CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-192

OWENS VALLEY FAULT ZONE

WESTERN INYO COUNTY, CALIFORNIA

by

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INTRODUCITON

Potentially active faults in western Inyo County that are evaluated in this Fault Evaluation Report (FER) collectively comprise the Owens Valley fault zone (Figure 1). The Owens Valley study area is located in parts of the Fish Springs, Black- rock, Independence, Bee Springs Canyon, Manzanar, Union Wash, and Lone Pine 7-1/2-minute quadrangles and the Waucoba Mtn. and Olancha 15-minute quadrangles (Figure 1). Traces of the Owens Valley fault zone were zoned for Special Studies in 1976 on parts of the Big Pine, Waucoba Mtn., Independence, Lone Pine, and Olancha 15-minute quadrangles (CDMG, 1976a-1976j; Figures 2a, 2b, 3a). These quadrangles are re-evaluated because zoning in 1976 was based entirely on the work of others and on the criterion of Quaternary active faulting. Moreover, most of the faults were based on poor-quality copies of unpublished and un-annotated maps that were difficult to interpret (Slemmons and others, 1970). Some faults in these quadrangles may not meet the current criteria for zoning (Hart, 1985) and most zones are unnecessarily wide. Those faults determined to be sufficiently active (Holocene) and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act (Hart, 1985).

SUMMARY OF AVAILABLE DATA

The Owens Valley study area is located in a major, north-trending fault-bounded depression situated between the Sierra Nevada to the west and the White-Inyo Mountains to the east. The floor of Owens Valley (elevation 3,800 to 4,000 feet) is generally flat and slopes gently south toward Owens Lake. The low relief of Owens Valley is interrupted by the Poverty Hills south of Big Pine, the Alabama Hills just west of Lone Pine, and scattered volcanic cones of the Big Pine Volcanic Field south of Big Pine. Development in the study area is low and is mostly confined to the towns of

Independence, Lone Pine, Cartago, and Olancha (Figure 1). In addition, local agricultural activities and cattle grazing modify land surfaces.

The Owens Valley study area is located in the western part of the Basin and Range geomorphic province and is characterized by oblique Basin and Range extensional tectonics which results in both normal and right-lateral faulting. Predominant rock types in the study area include Mesozoic plutonic and metamorphic rocks, Quaternary volcanic rocks, and Quaternary surficial deposits (Strand, 1967; Matthews and Burnett, 1965; Streitz and Stinson, 1974). Quaternary surficial deposits are the most abundant in the study area and generally consist of alluvium and lacustrine sediments. Beanland and Clark (in prep.) estimate that the age of the surface of the valley floor is approximately 10 ka (Holocene), with younger deposits (such as Owens River fluvial deposits) incised into or overlying the lake beds.

The Owens Valley fault zone is an approximately 100 km long, north to northwest trending zone of generally right-lateral strike-slip faults with a component of down-to-the-east vertical displacement (Beanland and Clark, in prep.). Maximum right-lateral displacement may total approximately 20 km, based on correlation of the Independence dike swarm and two Cretaceous plutons across Owens Valley (Ross, 1962; Beanland and Clark, in prep.). Maximum vertical displacement (down-to-east) along the Owens Valley fault zone is approximately 2,400 m near Lone Pine (Pakiser and others, 1964).

Surface rupture associated with the March 26, 1872 M7.8 (Toppozada and others, 1981) Owens Valley earthquake occurred along the entire length of the Owens Valley fault zone (Whitney, 1872; Gilbert, 1884; Hobbs, 1910; Bateman, 1961; Oakshott and others, 1972; Hill, 1972; Beanland and Clark, in prep.). Average net surface displacement along the Owens Valley fault zone in 1872 was about 6m, with a maximum net displacement of about 11m (Beanland and Clark, in prep.). Average right-lateral component of displacement was about 6m and the average component of vertical displacement was about 1m (Beanland and Clark, in prep.). Total fault rupture length, from Owens Lake to north of Big Pine, was 90 to 110 km.

Late Quaternary slip-rates vary along different segments of the Owens Valley fault zone. Lubetkin and Clark (1985, 1987) reported a slip-rate from 0.5 mm/yr to 1.7 mm/yr along the Lone Pine fault; Martel and others (1987) reported a slip-rate of 0.25 mm/yr along the Fish Springs fault, based on an offset cinder cone that is approximately 3.14×10^5 years old (Figures 1, 3a). The average net slip-rate along the Owens Valley fault zone is probably on the order of about 3 mm/yr, although the strike-slip component of displacement is not well-constrained (Beanland and Clark, in prep.).

The Owens Valley fault zone was first mapped by W.D. Johnson (Hobbs, 1910). Mapping that will be evaluated in this FER includes Bateman (1965), Ross (1965), Nelson (1966), Carver (1970), Slemmons (1970), Lubetkin (1980), Lubetkin and Clark (1985), Martel (1984), and Beanland and Clark (in prep.). Knopf (1918), used to compile a part of the SSZ map of the SE 1/4 Lone Pine quadrangle, will not be evaluated in this FER because of the small scale of

mapping (1:125,000). The Owens Valley fault zone will be discussed from north to south.

FISH SPRINGS AND SW 1/4 WAUCOBA MTN. QUADRANGLES

Segments of the Owens Valley fault zoned for special studies in 1976 on the SE 1/4 Big Pine (Fish Springs) and SW 1/4 Waucoba Mtn. quadrangles were based on mapping by Nelson (1966) and Slemmons (1970) (Figures 2a, 3a). Nelson (1966) mapped the geology on the Waucoba Mtn. 15-minute quadrangle and showed short, discontinuous traces of the Owens Valley fault offsetting Holocene alluvium (locality 1, Figure 3a).

Slemmons (1970) mapped the entire length of the Owens Valley fault zone at a scale of 1:62,500, based on interpretation of low-sun angle aerial photographs and limited field mapping. Fault traces depicted on the 1976 SSZ maps represent those traces presumed to have ruptured during 1872, based on a small scale map published in California Geology (Hill, 1972). Maps by Slemmons (1970) are not annotated and the orientation of fault scarps is not indicated. These maps, significant parts of which were mapped by University of Nevada, Reno graduate students, probably should be considered to be lineament maps rather than fault maps. Only those faults zoned in 1976 will be evaluated in this FER. Those faults west of the main Owens Valley fault which were not zoned in 1976, will be evaluated along with other Sierra Nevada range front faults in a later fault evaluation report.

Beanland and Clark (in prep.) mapped the entire Owens Valley fault zone in detail, based on aerial photographic interpretation and approximately three months of detailed field mapping in late 1985 and 1986 (Figures 2b, 3a, 3b). Mapping by Beanland and Clark (in prep.) represents the most detailed and documented record available of Holocene faulting along the Owens Valley fault zone.

Bateman (1965) mapped segments of the Owens Valley fault zone on the Big Pine 15-minute quadrangle (Figure 2a) that showed Pleistocene alluvium and volcanic deposits to be offset. Although not used to compile the 1976 SSZ maps, Bateman's fault traces are located with considerable accuracy.

The Owens Valley fault zone in the Fish Springs and SW 1/4 Waucoba Mtn. quadrangles is complex and is generally delineated by three separate segments; the Red Mountain segment on the west, the Crater Mountain segment in the center, and the Tinemaha segment on the east (Figures 2a, 3a).

The Red Mountain segment, mapped by Bateman (1965), Slemmons (1970), and Beanland and Clark (in prep.) is a north-trending normal fault with down to the west displacement (Figures 2a, 3a). The Red Mountain segment forms the west side of a horst block and offsets an alluvial fan surface reported to be early Wisconsin in age (Tahoe equivalent; 65 ka to 105 ka) by Martel (1984) and Martel and others (1987). Beanland and Clark suggested that the Red Mountain segment may not have had significant fault rupture during 1872, based on the relatively degraded scarp profile. Traces mapped by Bateman (1965) and Beanland and Clark (in prep.) generally agree, although differences in detail exist (Figures 2a, 3a). Slemmons (1970) mapped a complex

zone of faults that only locally coincide with faults mapped by Beanland and Clark (Figures 2a, 3a).

The Crater Mountain segment is characterized by a north-trending, complex zone of faults with both down-to-the-east normal and right-lateral strike-slip displacement (Figures 2a, 3a). The southern part of the Crater Moun- tain segment offsets alluvium fans that are late Pleistocene to early Holo- cene in age. Displacement is purely dip-slip along this segment of the fault, based on the lack of lateral displacement of a 315 ka cinder cone (site 33, Figure 3a) (Beanland and Clark, in prep; Martel, 1984). Martel (1984), who mapped a 1.3 km portion of the Crater Mountain segment that he termed the Fish Springs fault, suggested that a stream terrace vertically offset about 1.3m was probably the result of faulting during the 1872 earthquake (locality 2, Figure 3a). The work of Martel is not shown on Figure 2a, but is similar to faults shown on Figure 3a. North of locality 3 (Figures 2a, 3a), the Crater Mountain segment is characterized by right-lateral strike-slip displacement (site 35, Figure 3a). Mapping by Bateman (1965) and Beanland and Clark (in prep.) generally agree, although differences in detail exist. Slemmons mapped a more complex zone of faults that only locally coincides with mapping by Beanland and Clark (i.e., localities 3, 4, and 5, Figures 2a, 3a).

Martel (1984) and Beanland and Clark (in prep.) observed that the Poverty Hills lies between left-stepping segments of the Owens Valley fault zone (Crater Mountain and Tinemaha segments) and that this uplifted bedrock high is consistent with right-lateral strike-slip deformation (Figure 3a). Slemmons (1970) mapped a complex zone of short, discontinuous lineaments in the Poverty Hills (Figures 2a, 3a). Bateman (1965), Nelson (1966), and Beanland and Clark (in prep.) did not map these features.

The Tinemaha segment of the Owens Valley fault zone was mapped by Slemmons (1970), Nelson (1966), and Beanland and Clark (in prep.) (Figure 3a). The location of faults mapped by Slemmons (1970) and Beanland and Clark only locally coincides. Beanland and Clark mapped a more discontinuous zone of faulting that offsets Holocene alluvium (Figure 3a).

BLACKROCK-INDEPENDENCE-BEE SPRINGS CANYON QUADRANGLES

Faults zoned for special studies in the Blackrock (NW 1/4 Independence), Independence (SW 1/4 Independence), and Bee Springs Canyon (SE 1/4 Indepen- dence) quadrangles were based on mapping by Ross (1965) and Slemmons (1970) (Figure 2a). The Owens Valley fault zone in these quadrangles, informally referred to as the Independence segment in this report, is a linear, northwest-trending fault that offsets the youngest sedimentary deposits of Ross (1965), which are presumed to be Holocene (Figure 2a). Slemmons (1970) partly agrees with Ross, but shows numerous additional fault traces.

Beanland and Clark (in prep.) reported that this segment of the fault, delineated by a generally east-facing scarp in Holocene lacustrine and fluvial deposits, is characterized primarily by right-lateral strike-slip displacement. Evidence supporting this style of deformation cited by Beanland and Clark includes a right-laterally offset drainage (site 30),

changes in direction that scarp faces (locality 6, site 27), and closed depressions associated with a right-step in fault traces (site 19) (Figure 3a). Beanland and Clark reported liquefaction features associated with the 1872 earthquake (sand boils, sites 23, 22, and 20, Figure 3a).

There is fairly good agreement between Ross (1965), Slemmons (1970), and Beanland and Clark with respect to the location of the principal trace of the Independence segment (Figures 2a, 3a). Ross (1965) and Beanland and Clark mapped a very narrow, linear fault zone southeast to site 18 (Figures 2a, 3a). Slemmons mapped additional, generally more northwest-trending lineaments along the northern part of the Independence segment (locality 7, Figure 2a) and a zone of northeast-trending lineaments at the southern end of the Independence segment (locality 8, Figure 2a). Ross and Beanland and Clark did not map these features (Figures 2a, 3a).

Beanland and Clark excavated two trenches that exposed faulted soil (A horizon) and late Holocene floodplain deposits (site 18, Figures 3a and 4). The fault (N15° W 90°) vertically offsets the alluvium about 1/2 m. Right-laterally offset stream meander channels indicate approximately 3m to 4m of strike-slip displacement. Evidence of multiple fault rupture events was not observed and Beanland and Clark concluded that these displacement values are associated entirely with the 1872 earthquake.

MANZANAR AND UNION WASH QUADRANGLES

Segments of the Owens Valley fault zone in the Manzanar (NW 1/4 Lone Pine) and Union Wash (NE 1/4 Lone Pine) quadrangles zoned for special studies in 1976 were based on mapping by Slemmons (1970) and Knopf (1918) (NE 1/4 Lone Pine 15-minute quadrangle) (Figure 2a). Knopf's mapping was at a scale of 1:125,000 and will not be evaluated in this FER. However, Knopf's traces locally correspond to faults mapped by Beanland and Clark.

The Independence segment of the Owens Valley fault zone was mapped by both Slemmons (1970) and Beanland and Clark (in prep.) (Figures 2a, 3b). Beanland and Clark mapped a linear, well-defined fault characterized by right-lateral strike-slip displacement. Traces mapped by Slemmons are much more arcuate and only locally correspond with the trace mapped by Beanland and Clark (Figures 2a, 3b).

The Manzanar segment of the Owens Valley fault zone is a relatively broad, arcuate zone of northeast and northwest-trending normal faults that offset Holocene alluvium (Slemmons 1970; Beanland and Clark, in prep.) (Figures 2a, 3b). There is general agreement between Slemmons and Beanland and Clark with respect to the overall pattern and trend of faulting, but considerable differences in detail exist. Beanland and Clark reported a stream exposure of a fault (N15°W 75°E) that offsets a distal fan gravel deposit vertically about 1m (down-to-east) (site 16, Figure 3b).

The Manzanar segment merges with a well defined zone of faulting along the east side of the Alabama Hills (sites 11-15, Figures 2a, 3b). This fault zone, informally referred to in this report as the Alabama Hills segment, is characterized by east-side-down normal faulting and was mapped

by Knopf (1918), Slemmons, and Beanland and Clark, although differences in detail exist (Figures 2a, 3b). The fault offsets late Holocene colluvium, reported by Beanland and Clark, approximately 4.4m (site 13, Figure 3b). Beanland and Clark have postulated that the entire 4.4m of vertical offset at site 13 occurred during the 1872 earthquake. The average vertical component of offset was about 1m. A trench exposure of an offset alluvial fan observed by Beanland and Clark revealed a fault attitude of N5°W66°E (site 14, Figure 3b). Vertical displacement of this Holocene alluvial fan was about 4m.

A north-trending, narrow zone of en-echelon faults, referred to in this report as the East Valley segment, was mapped by Slemmons (1976) and Beanland and Clark (in prep.) (Figures 2a, 3b). The East Valley segment offsets Holocene alluvium and is delineated by a west-facing scarp (Beanland and Clark, in prep.) (Figure 3b). Although the general pattern of faulting mapped by Slemmons and Beanland and Clark is similar, considerable differences in location and extent of faulting exist (Figures 2a, 3b).

LONE PINE QUADRANGLE

Faults in the Lone Pine quadrangle (SE 1/4 Lone Pine 15-minute quadrangle) zoned for special studies in 1976 were based on mapping by Slemmons (1970), Knopf (1918), and Carver (1970) (Figure 2b). Although mapping by Carver (1970) was cited on the 1976 SSZ maps of the SE 1/4 Lone Pine and NE 1/4 and SE 1/4 Olancha 15-minute quadrangles, traces shown on the SSZ maps were taken from Slemmons (1970) (and students) (Figure 2b). Carver was a student of Slemmons and presumably compiled the Slemmons maps. Carver was the only citation used south of Diaz Lake because he was thought to be the sole source for Slemmons (Figure 2b) (Hart, p.c., Feb. 1988).

The Owens Valley fault in the Lone Pine quadrangle mapped by Slemmons is a broad, complex zone of north and northeast-trending, discontinuous faults that consist of the Alabama Hills segment and the Diaz Lake segment (Figure 2b). Beanland and Clark (in prep.) mapped traces similar to Slemmons, although considerable differences in detail exist (Figures 2b, 3b). Beanland and Clark did not map the short northeast and northwest-trending lineaments east of the Diaz Lake segment mapped by Slemmons (Figures 2b, 3b).

The Diaz Lake segment mapped by Beanland and Clark (sites 3, 4, 6-10, Figure 3b) offsets Holocene alluvium and forms a prominent groundwater barrier just west of Lone Pine. This segment of the Owens Valley fault zone is characterized by right-lateral strike-slip displacement with a component of normal dip-slip displacement (generally down to the west) (Figure 3b). Beanland and Clark reported approximately 50m of cumulative right-lateral strike-slip displacement at site 6 (Figure 3b). There may have been up to 10m of strike-slip displacement associated with the 1872 earthquake at site 10 (Figure 3b).

The Alabama Hills segment, located along the east flank of the Alabama Hills, is characterized by right-lateral strike-slip displacement with a significant component of normal dip-slip displacement (Beanland and Clark,

in prep.) (Figures 2b, 3b). The Alabama Hills segment was mapped by Slemmons, Carver (1970) and Beanland and Clark, but significant differences in detail exist (Figures 2b, 3b).

The Lone Pine fault, mapped by Lubetkin (1980) and Lubetkin and Clark (1985, 1987) is a short segment of the Alabama Hills segment (site 9, Figure 3b). The Lone Pine fault is delineated by a prominent scarp in an abandoned alluvial fan considered by Lubetkin and Clark to be late Tioga in age. Cumulative displacement along the Lone Pine fault in the last approximately 21,000 years consists of 6.4m of vertical displacement (down-to-east) and up to 16m of right-lateral offset (Lubetkin and Clark, 1987). Scarp profile studies, trench exposures, and rock varnish analysis indicate that the 6.4m high scarp probably formed in three separate events (Lubetkin and Clark, 1985). Fault rupture associated with the 1872 earthquake produced about 1 to 2m of vertical and 6m of right-lateral strike-slip displacement. Beanland and Clark (in prep.) also mapped the Lone Pine fault, but the trace seems to be mislocated about 75 meters west of the trace mapped by Lubetkin and Clark (Figure 3b).

Carver (1970) and Beanland and Clark (in prep.) mapped a broad, northeast-trending zone of grabens located at the northwest end of Owens Lake (Figures 2b, 3b). Carver (1970) indicated that these grabens were probably formed during the 1872 earthquake as a result of slumping or flowing of the lake margins toward the lake center, a result of non-tectonic (shaking) processes. Differences in detail exist with respect to the location and complexity of the features mapped by Beanland and Clark and Carver (1970) (Figures 2b, 3b).

West of the northern shore of Owens Lake, the Alabama Hills segment splays into a broad zone of discontinuous normal faults with predominantly normal dip-slip displacement (down-to-the-east) (Figures 2b, 3b). This zone of faults was mapped by Carver (1970) and zoned for special studies in 1976. Beanland and Clark mapped a considerably narrower zone and stated that most of these faults probably did not rupture during 1872 (Beanland, p.c., November 1987) (Figure 3b). The Sierra Nevada range front projects into Owens Valley at this location and the complex, distributive nature of faulting probably reflects the junction between the Sierra Nevada and Owens Valley fault zones.

The Owens Valley fault zone along the west side of Owens Lake, referred to in this report as the Owens Lake segment, was zoned for special studies in 1976, based on mapping by Carver (1970) (Figure 2b). An approximately 1.5 km wide zone of northwest to north-northeast trending lineaments was mapped on the late Holocene playa surface of Owens Lake (locality 9, Figure 2b). Beanland and Clark (in prep.) mapped a single north-northwest-trending fault at site 2 (Figure 3b). This fault ruptured in 1872 and displaced the playa surface vertically 0.3 to 0.5m (west side down).

NE 1/4 AND SE 1/4 OLANCHA QUADRANGLES

Segments of the Owens Valley fault zoned for special studies in 1976 in the NE 1/4 and SE 1/4 Olancha quadrangles were based on mapping by Carver (1970) (Figure 2b).

The Owens Lake segment of the Owens Valley fault zone mapped by Carver forms a broad, generally north-trending zone of lineaments in the Owens Lake playa. A broad zone of short, northeast-trending faults at Point Bartlett deforms Holocene lake sediments (site 1, Figures 2b, 3b) (Carver, 1970; Beanland and Clark, in prep.). Beanland and Clark did not map the Owens Lake segment farther south than locality 10 (Figures 2b, 3b). Considerable differences in location and extent of faulting exist between Carver (1970) and Beanland and Clark (Figures 2b, 3b).

The southern Alabama Hills segment mapped by Carver (1970) forms a zone of extremely discontinuous north to north northeast-trending normal faults (Figures 2b). Non-tectonic deformation (slumping/liquefaction features) associated with the 1872 earthquake along the margins of Owens Lake has been identified by Carver ("lake margin grabens") at localities 11-14 (Figure 2b). Beanland and Clark mapped a zone of grabens at locality 11, but there is little agreement with respect to location and extent of deformation (Figures 2b, 3b). Faults with generally down-to-the-east dip-slip displacement mapped by Carver (1970) and Beanland and Clark occur within and east of the "lake-margin grabens" (localities 15 and 16, Figures 2b, 3b). It seems difficult to distinguish with confidence between extensional tectonic deformation and the non-tectonic "lake margin grabens" when these features have similar trends.

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the Owens Valley study area was accomplished using U.S. Bureau of Land Management (CA01-77, approximate scale 1:24,000), University of Nevada, Reno (OV and OVN-HF, approximate scale 1:12,000 and 1:10,000), and U.S. Geological Survey (GS-VJZ, approximate scale 1:54,000) aerial photographs.

Approximately 4-1/2 days were spent in the field in November 1987 and 1/2 day in February 1984 by this writer. Selected fault segments were verified and subtle features not observable on the aerial photographs were mapped in the field. Results of aerial photographic interpretation and field observations by this writer are summarized in red on Figures 3a and 3b.

Traces of the Owens Valley fault zone in the study area are generally very well-defined and are characterized by abundant geomorphic evidence of Holocene faulting. The major emphasis of this writer was to evaluate faults mapped by Slemmons (1970), Carver (1970), and Beanland and Clark (in prep.) rather than perform independent mapping. Generally, it was determined that the quality of mapping by Beanland and Clark (in prep.) is very high and that most traces were verified. Mapping by Slemmons (1970) was only locally

verified by this writer. Faults that were similar in trend and continuity with faults mapped by Beanland and Clark often were mislocated.

FISH SPRINGS AND SW 1/4 WAUCOBA MIN. QUADRANGLES

The Red Mountain segment of the Owens Valley fault zone is moderately well to well-defined and is delineated by geomorphic evidence of Holocene normal displacement (down-to-the-west) with a possible right-slip component, such as closed depressions, ponded alluvium, right-laterally deflected drainages, and a moderately sharp scarp in a Tahoe - equivalent alluvial fan (Figure 3a). Faults mapped by Beanland and Clark were verified except locally at the southern end of the fault were differences in location exist (Figure 3a). Faults mapped by Slemmons (1970) were not verified by this writer (Figures 2a, 3a). The principal trace of the Red Mountain segment mapped by Slemmons is mislocated (Figure 2a).

The Crater Mountain segment is very well-defined and is delineated by geomorphic evidence of Holocene normal faulting along the southern part of the trace (locality 2, site 33) and right-lateral strike-slip displacement along the northern part of the trace (locality 5, site 35) (Figure 3a). The scarp just north of locality 2 is beveled, indicating progressive deformation (Figure 3a). Martel's (1984) observation that 1872 fault rupture was indicated by an offset stream terrace was verified by this writer (locality 2, Figure 3a). Faults mapped by Slemmons (1970) along the Crater Mountain segment generally were not verified. The principal traces, partly verified with respect to pattern and trend, are mislocated (Figure 2a). The complex zone of short faults at locality 4 occur in Mesozoic bedrock and were not delineated by geomorphic evidence of recent faulting (Figure 2a).

The Poverty Hills is an uplifted bedrock high between the left-stepping Crater Mountain and Tinemaha segments (Figure 3a). Faults in the Poverty Hills mapped by Slemmons were not verified by this writer as recently active faults (Figure 3a). Those faults that were moderately well-defined may be differential erosion features, although minor, distributive faulting of Holocene age cannot be ruled out.

The Tinemaha segment of the Owens Valley fault zone is generally well-defined and is delineated by scarps and tonal lineaments in Holocene alluvium, troughs, and closed depressions (Figure 3a). Faults mapped by Beanland and Clark were generally verified, although a difference in location of up to 30m locally exists (Figure 3a). Faults mapped by Slemmons were only locally verified (e.g. locality 17, Figure 3a). The northern extension of the Tinemaha segment mapped by Slemmons was not verified (locality 18, Figure 3a).

BLACKROCK - INDEPENDENCE - BEE SPRINGS CANYON QUADRANGLES

The Independence segment of the Owens Valley fault zone is generally extremely well-defined and is delineated by abundant geomorphic evidence of Holocene right-lateral strike-slip displacement with a component of normal dip-slip displacement (down-to-east) (Figure 3a). Geomorphic evidence mandatory of Holocene displacement includes well-defined scarps and tonal

lineaments in unconsolidated Holocene alluvium, closed depressions, troughs, and right-laterally offset drainages (sites 30, 29, 21, and 18, Figure 3a). Faults mapped by Beanland and Clark were verified and only minor differences in detail exist between their mapping and mapping by this writer (Figure 3a). Faults mapped by Ross (1965) also were verified by this writer (Figure 2a). Minor faults mapped by Slemmons west and east of the principal trace of the Independence fault generally were not verified by this writer or are poorly defined (Figure 2a). The distinctive pattern of northeast-trending, left-stepping minor faults mapped by Slemmons in the Blackrock (NW 1/4 Independence) quadrangle was not verified by this writer (Figure 2a).

MANZANAR AND UNION WASH QUADRANGLES

The Independence segment of the Owens Valley fault zone in the Union Wash quadrangle is well-defined and is delineated by geomorphic evidence of Holocene right-lateral strike-slip faulting with a component of normal dip-slip displacement (Figure 3a). Scarps and tonal lineaments in the modern stream channel of the Owens River indicate historic surface fault rupture associated with the 1872 earthquake. Faults mapped by Beanland and Clark were verified by this writer (Figure 3a). The somewhat sinuous trend and minor branch faults mapped by Slemmons along the Independence segment were not verified by this writer (Figure 2a).

The Manzanar segment of the Owens Valley fault zone consists of a broadly arcuate zone of principally normal faults (Figure 3b). Traces of the Manzanar segment are characterized by geomorphic features indicating Holocene normal faulting such as well-defined, generally east-facing scarps in Holocene alluvium, tonal lineaments in alluvium, closed depressions, and vertically offset drainages (Figure 3b). A right-lateral component of slip possibly characterizes the southern part of the Manzanar segment, based on linear tonal contrasts in alluvium and a possibly right-laterally deflected drainage (Figure 3b). Faults mapped by Beanland and Clark were verified in general, but differences in detail and location exist (e.g. localities 19, 20, 21, Figure 3b). Traces mapped by Slemmons locally were verified, although considerable differences in detail exist (Figure 2a).

Faults along the east side of the Alabama Hills are very well-defined and are characterized by geomorphic evidence of Holocene normal faulting, such as well-defined, east-facing scarps in Holocene alluvial fans and colluvium, and vertically offset drainages (Figure 3b). The trench at site 14 (Figure 3b) exposed evidence of Holocene displacement. A debris flow deposit (unit 2) has a weak A soil horizon and is vertically displaced about 6.5 feet (Figure 5, Photos 1, 2). This fault strand may not have ruptured during 1872, based on the scarp slope angle of 26° and approximately 5 feet of scarp retreat. The fault strand (not exposed) about 15 feet east of the logged fault strand probably did rupture in 1872 (Figure 5, Photo 2). Scarps in Holocene alluvial fans have profiles characteristic of normal faulting no more than a few hundred years old at most, and clearly record fault rupture during the 1872 earthquake (site 13, locality 22, Figure 3b). Faults mapped by Beanland and Clark were verified by this writer along the east side of the Alabama Hills in the Union Wash quadrangle: traces correspond almost exactly (Figure 3b). Mapping along the east side of the

Alabama Hills by Slemmons was only locally verified by this writer (Figures 2a, 3b). The prominent, very well-defined scarp at locality 22 was not mapped by Slemmons (Figures 2a, 3b).

The East Valley segment is moderately well-defined and has geomorphic evidence of Holocene displacement (Figure 3b). West-facing scarps in unconsolidated Holocene alluvium (partly eolian deposits?) and tonal lineaments in Holocene alluvium characterize this segment of the Owens Valley fault zone. Faults mapped by Beanland and Clark were verified by this writer (Figure 3b). However, Beanland and Clark do not indicate whether or not this fault segment ruptured in 1872. The East Valley segment mapped by Slemmons was not verified (Figures 2a). The fault zone has a more northerly trend, the discontinuous en echelon pattern could not be verified, and the fault zone is west of faults mapped by Beanland and Clark and this writer (Figures 2a, 3b).

LONE PINE QUADRANGLE

The Alabama Hills segment of the Owens Valley fault zone is characterized by discontinuous, well-defined faults with geomorphic evidence of Holocene displacement (Figure 3b). Both right-lateral strike-slip and normal dip-slip displacement characterize this fault segment. The Lone Pine fault of Lubetkin and Clark (1985) is very well-defined and is delineated by a prominent east-facing scarp in a late-Tioga alluvial fan (site 9, Figure 3b; Photo 4). The scarp in bouldery alluvium has a profile with a free-face slope angle indicating very young faulting. The right-laterally offset drainage channel reported by Lubetkin and Clark (1985) was verified by this writer (Figure 3b). Faults mapped by Beanland and Clark along the Alabama Hills segment of the Owens Valley fault zone were mostly verified by this writer, although differences in detail exist (Figure 3b). In addition to the relocation of the Lone Pine fault, additional faults mapped by this writer include those located west and south of Diaz Lake, a short fault that offsets an alluvial fan at locality 23, and several east-facing scarps in an older alluvial fan (Tahoe-equivalent?) at the southern end of the Alabama Hills segment (Figure 3b). Faults mapped by Slemmons (1970) and Carver (1970) along the Alabama Hills segment were only locally verified (Figure 2b). The Lone Pine fault is not correctly mapped and many minor, north-trending lineaments along the Alabama Hills could not be verified (Figures 2b).

The Diaz Lake segment of the Owens Valley fault zone is moderately defined to well-defined and is characterized by geomorphic evidence of Holocene right-lateral strike-slip faulting, such as linear scarps in Holocene alluvium, troughs in Holocene alluvium, right-laterally deflected drainages, and reversals of apparent vertical offsets (Figure 3b). The Diaz Lake segment passes just west of Lone Pine and is delineated by a prominent groundwater barrier in Holocene alluvium (Figure 3b). Faults mapped by Beanland and Clark along the Diaz Lake segment were generally verified by this writer, although differences in detail exist south of Diaz Lake (Figure 3b).

Faults mapped by Slemmons (1970) and Carver (1970) along the Diaz Lake segment locally were verified by this writer, although considerable differences in detail exist (Figures 2b, 3b). A broad zone of northeast-trending and northwest-trending lineaments east and south of Lone Pine mapped by Slemmons was not verified by this writer, except as shown on Figure 3b. Two northeast-trending grabens may be related to shaking or liquefaction associated with the 1872 earthquake (locality 24, Figure 3b).

The northeast-trending zone of faults mapped by Carver (1970) and Beanland and Clark was generally verified by this writer, although differences in detail exist (Figures 2b, 3b). These features, characterized by well-defined grabens in Holocene alluvium, are clearly the result of shaking effects associated with the 1872 earthquake. These features mapped by Beanland and Clark and this writer are not completely mapped (Figure 3b).

NE 1/4 AND SE 1/4 OLANCHA QUADRANGLES

Segments of the Owens Valley fault zone in the NE 1/4 and SE 1/4 Olancha quadrangles are discontinuous and only locally well-defined (Figures 2b, 3b). The southern end of the Alabama Hills segment locally offsets latest Pleistocene alluvial fans and is delineated by moderately well-defined, though discontinuous, generally east-facing scarp (localities 15, 16, Figure 3b). North-trending grabens at localities 11-14, (Figures 2b, 3b) are probably related to seismic shaking/liquefaction processes, although the general trend is sub-parallel to other extensional faults of a tectonic nature.

The Owens Lake segment, which is very discontinuous, is locally well-defined and offsets Holocene lacustrine deposits (Figure 3b). Faults mapped by Beanland and Clark were verified by this writer (Figure 3b) on the NE 1/4 Olancha quadrangle; they did not map recently active faults south of this quadrangle. Faults mapped by Carver (1970) were only locally verified by this writer; most lineaments along the Owens Lake segment are either poorly defined or could not be verified (Figure 2b).

SEISMICITY

Seismicity in the Owens Valley study area is depicted in Figure 6. A and B quality epicenter locations by California Institute of Technology are for the period 1932 to 1985 (CIT, 1985).

Lone Pine was the epicenter of the M7.8 (Toppozada and others, 1981) 1872 earthquake. However, the Owens Valley study area has been characterized by relative seismic quiescence during the period 1932-1985. A few scattered epicenters of magnitude 3 to 4 occurred around the Lone Pine area and within the Owens Lake area, but distinctive patterns of seismicity that can be directly related to specific fault traces are not present (Figure 6).

CONCLUSIONS

The Owens Valley fault zone in the Owens Valley study area is generally very well-defined and is delineated by abundant geomorphic evidence of Holocene faulting (Figures 3a, 3b). Style of deformation along the Owens Valley fault zone is oblique-slip. Beanland and Clark (in prep.) reported that the Owens Valley fault zone is characterized by right-lateral strike-slip displacement with a component of normal dip-slip displacement. Beanland and Clark estimated that the ratio of horizontal to vertical displacement during the Holocene was probably about 6:1. The Owens Valley fault zone ruptured during the 1872 earthquake throughout most of the study area. The average right-lateral strike-slip displacement was about 6m and the average vertical component of displacement was about 1m (Beanland and Clark, in prep.).

Faults mapped by Beanland and Clark (in prep.) along the Red Mountain, Crater Mountain, Tinemaha, Independence, Manzanar, Alabama Hills, East Valley, Diaz Lake, and Owens Lake segments of the Owens Valley fault zone generally were verified by this writer and are characterized by abundant geomorphic evidence of Holocene and historic right-lateral oblique (normal) slip displacement (sites 35, 31, 30, 29, 21, 18, 16, 13, 7, 3, Figures 3a, 3b). Although minor differences in detail exist, mapping by Beanland and Clark was usually verified by this writer.

Mapping by Slemmons (1970), which was zoned for special studies in 1976 (CDMG, 1976a-1976j) generally was not verified by this writer (Figures 2a, 2b, 3a). Slemmons produced a lineament map, but individual traces were not annotated and differentiation between late Quaternary and Holocene faulting was generally not attempted (Slemmons, p.c., September 1983). Faults mapped by Slemmons (1970) that were in general verified by this writer often were mislocated, locally as much as 800 feet.

Segments of the Owens Valley fault zone mapped by Carver (1970) include the southern Alabama Hills, southern Diaz Lake, and the Owens Lake segments (Figure 2b). Traces mapped by Carver were locally verified by this writer, although considerable differences in detail exist and those traces that were well-defined often were significantly mislocated (Figures 2a, 3b).

Nelson (1966) mapped three short segments of the Owens Valley fault zone in the SW 1/4 Waucoba Mtn. quadrangle and Ross (1965) mapped most of the Independence segment in the Independence 15-minute quadrangle (Figure 2a). These fault were generally verified by this writer and both Ross (1965) and Nelson (1966) mapped Pleistocene alluvium offset along the fault. However, both maps are a relatively small scale (1:62,500) and lack the detailed documentation of Holocene displacement provided by Beanland and Clark (in prep.).

Zones of generally well-defined grabens in late Pleistocene and Holocene alluvium were mapped by Carver (1970) and Beanland and Clark (in prep.) around the margins of Owens Lake in the study area (Figures 2b, 3b). Carver suggested that these features, or "lake-margin grabens", are related to landslide/liquefaction processes associated with the 1872 earthquake

(Carver, 1970, p. 70). It is relatively easy to recognize the lake-margin grabens, but except for the east-northeast-trending zone along the northwest margin of Owens Lake, it is difficult to rule out an entirely non-tectonic mechanism for those grabens along a north to north-northwest trend (localities 11-14, Figure 2b).

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active and "well-defined" (Hart, 1985).

OWENS VALLEY FAULT ZONE

Rezone for special studies well-defined traces of the Owens Valley fault zone mapped by Beanland and Clark (in prep.), and Bryant (this report), as depicted in Figures 2b, 3a, 3b (highlighted in yellow). Principal references cited should be Bateman (1965), Beanland and Clark (in prep.), Carver (1970), Ross (1965) and Bryant (this report).

Report reviewed, approved.
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6/1/88

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May 19, 1988

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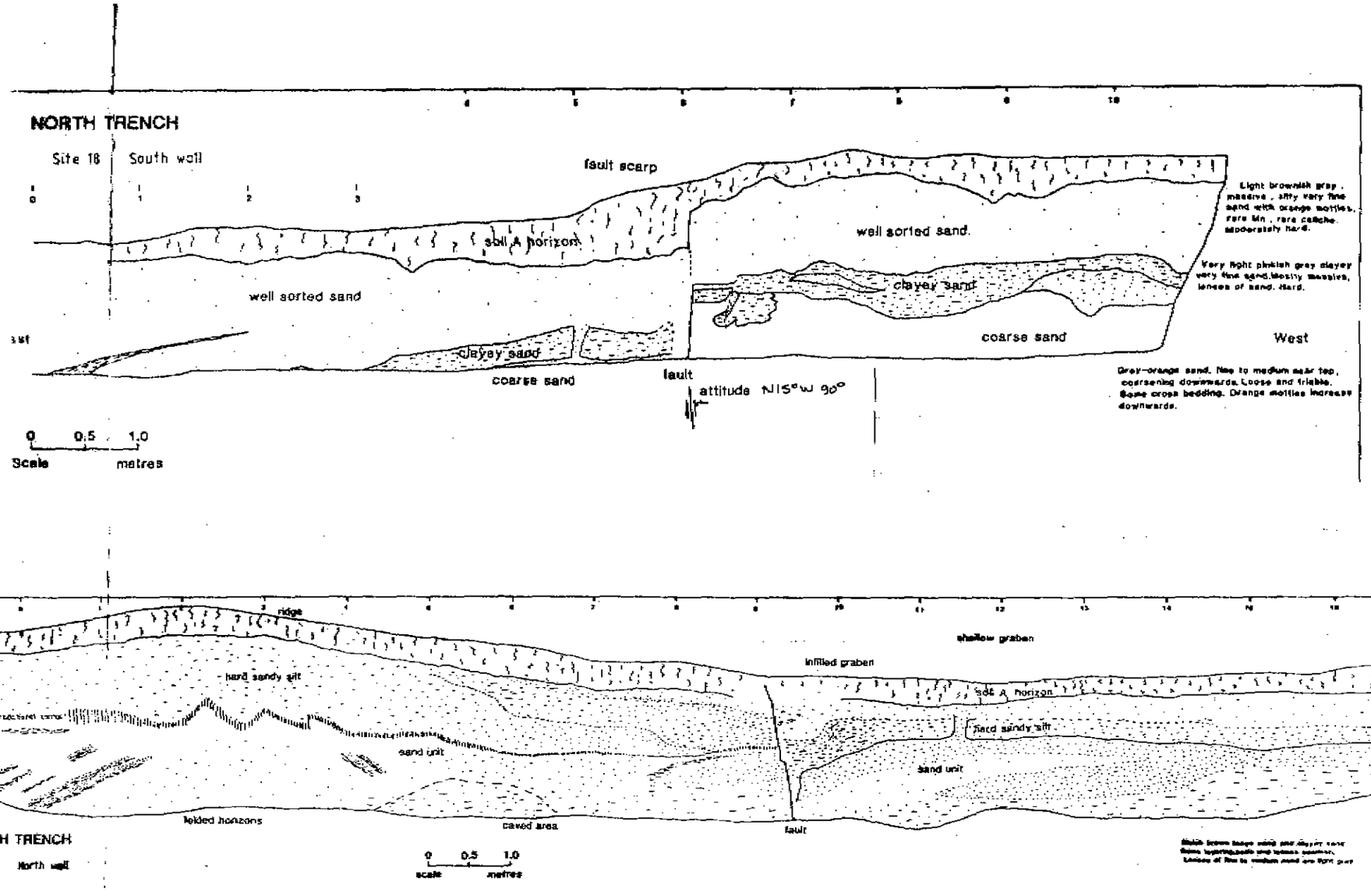


Figure 4 (to FER-192). Logs of trenches excavated by Beanland and Clark (in prep.) across Owens Valley fault zone (Independence segment) at site 18 (Figure 3a). Fault offsets late Holocene floodplain deposits of Owens River. Alluvium and A soil horizon are vertically offset about 0.5m. Meander channels at this location are offset about 3 to 4 m. Beanland and Clark reported reported that there was no evidence of multiple offsets observed in trenches and concluded that the magnitude of displacement represents 1872 offset.

Photo 1 (to FER-192). North wall of trench, showing faulted alluvial fan along Alabama Hills segment of Owens Valley fault zone (site 14, Figure 3b). Hammer is 18" long. See Figure 5 for sketch of this fault exposure.

Photo 2 (to FER-192). View west of trench in Photo 1 and Figure 5. Fault is delineated by two segments in this view (arrows at scarp crests).

Photo 3 (to FER-192). View southwest of 4.4m-high scarp at site 13 (Figure 3b). A thin veneer (~0.3m) of late Holocene colluvium overlies fluvial/lacustrine deposits. Beanland and Clark (in prep.) concluded that the scarp probably formed in 1872, thus producing the maximum vertical displacement observed along Owens Valley fault zone.

Photo 4 (to FER-192). Well-defined east-facing scarp developed in an abandoned late Tioga-age alluvial fan, view north (near site 9, Figure 3b). Lubetkin and Clark (1985) reported that this scarp was formed during at least three fault rupture events. The 1872 offset (about 2m) is delineated by free-face scarp slope.

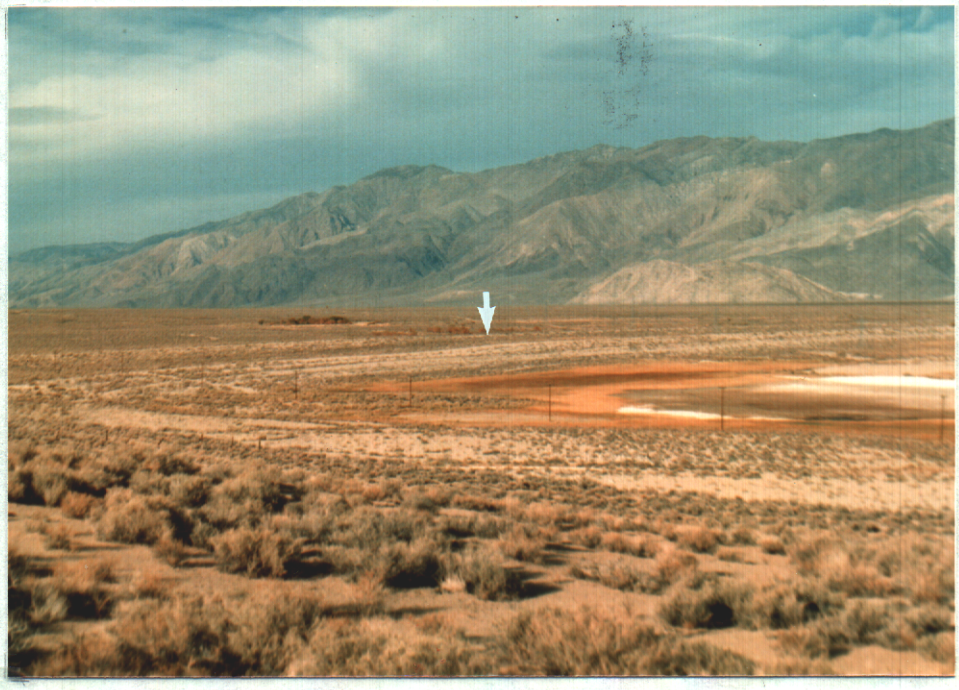
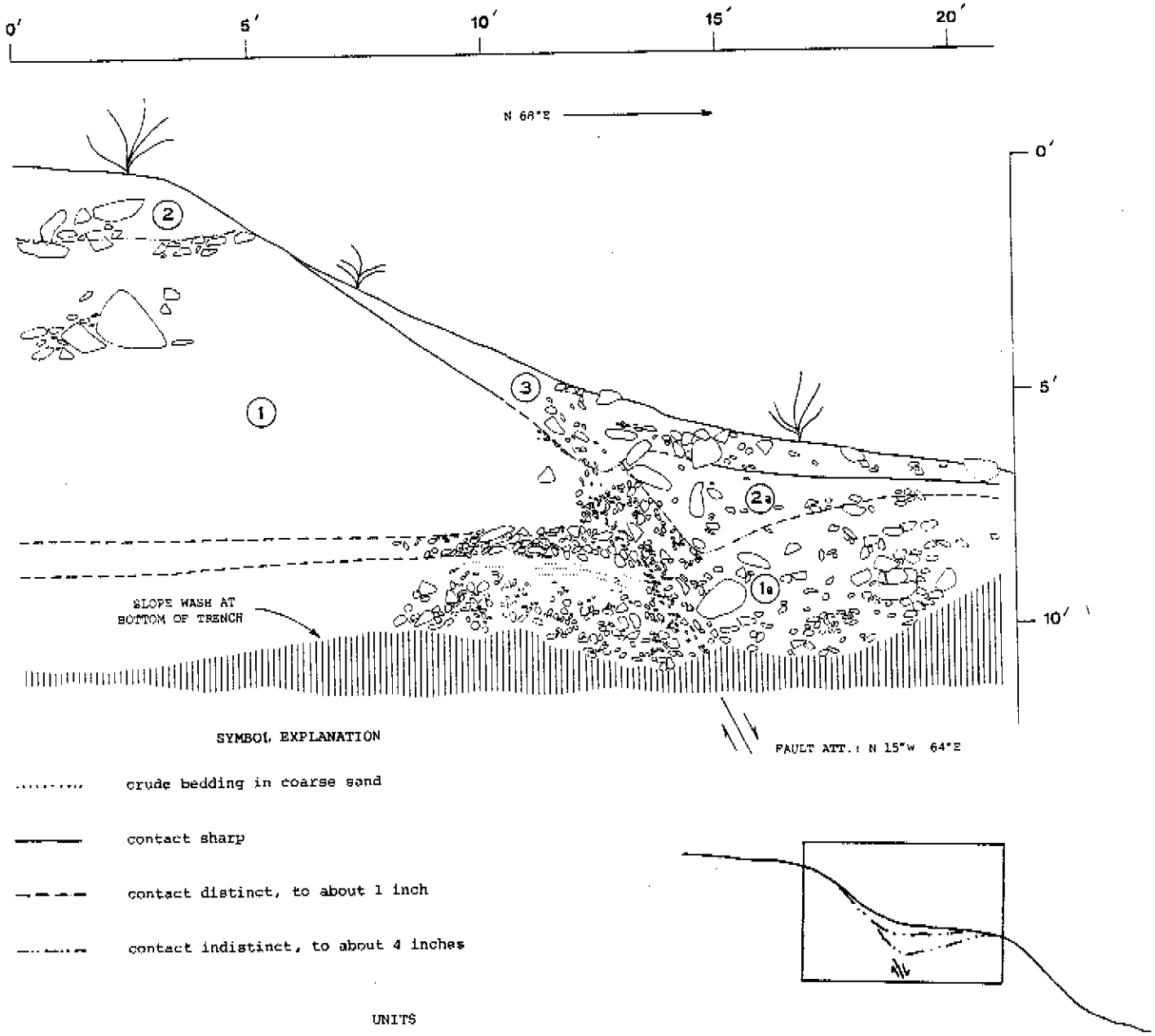


Photo 5 (to FER-192). A monoclinal warp (arrow) in late Holocene beach ridges delineates down-to-the-west displacement along the Diaz Lake segment of the Owens Valley fault zone; view east-northeast (site 3, Figure 3b).



SYMBOL EXPLANATION

crude bedding in coarse sand

contact sharp

contact distinct, to about 1 inch

contact indistinct, to about 4 inches

UNITS

(1) Pale brown (10 YR 6/3 D) gravel with cobbles and occasional boulders to 18 inches in diameter, predominantly consisting of sub-angular metamorphic clasts locally derived from Alabama Hills less than 1 mile to west. Silty sand matrix, moderately indurated. Crude bedding dips 1° to 3° to west, indicating tectonic tilting. Unit is alluvial fan deposit.

(1a) Similar to unit 1, but poorly indurated due to fracturing of downthrown block.

(2) Pale brown (10YR 6/3 D) cobbly silty sand, massive, structureless, poorly indurated, occasional boulders to 18 inches in diameter. Unit probably is debris-flow deposit.

(2a) Unit is probably same as unit 2.

(3) Pale brown (10YR 6/3 D) sandy gravel, crude bedding roughly parallels scarp slope. Unit is scarp-derived debris wash.

Figure 5 (to FER-192). Log of north wall of trench excavated across Alabama Hills segment of Owens Valley fault zone at site 14 (Figure 3b) (log by Bryant, this report). See photos 1 and 2.