occurs on trend with and immediately south of the Scipio Valley segment. Although it appears to be a continuation of the Scipio Valley segment it is considered separately because evidence for the young event is not present. The subdued expression of these scarps suggests that they are older than the high stand of Lake Bonneville.

4. Pavant Range

In contrast to other scarps shown on the map, the Pavant Range scarp hugs the base of the steep eastern face of the range. Locally the scarp exposes bedrock of the mountain block by displacement of a thin veneer of colluvium mantling slopes as steep as 35°. In such places the scarp appears very fresh. Several profiles measured where the scarp occurs on alluvium at the mouths of canyons, however, suggest that the scarp may be older than might be inferred from its appearance in the colluvium.

5. Maple Grove

The scarp in this segment is formed on very coarse alluvial fan gravels. Boulders as much as 2 m in diameter are common in the upper part of the deposit, forming a less erodible layer that contributes to scarp angles as steep as 47°. The amount of dissection of the scarp and its broadly rounded crest suggest that the scarp is older than the high stand of Lake Bonneville. No evidence of scarps as young as those noted directly to the north and south along the Pavant Range were noted along this segment.

6. Clear Lake scarp

In the Sevier Desert south of Delta, a 20 km-long zone of fault traces extends from the Union Pacific railroad tracks south-southeast to a short distance south of the map boundary. Indicated displacements are down to the east. The faults are located to the south and along strike of a conspicuous east-facing scarp (not shown on map) formed on basaltic bedrock north of the railroad and are parallel in strike with the southern scarps of the Drum Mountains area. The faults are conspicuous on aerial photographs because (1) they cut oblique to the northeast-trending low-amplitude linear ridges (sief dunes) that are the most visible physiographic feature in the area, and (2) they tend to separate domains of contrasting vegetation and (or) surficial material. Along part of the zone the faults are marked by a scarp 1-2 m high, but elsewhere they are either marked by a low-amplitude berm or are unmarked by any clearly discernible topographic feature. This zone of scarps and lineaments is formed on fine-grained loose to weakly consolidated lacustrine sediments and on eolian deposits composed of materials derived from those sediments.

Despite the fact that the faults are not everywhere marked by scarps, they are shown on the map as continuous lines. This departure from the stated guidelines for compilation was made because we infer that the faults moved during the late Quaternary and that scarps probably existed along the entire zone but have been obliterated locally by highly active eolian redistribution of surficial materials.

A profile was measured about 100 m south of the intersection of the scarp with the road that connects Clear Lake siding with Clear Lake. The scarp at that locality is 2 m high and has a maximum slope angle of 10°. A test pit dug to a depth of about 1 m into the scarp revealed sandy material that contains sparse suspended pebbles and minor silt. The upper 20 cm is weakly cemented, possibly by pedogenic carbonate, and grades downward into surprisingly loose noncemented sediment in the lower 70 cm. It is not known whether the loose sediment is lacustrine or eolian or whether it is faulted or deposited on the scarp after faulting. The presence of sparse suspended pebbles suggests a lacustrine origin which, if correct, indicates that the loose sediment is faulted. In any case, a high potential for rapid scarp modification makes the scarp unsuitable for morphologic comparison with other scarps in the Delta quadrangle.

7. House Range

Although there are insufficient profile data to determine the age of this scarp, the fact that shoreline features are displaced across the scarp clearly indicates that it is younger than the high-stand of Lake Bonneville.

8. Cricket Mountains

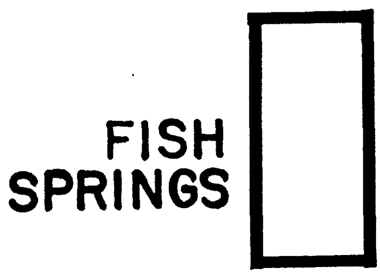
Although these two short scarps occur below the level of the high stand of Lake Bonneville, they are clearly older than the high stand. The scarps are modified by wave action and in places faint traces of shorelines are preserved on the faces of the scarps. The scarps are formed on a very coarse gravel of quartzite boulders. Boulders 30-50 cm seem most common; some are as large as 1 m diameter. The segment of the scarp that is preserved may be the result of an unusual resistance to erosion of the deposits on which they are formed.

9. Deep Creek and Tintic

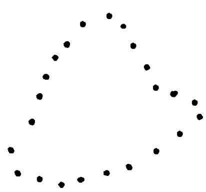
These have not been examined in the field, but their appearance on aerial photographs suggests that they are among the oldest scarps that we have recognized in western Utah. They are preserved as isolated, highly dissected short segments largely buried by alluvium of several distinctively different ages. The existence of the Tintic scarp was pointed out to us by H. T. Morris (written commun., 1977).

Explanation for Plate 1

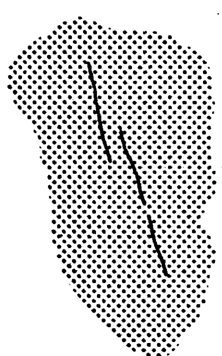
Fault scarps in unconsolidated sediments



Zone of fault scarps and name of locality



Approximate location of the high stand of Lake Bonneville



Area of Quaternary basalt containing fault scarps

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