CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-153

Northern Owens Valley, Fish Slough, and White Mountains frontal faults, Inyo and Mono Counties

by

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INTRODUCTION

Potentially active faults located in northern Inyo and southern Mono counties near the community of Bishop include the northern Owens Valley fault zone, the Fish Slough fault zone, and the White Mountains frontal fault zone (figure 1). These faults are being evaluated as part of a statewide effort to evaluate faults for recency of movement. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act (Hart, 1980).

REVIEW OF AVAILABLE DATA

The Bishop study area, bounded on the west by the Sierra Nevada and on the east by the White Mountains, is characterized by Basin and Range style normal faulting. Topography in the study area ranges from the relatively flat valley floor of northern Owens Valley to gently dipping alluvial slopes and fans issuing from the White Mountains and Sierra Nevada, to the very steep scarp along Fish Slough. The precipitous slopes of the Sierra Nevada and White Mountains border the study area.

Predominant rock types encountered in the study area include Pleistocene (700,000 yr. old) Bishop tuff, older and younger alluvial fans along the western White Mountains front, late Pleistocene to Holocene and modern alluvium in the Owens River flood plain (Bateman, 1965; Crowder and Sheridan, 1972; McKee and others, 1982). Cretaceous Cathedral Peak granite of the Sierra Nevada batholith crops out near Keough Hot Springs. Paleozoic and Mesozoic metamorphic and granitic rocks crop out along the east margin of the White Mountains frontal fault.

Development is relatively intense within the city limits of Bishop, and somewhat less intense east and west of Bishop at the airport and Piute-Shoshone Indian Reservation, respectively. Modest agricultural use principally occurs south of Bishop, but the majority of the study area has not been significantly modified by man.

Three principal fault zones will be evaluated in this FER, the northern Owens Valley fault zone, Fish Slough fault zone, and White Mountains frontal fault zone. The northern Owens Valley fault zone, located from Keough Hot Springs along a northerly trend to about Section 19, T7S, R32E, becomes a broad zone of discontinuous faults in alluvium (figures 2a, 3). It is not clear where the northern Owens Valley fault zone ends and the Fish Slough fault begins. They may, in fact, be one more or less continuous zone. However, in this FER north-trending faults north of Line Road in Bishop are considered to be segments of the Fish Slough fault zone (figures 2a, 3).

North-trending faults along the west side of the White Mountains in the study area are termed the White Mountains frontal fault zone (figure 2a). This is to distinguish this previously unnamed zone of faults from the White Mountains fault zone of Crowder and Sheridan (1972) that occurs north of the study area (figure 1).

Northern Owens Valley Fault Zone

The northern Owens Valley fault zone is a north-northwest-trending, complex zone of normal faults (figures 2a, 2b). The predominant sense of recent offset is mountain-side down (west-side down) normal faulting, although some east-side down faulting is present. This sense of displacement differs significantly from the predominantly valley side down (east side down) displacement observed along the Sierra Nevada escarpment both north and south of the Bishop study area (figure 1). Bateman (1965) includes the northern Owens Valley fault zone in the Bishop study area as part of a larger structure he calls the Coyote warp. The Coyote warp, which is characterized by warping associated with predominantly mountain-down normal faults, probably represents a complex left-step between well-defined frontal faults of the Sierra Nevada fault zone. The northern extent of surface fault rupture associated with the 1872 Owens Valley earthquake occurred four and one-half to five miles southeast of the study area near Klondike Lake (Whitney, 1872; Bateman, 1961; CDMG, 1972). Surface rupture associated with the great 1872 Owens Valley earthquake was generally east-side down normal, but a component of right-lateral strike-slip displacement was observed (Whitney, 1872; Bateman, 1961; Carver, 1970).

Bateman (1965) mapped a north-northwest-trending zone of discontinuous normal faults along the northern Owens Valley fault zone (figure 2a). Most of these faults have down-to-the-west (mountain-side down) displacement. Faults in Section 6, T8S,R33E, offset young alluvial fan deposits thought to be late-Pleistocene to Holocene in age by Bateman (1965). A prominent graben (or sidehill trough) located north of Keough Hot Springs offsets older alluvium and Cretaceous granite against young (Holocene?) alluvium. South of Keough Hot Springs, Bateman mapped talus offset against young alluvium (figure 2a). Bateman mapped several discontinuous faults in Holocene and Pleistocene alluvium (based on air photo interpretation) that are not depicted on his geologic map (Bateman, 1965, Plate 3), but are shown on a structure map (Bateman, 1965, Plate 7; figure 2a, this FER). Some of these faults with minor displacements may be the result of shaking, although they generally lie along the structural trend of the Owens Valley fault zone. Bateman (1965) does not map faults in alluvium just south and east of the Bishop city limits.

Slemmons and others (1970) map an extremely complex zone of essentially north, northwest, and northeast-trending faults along the northern Owens Valley fault zone (figure 2b). Slemmons' map is not annotated, and orientation of fault scarps are not indicated. This writer contacted Slemmons in September 1983 to discuss his mapping in the Bishop quadrangle. The majority of fault traces in the Bishop quadrangle were mapped, using low-sun aerial photos, by University of Nevada, Reno students. Slemmons stated that there was no attempt to differentiate between late Quaternary and Holocene faults. He further stated that not all traces along a northeast trend are fault features: some are sand dune deposits or wind erosion features (yardangs). However, Slemmons believes that most traces are "shatter" features of tectonic origin (i.e. northeast-trending faults related to a right-

lateral couple). Slemmons postulates that the northern Owens Valley fault zone (which he calls the Mid-valley fault zone) connects with the Fish Slough fault zone along the zone of northeast-trending faults.

The relatively few faults that Bateman (1965) mapped from Keough Hot Springs north to Section 31, T7S,R33E are not mapped by Slemmons and others. However, the density of faults mapped by Slemmons and others north of Rawson Creek is approached by Bateman (1965). Slemmons and others map north-trending faults in the flood plain of the Owens River in the southern part of the FER study area.

Envicom (1976) mapped segments of the northern Owens Valley fault zone in their seismic safety element prepared for Inyo and Mono counties (figure 2a). North-northwest-trending normal faults in alluvium generally correspond to faults mapped by Bateman (1965) from near Keough Hot Springs north to Section 31, T7S, R33E. Envicom (1976) extends a north-northeast-trending fault mapped by Bateman (1965) in Section 19, T7S, R33E toward the Bishop airport (figure 2a). Holocene alluvium and flood plain deposits of the Owens River area are offset by this zone of faults (Envicom, 1976).

Envicom (1976) trenched segments of the northern Owens Valley fault zone just south of Bishop (figure 2a). Trenches T_5 and T_6 were excavated across a northwest-facing scarp and tonal lineament in Holocene alluvium. T_5 exposed faulted alluvium. Two shears were exposed and both dip steeply to the west, consistent with down-to-the-west offset indicated by the scarp. A clayey silt bed is vertically offset a total of about 2-1/2 feet. T_6, located 880 feet southwest of T_5, did not expose shears in alluvium. The well-defined west-facing scarp at T_5 dies out northeast of T_6, and it is possible that faulting at the surface is expressed as a subtle monoclinal warp. Nearly horizontal sand and gravel beds seem to be slightly disrupted between stations 70 to 85 in T_6, which is consistent with warping. The depth of T_6 is from three to nine feet at this location. T_4, excavated across a well-defined tonal lineament, exposed a steeply west-dipping fault. Alluvial gravels are vertically offset about four feet, down to the west. T_2 was excavated across a northwest-facing scarp in alluvium south of the Bishop airport. The trench excavation exposed a steeply west-dipping fault that vertically offset Holocene alluvial sands at least six feet, down to the west.

Fish Slough Fault Zone

The Fish Slough fault zone is a prominent, north-trending zone of normal faults (figures 2a, 3). The left-stepping pattern of faults along the Fish Slough fault zone, and of faults to the west in the Volcanic Tablelands, suggests a component of right-lateral strike-slip displacement. The Fish Slough fault is characterized by a prominent west-facing scarp offsetting Pleistocene Bishop Tuff (700,000yrs BP). The scarp is up to 400 feet high along the east side of Fish Slough, but alluvium deposited in Fish Slough obscures the maximum amount of displacement. Envicom (1976) speculates that up to 500 feet of down-to-the-west displacement has occurred along the Fish Slough fault. Bateman (1965, Plate 5, cross-section A'-A") indicates that about 500 feet of cumulative displacement of the Bishop Tuff has occurred along two traces of the Fish Slough fault.

Bateman (1965) mapped a relatively complex zone of down-to-the-west normal faults bounding the east side of Fish Slough in the Bishop quadrangle. Bateman mapped Holocene alluvium against Pleistocene Bishop Tuff, but he does not extend the Fish Slough fault south into Owens River flood plain deposits.

Crowder and Sheridan (1972) mapped the Fish Slough fault in the White Mountain Peak quadrangle (figure 2a). They mapped Holocene alluvium and talus against Bishop Tuff along the fault, but is not clear whether these deposits are faulted or have been deposited against the scarp. The northern end of the Fish Slough fault mapped by Crowder and Sheridan splays into a zone of northwest-trending faults, with the northernmost segment trending northeast. Holocene alluvium in Chidago Canyon is mapped as offset (figure 2a). The northeast-trending fault is partly concealed by the large Milner Creek alluvial fan (figure 2a).

Envicom (1976) did not map the principal trace of the Fish Slough fault north of the Owens River. However, they mapped north-trending faults in alluvium south of Owens River and consider these faults to be segments of the Fish Slough fault zone (figure 2a). Faults south of the Owens River are normal with down-to-the-west displacement and offset Holocene alluvium and flood plain deposits mapped by Bateman (1965). A trench (T_1) excavated across a west-facing scarp in alluvium exposed two near-vertical shears in alluvium (figure 4). About five feet of down-to-the-west cumulative displacement was observed along a bed of alluvial sand. The east shear extends to the ground surface. Although datable deposits were not observed in T_1, Envicom discovered a piece of wood at a depth of 15 feet in a gravel quarry near Five Bridges (figure 2a). A radiocarbon age of about 12,000 yrs.BP was determined for this sample. It is probable that deposits exposed in T_1 are no older, and are probably younger, than the deposits near Five Bridges.

Envicom (1976) mapped additional northeast-trending lineaments in alluvium west of the Fish Slough fault zone that they consider to be branch faults (not shown in this FER). These lineaments are based on airphoto interpretation and generally have not been confirmed as faults. A possible exception is just north of the Bishop fairgrounds where Envicom excavated trench T_3 (figure 2a). A monoclinal warp with down-to-the-east displacement was observed at Station 50. About five feet below the ground surface, a small "horst" of silt is bounded by shears and has been vertically displaced at least three feet. The sense of offset indicated by the shears and the sense of offset indicated by the overlying warped gravels is not consistent and may have been caused by liquefaction..

Two northwest-trending lineaments mapped by Envicom (1976) that intersect West Line Street west of U.S. Highway 395 were investigated by Woodward-Clyde Consultants (WCC, 1978) and P. Saint-Amand (1981) (figure 2a). WCC excavated three trenches and exposed evidence indicating that channel deposits, rather the faulting, are delineated by the tonal lineament. Saint-Amand (1981) investigated a site west of the WCC (1978) area (figure 2a). No trenches were excavated, but Saint-Amand concluded that the lineament mapped by Envicom (not shown on figure 2a) was artificial.

Envicom considers the Fish Slough fault zone to be active. They estimate that slip-rates along the Fish Slough fault zone range from 0.4' to 1.2' per 1,000 years, or from 0.12mm to 0.37mm/yr. If about 500 feet of displacement of 700,000-year-old Bishop Tuff has occurred, one could estimates a slip rate of about 0.22mm/yr. In comparison, Clark and others (1983) estimate that the Fish Springs fault, a segment of the Owens Valley fault zone about 13-1/2 miles south of the study area that ruptured during the 1872 earthquake, has a slip rate of from 0.5mm/yr to 1.0mm/yr during late Quaternary time.

The California Department of Water Resources (DWR) investigated Fish Slough as a potential reservoir site (DWR, 1964). Exploratory borings were placed along the proposed dam axis, and three faults offsetting Bishop tuff

were encountered (figures 2a, 3, 7). The base of the unit 4 tuff (Bishop tuff) is vertically offset about 110' down to the west, between borings LA-1 and LA-2 (figures 2a, 7). Additional minor faults were encountered between borings C-2 and LA-1 and C-1 and C-2 (figure 7). The Volcanic Tableland surface is vertically offset about 400 feet at this location, suggesting that: (1) displacement along the Fish Slough fault is distributed over a zone, and (2) the main fault is probably located just east of LA-2 (figures 2a, 3). Stratigraphic evidence of post-Bishop tuff offsets were not apparent, although this type of exploration is not necessarily suitable for observing discrete shears or offsets in semiconsolidated to unconsolidated alluvium. DWR concluded that the Fish Slough fault is capable of future surface fault rupture on the order of about 10 feet, both horizontally and vertically, and, therefore, abandoned Fish Slough as a potential damsite.

White Mountains Frontal Fault Zone

The White Mountains frontal fault zone is a north-northwest-trending zone of discontinuous normal faults bordering the western front of the White Mountains (figure 2a). Most of the faults in this zone are short, mountain-side-down (east-side-down) normal faults that offset older, dissected late Pleistocene alluvial fans and young, probably Holocene fans. This zone of recent faults presumably connects with a major west-dipping normal fault at depth, which would be consistent with large-scale uplift of the White Mountains (Bateman, 1965).

Bateman (1965) mapped essentially east-side-down normal faults in the Bishop quadrangle that cut older dissected alluvium (figure 2a). Late Pleistocene to Holocene-age alluvial fan surfaces are faulted south (Sec. 8, T8S, R34E) and north (Sec. 30, T7S, R34E) of Black Canyon, on the Poleta Canyon fan (Sec. 13, T7S, R34E), north of Silver Canyon in Section 15, T6S,R33E, on the Coldwater Canyon fan in Section 35, T5S,R33E, and in Sections 27 and 22, T5S, R33E (figure 2a).

Crowder and Sheridan (1972) mapped late Pleistocene and Holocene alluvial fans as offset by segments of the White Mountains frontal fault zone in the White Mountain Peak quadrangle (figure 2a). A north-northwest-trending segment is fairly continuous as mapped by Crowder and Sheridan from just north of Piute Creek to just south of the Milner Creek alluvial fan. Late Pleistocene and Holocene alluvial fans are mapped as offset along this down-to-the-east normal fault (figure 2a).

Slemmons and others (1970) mapped a north-trending zone of faults along the west front of the White Mountains in the Bishop quadrangle (figure 2b). They only map as far as two miles north of Silver Canyon, and they do not map faults along the mountain front farther south than about two miles south of Poleta Canyon. The general trend and location of faults mapped by Slemmons and others along the front of the White Mountains generally corresponds with faults mapped by Bateman (1965), although differences in detail exist (figures 2a, 2b).

McKee and others (1982) have compiled a geologic map of the White Mountains wilderness area using the mapping of Bateman (1965) and Crowder and Sheridan (1972) in the FER study area. They conclude that faults that offset unconsolidated alluvium are active.

AIR PHOTO INTERPRETATION

Air photo interpretation by this writer of faults of the northern Owens Valley, Fish Slough, and White Mountains frontal fault zones was accomplished using U.S. Bureau of Land Management CA-01 (1977) color air photos at a scale of 1:24,000. Interpretation of selected segments of the northern Owens Valley and Fish Slough fault zones was accomplished using 1968 (University of Nevada, Reno) low-sun-angle air photos. Results of air photo interpretation by this writer are summarized on figure 3.

Northern Owens Valley Fault Zone

Segments of the northern Owens Valley fault zone interpreted by this writer are shown on figure 3. Principal fault traces from Keough Hot Springs northwest to Section 31, R7S,R33E are in general agreement with fault traces mapped by Bateman (1965) and Envicom (1976), although differences in detail exist (figures 2a, 3). Well-defined scarps in late Pleistocene and Holocene alluvial fans, tonal lineaments and vegetation contrasts in alluvium, ponded alluvium, beheaded and vertically offset drainages were observed along these segments of the northern Owens Valley fault zone. These features strongly suggest Holocene normal faulting (figure 3). Geomorphic evidence of a component of right-lateral strike-slip displacement was not observed by this writer.

To the north, the fault zone is distributive and discontinuous. Slemmons and others (1970) map an incredibly complex zone of faults in Sections 29, 30, 31, and 32, T7S, R33E. No attempt was made by this writer to photo-check all of these traces. Many of the traces mapped by Slemmons and others are characterized by tonal lineaments in alluvium with no associated scarps. Bateman (1965) also mapped a complex zone of northeast-trending, discontinuous lineaments in this area, but the density of lineaments is much less. It is suspected by this writer that many of the lineaments are due to secondary shaking effects. However, other lineaments may represent faults with very minor displacements. Ground cracking was very common in the Bishop area as a result of the 1872 earthquake (Whitney, 1872: Bateman, 1961; CDMG, 1972). The many faults Slemmons and others mapped in the Owens River flood plain could not be verified by this writer.

Holocene faulting along a zone of distributive, northeast-trending faults occurs south of Bishop (figure 3). Well-defined tonal lineaments in Holocene alluvium and scarps with associated closed depressions in alluvium characterize fault segments in this distributive fault zone (figure 3). Trenches ($T_{2,\ 4,\ 5,\ 6}$) excavated by Envicom (1976) confirm that these features are probably due to faulting and have significant rates of displacement, locally exceeding 0.1mm to 0.2mm/yr.

Fish Slough Fault Zone

The principal trace of the Fish Slough fault zone is characterized by a prominent, well-defined, west-facing scarp that offsets an erosional (?) surface of the 700,000-year-old Bishop Tuff (figure 3). The scarp height is up to 400 feet high in Section 6, T6S, R33E. Emphemeral geomorphic evidence of Holocene normal faulting was not observed by this writer along most of the principal trace of the Fish Slough fault, although areas of ponded alluvium, a possible closed depression, and slumping of an extremely pristine scarp freeface were observed (figure 3). Many geomorphic features indicative of Holocene normal faulting may not be preserved along the Fish Slough fault because of the relatively large size of the scarp, the amount of loose debris (talus) shed from the scarp, and the modification at the toe of the slope by Fish Slough.

The area just south of Fish Slough along the projected southerly trace of the Fish Slough fault in the vicinity of Five Bridges has been extensively modified by sand and gravel quarry operations. Two parallel tonal lineaments in Section 18, T6S, R33E may be a segment of the southern extension of the Fish Slough fault, but the tonal lineaments are not well-defined (figure 3). Well-defined west-facing scarps in alluvium west and northwest of the Bishop airport probably represent the southernmost strands of the Fish Slough fault zone. The northern part of the fault in Section 20, T6S, R33E has been modifided by stream erosion, but ponded areas on the west side of the scarp suggest Holocene activity. Envicom (1976) trenched the well-defined fault in alluvium located in Section 32, T6S, R33E and confirmed that the west-facing scarp was due to recent faulting (figures 3, 4).

A north-trending zone of faults in late Pleistocene and Holocene terrace deposits, considered here a segment of the Fish Slough fault zone, is characterized by well-defined scarps, tonal lineaments, and a prominent graben with a closed depression in Section 25, T6S, R33E (figure 3). Both Bateman (1965) and Slemmons and others (1970) map faults to the west, but these faults are not as well-defined.

White Mountains Frontal Fault Zone

The White Mountains frontal fault zone is characterized by well-defined, generally mountainside-down normal faults that offset Pleistocene and Holocene alluvial fans (figure 3). Geomorphic evidence of Holocene faulting is not as well defined along a segment of the fault zone from south of Section 36, T6S, R33E to just north of Section 31, T7S, R34E (figure 3).

The White Mountains frontal fault zone is characterized by well-defined scarps in late Pleistocene alluvial fan surfaces, vertically offset and beheaded drainages, ponded alluvium, and occasional beheaded drainages (figure 3). These features align with a few low scarps and tonal lineaments in Holocene alluvial fans and active stream channels, strongly indicating Holocene activity. Air photo interpretation by this writer of faults along the White Mountains frontal fault zone north of Sect. 25, T6S, R33E generally corresponds with faults mapped by Bateman (1965) and Crowder and Sheridan (1972), although differences in detail exist (figures 2a, 3).

Faults mapped by Slemmons and others (1970) between Section 14, T6S, R33E and Section 19, T7S, R33E generally agree with mapping by Bateman (1965), Crowder and Sheridan (1972), and this writer (figures 2a, 2b, 3). However, faults mapped by Slemmons and others west of the White Mountains alluvial fans are not well-defined and could not be verified by this writer (figure 3).

No geomorphic evidence of recent faulting was observed by this writer north of Section 21, T4S, R33E (figure 3). However, air photos were not interpreted north of Section 16, T4S, R33E.

FIELD OBSERVATIONS

Eight days were spent in the Bishop area during the month of June 1983 by this writer in order to verify selected faults interpreted from air photos. Two additional days in September 1983 were spent with E.W. Hart checking geomorphic features and examining soils to determine recency. One day in February 1984 was spent mapping segments of the White Mountains frontal fault zone in the southeastern part of the study area.

An attempt was made to measure fault scarp heights and scarp-slope angles in order to estimate recency of faulting based on the work of Wallace (1977). Points of observation and locations where fault scarp profiles were measured are shown on figure 3 and are summarized in Table 1. It should be emphasized that these measurements represent only approximations of scarp height, slope angle, and width of scarp crest. Scarp height was measured using the method described by Lahee (1961, p. 454). Scarp-slope angle was estimated by using a clinometer and measuring the profile angle. This method is not very accurate and probably records a slope angle slightly less than maximum slope angle. The width of the scarp's crest was estimated by pacing.

A direct correlation between the ages indicated by fault scarp profiles measured by Wallace (1977) in Nevada and scarp profiles measured during investigations for this FER cannot be made due to different lithology, climate, and styles of faulting (Mayer, 1982). However, the data presented by Wallace (1977, 1978) can be used as a guide (or additional factor) when evaluating the geomorphic features and age of offset deposits (when known) for recency of faulting. Some very general guidelines for estimating scarp ages are summarized as follows. Fault scarp angles for faults in unconsolidated alluvium and colluvium no older than 10,000 to 12,000 yrs BP can range from 10° to 35° (Wallace, 1977). The average scarp angle is about 22°, based on figure 8 of Wallace (1977), although figure 12 for Wallace (1977) indicates that scarp angles of about 19° represent minimum Holocene age. The scarp crest width for scarps no older than about 10,000yrs BP ranges from 3.2 to about 19 feet (figure 11 from Wallace, 1977). Wide variations occur, but these figures probably represent minimum criteria suggesting Holocene ages.

Northern Owens Valley Fault Zone

A well-defined, west-facing scarp offsetting older (late Pleistocene) alluvium against younger (Holocene) alluvium is associated with a beheaded drainage, a vertically offset drainage, and ponded alluvium in Section 31, T7S, R33E (figure 3). The scarp angle was difficult to measure because of dense brush (probable groundwater barrier) and the density of large boulders covering the slope. However, a possible remnant of a free-face near the base of the scarp was observed by this writer and, in places, there appears to be evidence of multiple offsets (figure 3, Table 1). Because of the difficulty of measuring scarp angles, the impression of multiple offsets may be a manifestation of the boulder and vegetation cover.

The pattern of lineaments mapped by Slemmons and others north of Rawson Creek is extremely complex (figure 2b). Most of these features are tonal lineaments, but a few (figure 3) are associated with scarps. These faults occur in older alluvium and are characterized by scarp angles ranging from 10° to 14° (figure 3, Table 1). Some of the scarps are very subtle and are not well-defined. Extensive modification by grading has occurred along the trace of two west-facing faults in Section 19, T7S, R33E; thus, information pertinent to recency of faulting could not be evaluated.

Fish Slough Fault Zone

The principal trace of the Fish Slough fault is a very prominent feature in the Bishop area. The west-facing scarp in 700,000-year-old Bishop Tuff is very well-defined in general, but there is a paucity of smaller, ephemeral geomorphic features indicating Holocene activity. This is probably due to the relatively large scarp (up to 400 feet high), the large talus slope, and the alternating erosion and grading of Fish Slough. The upper part of the scarp

is a free-face from Section 18, T6S, R33E north to about Section 18, T5S, R33E (figure 3), and the scarp crest is very sharp along this segment of the Fish Slough fault. Both the free-face and sharp crest may, in part, be due to the resistant nature of the welded tuff rather than recency of faulting. Thus, it is possible that the Fish Slough fault may be a fault line scarp produced in part by sapping.

North-trending faults south of the Owens River are considered segments of the Fish Slough fault zone. The faults in Sections 29 and 32, T6S, R33E are well-defined and offset flood plain deposits consisting of unconsolidated, moderately sorted sand (figure 3). A possible vertically offset drainage was observed just south of Highway 6, but the area behind the scarp's crest has been modified by man, and it is uncertain whether or not the offset drainage is artificial (figure 3). The scarp angle is about 18°, height about 6 feet. The width of the crest could not be measured due to modification by man.

Just north of the Owens River, two north-trending lineaments located in Section 18, T6S, R33E are poorly defined and may be the result of secondary faulting (figure 3).

Several north to north-northeast-trending faults, located in Sections 25 and 26, T6S, R33E, considered to be segments of the Fish Slough fault zone, are well-defined and are delineated by scarps in Holocene(?) terrace deposits (figure 3). A closed depression associated with a west-facing scarp is located north of Dixon Road. The depression has been modified by cattle, and may be artificial.

The Fish Slough fault zone is somewhat distributive and splayed at its northern end and for a relatively short distance changes to a northeast trend (figure 3). The fault is concealed by Holocene alluvium of Milner Creek north of the SW-1/4 Sec. 19, T4S, R33E. Multiple offsets along the northernmost segment of the Fish Slough fault are suggested by a scarp profile with a 26° angle near the top of the slope and a 40° angle near the toe of the slope (figure 3). The fault offsets partly welded Bishop Tuff.

Lineaments trenched by Envicom (1976) in Section 31, T6S, R33E are not well-defined and could not be located easily in the field (figure 3).

White Mountains Frontal Fault Zone

The White Mountains frontal fault zone offsets alluvium and alluvial fans considered to be latest Pleistocene and Holcene by Bateman (1965) and Crowder and Sheridan (1972). Most of the faults mapped by Bateman and Crowder and Sheridan are well-defined, and those selected for field checking are easily located in the field (figure 3). Ephemeral features such as closed depressions and vertically offset drainages are not common along this fault zone because the fault zone occurs essentially within an area of active alluvial-fan building (Beaty, 1970).

A well-defined fault segment just south of Silver Canyon is delineated by a west-facing scarp in late Pleistocene alluvium. The scarp height is about 20 feet, and the maximum scarp angle is 29° (figure 3, Table 1). Well-defined east-facing scarps offset alluvial-fan surfaces of probable Holocene age near the mouth of Piute Creek (figure 3). A scarp angle of 22°, scarp height of about 5 feet, and crest width of about 4 feet were measured on an east-facing scarp located in Section 22, T5S, R33E (figure 3, Table 1). Just south of this location, a well-defined east-facing scarp in older alluvium is characterized by a 20° to 25° scarp angle about 15 feet high, and has a crest width of about 10 feet (figure 3, Table 1). A trough is located along the toe of the scarp, but this may be a drainage. Although this scarp is well-defined, a drainage channel cuts through the scarp

and is not offset (figure 3). However, Wallace (1978, p. 640) notes that erosion keeps pace with and regrades channels in a fraction of the 10,000 years it would take a fault with a slip rate of 0.3 mm/yr to produce a single event, 3m-high scarp. Knickpoints in channels cutting the 2-to-5m-high scarp formed during the 1915 Pleasant Valley earthquake have disappeared after about 60 years (Wallace, 1978).

Well-defined east-facing scarps offsetting older alluvium and Holocene(?) alluvial fans are located in Sections 27 and 34, T5S, R33E (figure 3). Ponded alluvium, beheaded drainages, and a vertically offset drainage indicate Holocene activity. A right-lateral deflection of the principal active channel in the alluvial fan of Coldwater Canyon occurs east of these well-defined fault scarps, but does not seem to be fault related (figure 3).

A north-northwest-trending zone of faults was observed near the southeastern end of the study area (figure 3). These short, discontinuous fault segments are delineated by generally well-defined, west-facing scarps in alluvial fans of probable Holocene age. These scarps in alluvium are associated with vegetation contrasts, closed depressions on a sidehill bench, and flowing springs issuing lukewarm water (figure 3). Scarp profiles in semiunconsolidated alluvium strongly suggest recent (Holocene) offset (Table 1).

SEISMICITY

Seismicity within the FER study area is depicted on figure 5. The source for this seismicity is the California Institute of Technology (CIT), and quality of epicentral locations is A and B. However, it should be pointed out that A quality data from the U.S. Geological Survey and from CIT differ significantly. A and B quality data from the USGS indicates epicenter locations within 1 km and 2.5 km, respectively. A and B quality data from CIT indicates epicenter locations within 5 km. The A quality hypocenter data from CIT differs from B quality data only in that A quality events are specially investigated.

Epicenter locations in the FER study area suggest that the Fish Slough fault zone is seismically active. An apparent north-south alignment of epicenters is located west of the Fish Slough fault zone, which would be consistent with the geometry of the fault. However, these are somewhat tenuous assummptions due to the quality of epicenter locations. A few epicenters also lie along the White Mountains frontal fault zone.

CONCLUSIONS

Faults within the Bishop-White Mountains study area are principally related to Basin and Range style faulting resulting from general east-west extension. A right-lateral strike-slip component of displacement was associated with normal faulting along the Owens Valley fault zone during the 1872 earthquake (Whitney, 1872, Bateman, 1961). Although specific geomorphic evidence indicating a component of strike-slip displacement was not observed by this writer, the left-stepping pattern along the Fish Slough fault zone and its southern extension south of Bishop may suggest a right-lateral component.

Northern Owens Valley Fault Zone

Faults along the northern Owens Valley fault zone within the FER study area generally are well-defined and are characterized by scarps in Pleistocene and Holocene alluvium mapped by Bateman (1965), vegetation contrasts in alluvium, ponded alluvium, beheaded drainages, and possible closed depressions (figures 2a, 3). Generally, faults mapped by Bateman (1965) and Envicom

(1976) were verified by this writer. Slemmons and others (1970) (principally mapping by University of Nevada, Reno students) depict an extremely complex pattern of faults along the northern Owens Valley fault zone (figure 2b). However, the principal fault zone mapped by Bateman (1965), Envicom (1976), and this writer (figures 2a, 3) was not mapped by Slemmons and others (figure 2b). The complex zone of faults north of Rawson Creek (figure 2b) is probably due to shaking effects because most of the features are tonal lineaments with no associated scarps.

Envicom (1976) trenched segments of the northern Owens Valley fault zone and exposed evidence of faulted alluvium (figures 2a, 3). Additional inferred faults mapped by Envicom west of the Bishop area (not shown) generally are not well-defined, and investigations by Saint-Amand (1981) and Woodward-Clyde Consultants (1978) did not verify the presence of faults (figure 2a).

Fish Slough Fault Zone

The Fish Slough fault zone is a well-defined, north-trending zone of down-to-the-west normal faults (figure 2a). Maximum displacement of 700,000-year-old Bishop Tuff may be as great as 500 feet along the main trace of the Fish Slough fault (Bateman, 1965; Envicom, 1976). Geomorphic evidence of Holocene faulting is not common along the Fish Slough fault zone, but the relatively high scarp (maximum height about 400 feet) sheds a significant amount of debris which probably conceals ephemeral geomorphic evidence. The sharpness of the scarps, in part due to resistant welded tuff, may also be due in part to recency of faulting.

Envicom (1976) trenched a north-trending fault in Holocene alluvium (T_1) that they consider to be a branch of the Fish Slough fault zone. Alluvium was displaced about 5 feet, down to the west, along two near-vertical shears. Envicom has estimated that from 0.4 to 1.2 feet of displacement per 1,000 years (0.12mm/yr to 0.37mm/yr) has occurred along the Fish Slough fault.

Evidence of possible multiple displacements was observed at the northern end of the Fish Slough fault zone along a northeast-trending fault. A beveled scarp with an angle of 26° near the crest and 40° near the toe was observed (figure 3, Table 1). This fault is concealed by the Milner Creek alluvial fan to the northeast.

A zone of north to northeast-trending faults southwest of the main trace of the Fish Slough fault offsets terrace deposits mapped as latest-Pleistocene to Holocene by Bateman (1965) (figure 3). These faults are well-defined.

White Mountain Frontal Fault Zone

The White Mountains frontal fault zone is a north-trending zone of generally mountain side-down (east-side-down) normal faults (figures 2a, 3). Faults mapped by Bateman (1965) and Crowder and Sheridan (1972) offset alluvium of Pleistocene and probable Holocene age. These faults are generally well-defined and were verified by this writer (figure 2a, 3). Geomorphic evidence suggesting Holocene activity includes well-defined scarps in alluvium, ponded alluvium, beheaded drainages, some vertically offset drainages, and possible closed depressions (figure 3). Scarp profiles estimated by this writer along selected segments of the White Mountains frontal fault zone suggest activity during Holocene time, based on data by Wallace (1977, 1978) (Table 1).

These faults offset all but the very youngest alluvial fan surfaces. It is not possible to accurately date alluvial fan development, but Beaty (1970) indicates that the predominant mode of deposition is by debris flows following summer cloudbursts. This relatively catastrophic form of fan construction can

quickly bury, or erode, a modest scarp. Thus, it is probably rare to find a scarp offsetting the active alluvial fan surface.

Slemmons and others (1970) map faults along a portion of the west front of the White Mountains (figure 2b). These faults follow the general trend of faults mapped by Bateman (1965), but were not completely evaluated in this FER.

South of Section 36, T6S, R33E, fault segments of the White Mountains frontal zone are not as well-defined and geomorphic evidence of Holocene activity is generally delineated by tonal lineaments in Holocene alluvium that align with well-defined scarps in Pleistocene alluvium (figure 3). Offset alluvial fans of probable Holocene age, associated with springs, vegetation contrasts, a sidehill bench, and a closed depression were observed by this writer south of Section 30, T7S, R34E (figure 3).

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1980).

Northern Owens Valley Fault Zone

Zone for special studies well-defined faults shown on figure 6a. Principal references cited should be Bateman (1965), Envicom (1976), and this FER.

Fish Slough Fault Zone

Zone for special studies well-defined faults shown on figures 6a and 6b. Principal references cited should be Bateman (1965), Crowder and Sheridan (1972), Envicom (1976), and this FER.

White Mountains Frontal Fault Zone

Zone for special studies well-defined faults shown on figures 6a and 6b. Principal references cited should be Bateman (1965), Crowder and Sheridan (1972), and this FER.

I agree with the recommendations.
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March 8, 1984

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TABLE 1 (to FER-153) - Fault Scarp Profiles

Fault Name[1]	Location	Height	Angle	Crest Width	Material Offset	Scarp type[2]
NOV	Sect 31,T7S,R33E	6'	* locally possible freeface	*	late Pleistocene alluvium	bfs
NOV	Sect 29,T7S,R33E	22'	14°	22'	late Pleistocene alluvium	nf
NOV	Sect 19,T7S,R33E	5'	12°	*	late Pleistocene alluvium	nf
NOV	Sect 19,T7S,R33E same flt segment	12'	10°-12°	*	late Pleistocene alluvium	nf
NOV	Sect 19,T7S,R33E	5'	12°	*	late Pleistocene alluvium	nf
FS	Sect 29,T6S,R33E	6'	18°	*altered by man	Holocene flood plain deposits	nf
FS ?	Sect 25,T6S,R32E	*	18°	*	Holocene(?) terrace deposits	nf
FS ?	Sect 24,T6S,R32E	16'-18'	15°	15'	late Pleistocene terrace deposits	nf
FS	Sect 12,T5S,R32E	*	24° near crest 30° near base	*	Bishop tuff non-welded to partly welded	nf
FS	Sect 35,T4S,R32E	44'	25°	10'	Bishop tuff partly welded	nf
FS	Sect 24,T4S,R32E	* 20'	26° near crest 40° near base	*	Bishop tuff partly welded	nf
WM	Sect 35,T5S,R33E	10'	18°-20°	15'	Holocene(?) alluvial fan	bfs

TABLE 1 (to FER-153) - Fault Scarp Profiles (contd)

Fault Name[1]	Location	Height	Angle	Crest Width	Material Offset	Scarp type[2]
WM	Sect 35,T5S,R33E same flt segment	*	20°	*	Holocene (?) alluvial fan	bfs
WM	Sect 27,T5S,R33E	* 50'	uprl/3 25°,lrl/3 32°	15'	late Pleistocene alluvium	bfs
WM	Sect 26,T5S,R33E	22'	26°	10'-12'	late Pleistocene alluvium	bfs
WM	Sect 22,T5S,R33E	15'	20°-25°	10'	late Pleistocene alluvium	bfs
WM	Sect 22,T5S,R33E	5'	22°	4'	Holocene(?) alluvial fan	bfs
WM	Sect 21,T4S,R33E	2'	* 10°	*	Holocene(?) alluvial fan	bfs
WM	NW-1/4 Sect 36, T6S, R33E	8'	23°	6'	Holocene alluvium	nf
WM	NW-1/4 Sect 36 T6S, R33E (same fault)	6'	20°	5'	Holocene alluvium	nf
WM	SW-1/4 Sect 36 T6S, R33E (same fault)	3'	20°	10'	Holocene alluvium	nf
WM	SW-1/4 Sect 36 T6S, R33E (same fault)	*	25°	*	late Pleistocene alluvium	nf
WM	SW-1/4 Sect 8 T8S, R34E	11'	27°	4'	Holocene alluvium	nf

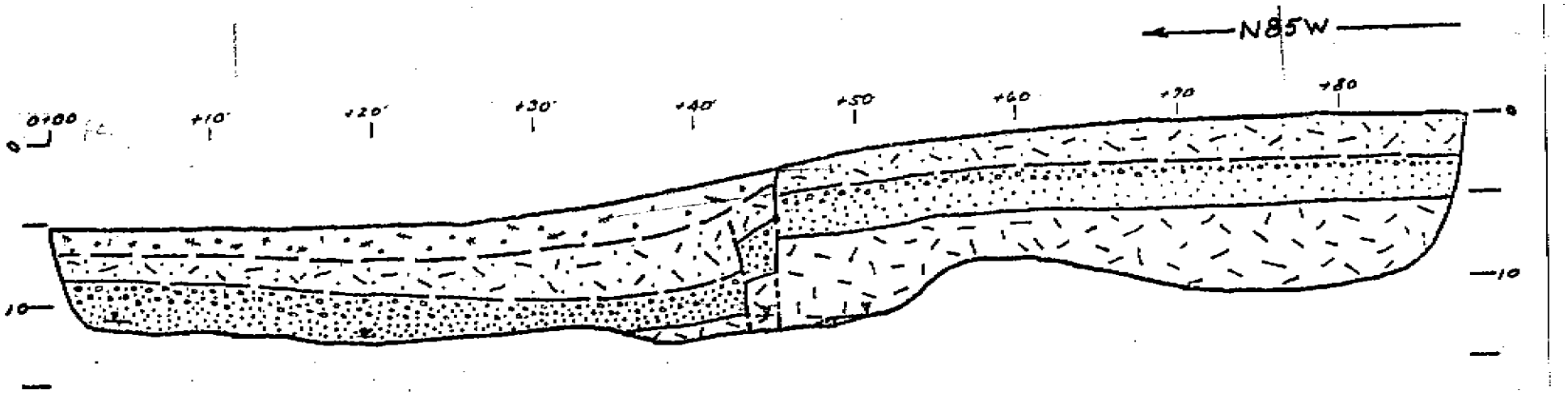
TABLE 1 (to FER-153) - Fault Scarp Profiles (contd)

Fault Name[1]	Location	Height	Angle	Crest Width	Material Offset	Scarp type[2]
WM	SW-1/4 Sect 8 T8S, R34E (same fault)	3-1/2'	22°	4'	Holocene alluvium	nf
WM	SW-1/4 Sect 8 T8S, R34E (same fault)	4'	24°	sharp	late Pleistocene alluvium	nf
WM	Sect 36, T6S, R33E	20'	29°	*	late Pleistocene alluvium	

1. NOV=northern Owens Valley fault zone; FS=Fish Slough fault zone; WM=White Mountains frontal fault zone.

2. bfs=back-facing scarp(mountain-side down); nf=normal fault scarp(valley-side down).

* Not measured.



SCALE 1" = 10'

Gravel

Coarse to medium grained sand

Fine to medium grained sand

Silt and fine sand, massive

Silt and clayey silt, massive

Silt, bedded

Clayey silt, bedded

Organic

Carbonaceous

Fault; dashed where approximately located.

All units assumed to be Holocene

Figure 4 (to FER-153). Log of trench T_1 excavated by Envicom (1976). See figures 2a and 3 for trench location.

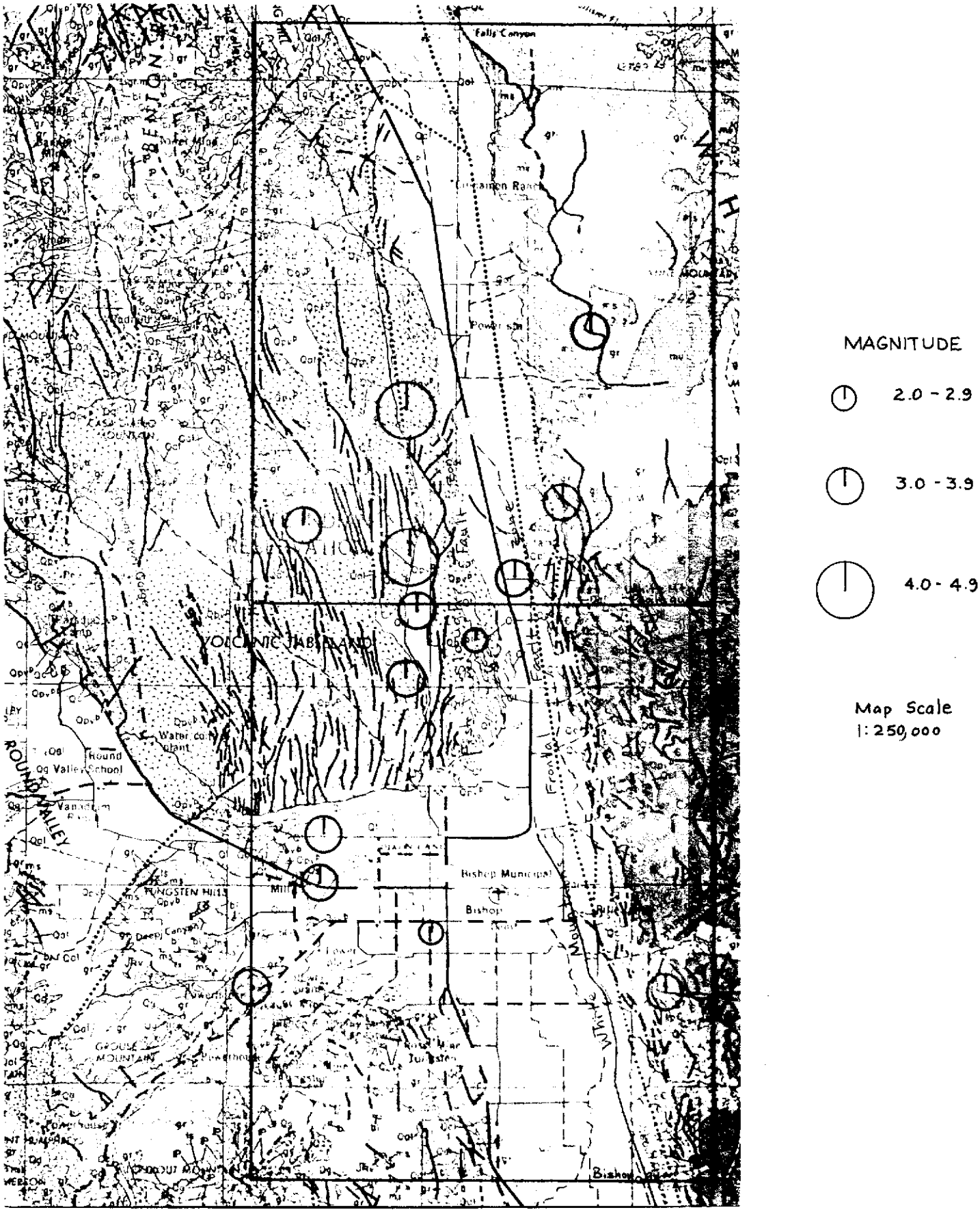


Figure 5 (to FER-153). Seismicity plot in the FER study area, showing A and B quality data from the California Institute of Technology for the period 1932 to 1980. Base map from Strand, 1967. (See text for discussion of CIT definition of A and B quality data).