STUDY OF SEISMIC ACTIVITY BY SELECTIVE TRENCHING ALONG THE ELSINORE FAULT ZONE, SOUTHERN CALIFORNIA

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ABSTRACT

Published literature and engineering geology reports bearing on potential seismicity of the Elsinore fault zone were reviewed. A field reconnaissance was accomplished to locate promising sites where trenches might reveal datable Holocene fault displacement history, and possibly times between major seismic events. Nine sites which have the potential of revealing ruptured Holocene sediments across strands of the Elsinore fault zone have been identified. Permission to trench three sites has been obtained and a site on the south branch of the Wildomar fault, a strand of the Elsinore fault zone southeast of Lake Elsinore, has been trenched.

Radiocarbon dating of sediments disrupted by the south branch of the Wildomar fault indicates activity within the past 4120 $\pm$ 260 years. The relationship between the dated sediment and two distinct sets of secondary faults which were active before and after the deposition of a gravel layer indicates that one or possibly two seismic events occurred since deposition of the dated sediments. The lack of correlation of sediments on opposite sides of the main fault, the orientation of a sub-parallel drag fold and slickensides in a silty clay layer suggest an important but unknown component of right-slip.

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INTRODUCTION

California's historic record is too short to estimate earthquake recurrence because the first recorded earthquake occurred in 1769, and instrumental seismology first began in 1933 (Allen et al, 1965). In an attempt to extend the seismic record, the magnitude and fault displacements during historic earthquakes and the long-term slip rates based on geologic data have been used to estimate earthquake recurrence intervals on the San Andreas and other major faults in southern California (Wallace, 1970; Lamar, Merifield and Proctor, 1973). This approach may provide a rough determination of the long-term average recurrence intervals. However, such estimates are subject to error because of uncertainty in dating the displaced rocks (Greensfelder, 1974) and large scatter in data relating earthquake magnitude and fault displacement (Bonilla and Buchanan, 1970). Significant local (Ambraseys, 1970) and worldwide (Davies and Brune, 1971) time variations in the level of seismicity also reduce the reliability of this method.

Information on the displacement of late Quaternary sediments may provide the best means of evaluating the seismic hazard on individual faults (Allen, 1975). Dating of Holocene materials in trench exposures across fault ruptures has revealed evidence of prehistoric earthquakes on the San Jacinto fault (Clark, et al, 1972), the San Fernando segment of the Sierra Madre fault system (Bonilla, 1973) and along the south-central reach of the San Andreas fault (Sieh and Jahns, 1976; Sieh, 1977, 1978). Additional trench exposures in late Quaternary materials across other active and potentially active faults in southern California are required to predict the approximate times and magnitudes of future earthquakes to be generated by individual faults.

The northwest trending Elsinore fault zone extends a distance of 200 km (125 miles) from directly north of the Mexican border to the northern end of the Santa Ana Mountains (Fig. 1). At the northern end of the Santa Ana Mountains, the Elsinore fault appears to split into the Chino fault, which continues north-northwest near the eastern margin of the Puente Hills, and the Whittier fault, which continues west-northwest along the southwest side of the Puente Hills (Gray, 1961; Weber, 1977). The Whittier fault extends over a distance of 32 kilometers (20 miles) from the Santa Ana River to the northwest end of the Puente Hills. At the northwest end of the Puente Hills, the Workman Hill and Whittier Heights faults appear to split from the Whittier

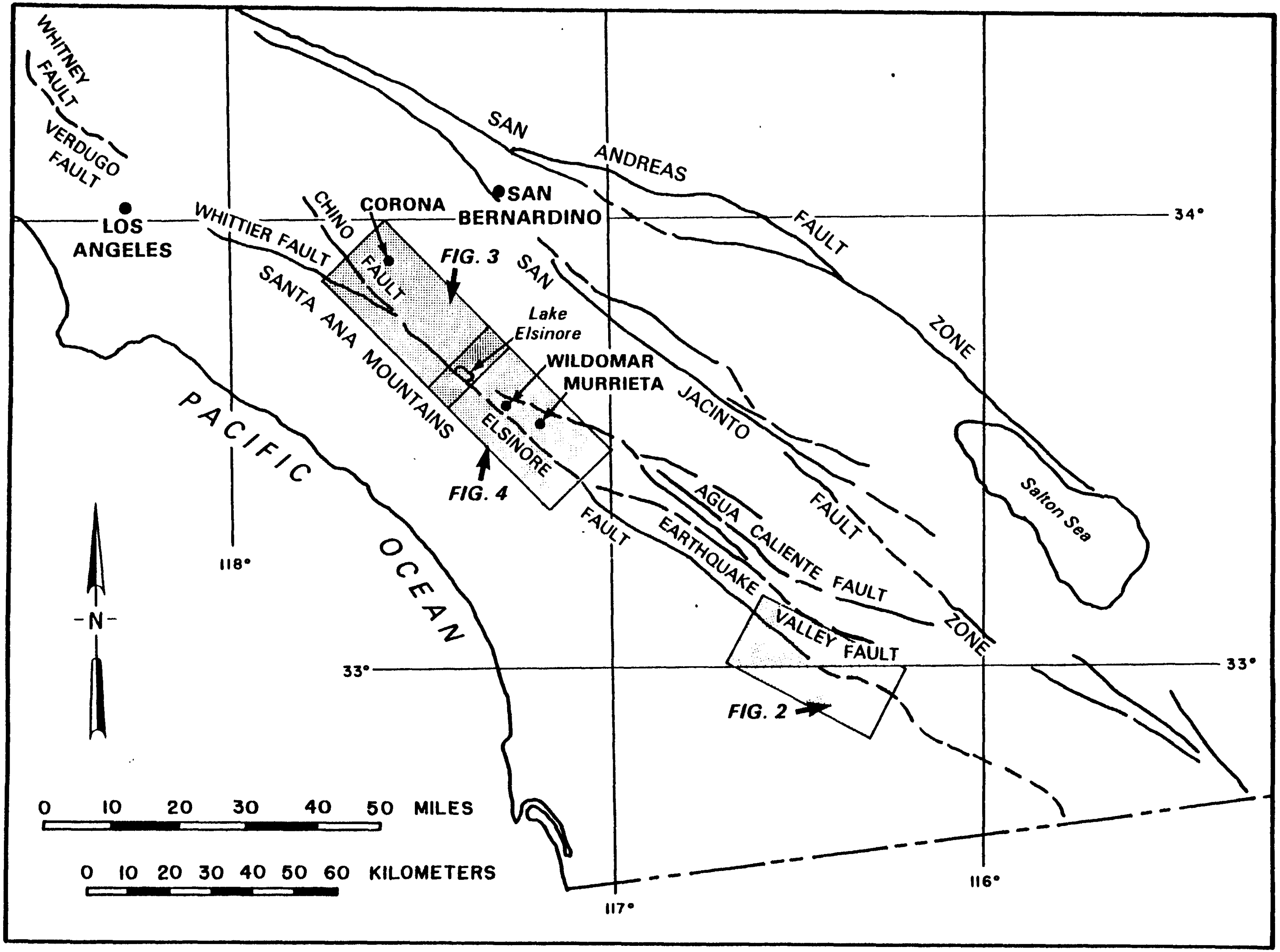

Fig. 1 - Map showing principal faults in southern California and area covered by detailed maps along Elsinore fault zone (Figs. 2-4).

fault (Daviess and Woodford, 1949). The continuation of these faults to the northwest is obscured by the recent alluvium of the San Gabriel Valley. Farther northwest in the Elysian Park-Repetto Hills area, several northwest-trending faults form an 8-kilometer (5-mile) wide zone of complex structure; it has been suggested (Lamar, 1961, 1970) that this zone represents a widened northwest continuation of the Whittier fault zone. To the northwest, the Eagle Rock and Whitney-Verdugo faults may represent principal strands of the Whittier-Elsinore fault zone (Lamar, 1970; Proctor et al, 1972).

Although the Elsinore fault zone is a major strand of the San Andreas fault system in southern California (Crowell, 1962), it has not been the site of a major earthquake in historic time. Based on length and evidence of late Pleistocene or Holocene displacement, Greensfelder (1974) has estimated that the Elsinore fault zone is reasonably capable of generating an earthquake with a magnitude as large as 7.5. The Whittier-Elsinore fault zone must be considered to have the potential for generating a major earthquake within or in close proximity to the southern California metropolitan area. However, information on prehistoric earthquakes is inadequate to estimate the probable recurrence interval and magnitude of future events. This report summarizes previous published data on displacement on the Elsinore fault zone and describes the results to date of an attempt to better define the seismic potential by review of engineering geology reports on seismic hazards prepared to satisfy the Alquist-Priolo Special Studies Zones Act of 1972 (Hart, 1980) and study of displaced Holocene sediments in trench exposures across fault ruptures within the Elsinore fault zone.

DISPLACEMENT HISTORY

Apparent offset of facies and thicknesses within Paleocene sediments along the Whittier-Elsinore fault in the area northwest of Lake Elsinore (Fig. 1) suggests 30 to 40 kilometers (20 to 25 miles) of right-slip (Lamar, 1961; Yerkes and Campbell, 1971; Sage 1973). However, Woodford et al (1972) believe that large post-Cretaceous strike-slip on the Whittier-Elsinore fault zone is precluded by the distribution of distinctive Upper Cretaceous and Paleocene strata on opposite sides of this fault zone. Based on the distribution of older rocks of the southern California batholith and associated metamorphic rocks, Weber (1977) has estimated that the total right-slip along the Elsinore fault in the same area is about 9-11 km (6-6½ miles).

Woodford (1960) and Woodford et al (1971) believe that post-Miocene right-slip on the Elsinore-Whittier-Chino fault zone has been 5 km (3 miles) or less, and Yerkes and Campbell (1971) suggest that most of the right-slip occurred in the middle Miocene. However, stratigraphic relations of upper Miocene and Pliocene rocks along the Whittier fault in the Puente Hills indicate 4600 meters (15,000 feet) of right-slip (Yerkes, 1972). This is similar to the 5 kilometer (3-mile) offset suggested by Lamar (1961) for lower Pliocene marine fans described by Conrey (1959, 1967), and the 5-km (3-mile) offset of a facies boundary between sandstone and conglomerate in an unnamed Pleistocene unit between Lake Elsinore and Murrieta described by Kennedy (1977). An ash horizon within this unit has been correlated with the 0.7 m.y. old Bishop Ash (Merriam and Bischoff, 1975; and personal communication from A. Sarna-Wojcicki, in Kennedy, 1977, page 5).

Much smaller displacements have been reported along the southeast segment of the Elsinore fault shown on Fig. 2. Weber (1963) has noted that basement rocks in the Julian area (Fig. 2) display only about 600 meters (2000 feet) of right separation. To the southeast, Gastil and Bushee (1961) and Hart (1964, 1974) show right separations of 760 to 2400 meters (2500 to 8000 feet) on the margins of a Bonsall Tonalite body exposed in Rodriquez Canyon (Fig. 2). Moyle (1968), Hart (1974) and Lowman (1980) question whether the Elsinore fault can be a continuous feature between Mason and Vallecito Valleys. A continuous fault would have to cut bedrock on a ridge between the valleys at Campbell Grade (CG, Fig. 2). Lowman (1980) shows that foliation in metamorphic rocks exposed along this ridge is uninterrupted across the inferred Elsinore fault trace, as shown on previous maps (Merriam, 1955; Strand, 1962; Weber, 1963). Farther southeast, Dr. Robert V. Sharp (1968; personal communication, 1972) reported that displaced cataclastic zones within plutonic rocks along the margins of Vallecito Valley (Fig. 2) limit the amount of right-slip on the Elsinore fault to about 5 kilometers (3 miles) or less. The cataclastic zones are probably at least as old as Middle Cretaceous (Sharp, 1967). Although the exact relationships are obscured by alluvium, the north end of the Thing Valley fault south of Agua Caliente Hot Springs appears to be displaced 700-1300 meters (2300-4300 feet) in a right-lateral sense by the south branch of the Elsinore fault, as mapped by Merriam (1955) and Buttram (1962). The Thing Valley fault was identified by study of satellite imagery (Merifield and Lamar, 1976; Lamar and Merifield, 1976).

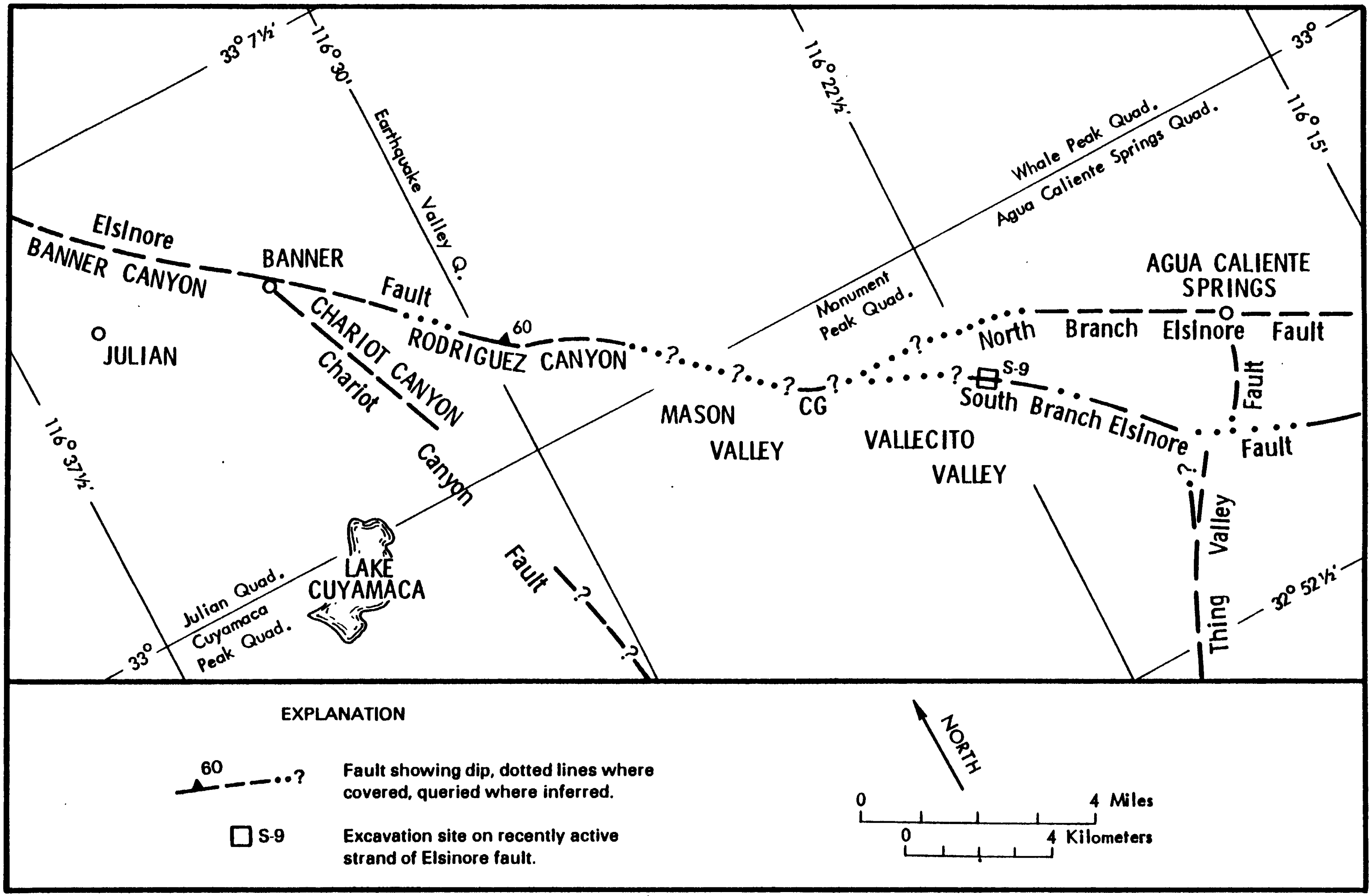

Fig. 2 - Map showing Elsinore fault zone between Banner Canyon and Agua Caliente Springs.
Abbreviation: CG: Campbell Grade. From Lamar and Merifield (1976).

The discrepancy between the pre-Pliocene displacement northwest of Lake Elsinore and the displacement in the Julian-Vallecito Valley area (Fig. 2) could easily be accounted for in the 100 kilometers (60 miles) which separate the areas. Allison (1974abc) has suggested that a portion of the right-slip could be distributed on the Chariot Canyon fault which branches from the Elsinore fault (Fig. 2). Several northwest to east-west trending faults also appear to splay off from the Elsinore fault southeast of Lake Elsinore (Fig. 1) (Mann, 1955; Rogers, 1965). Mann (1955) described stream offsets and horizontal striae on slickensided surfaces along these faults in the Temecula area. The faults studied by Mann, and other faults (Rogers, 1965), continue for a number of kilometers to the southeast; additional right-slip on the northwest portion of the Elsinore fault zone could be distributed on these faults. Detailed published maps of the area southeast of that described by Mann are not available. However, Rogers (1965) shows abrupt changes in basement rock type across the Agua Caliente, Lancaster and Aguanga faults. Lowman (1980) has suggested that the discrepancy in the amount of right-slip on the northern and southern portions of the Elsinore fault may be accounted for by the down-faulting of the Perris Basin, Warner Valley, and perhaps Mason Valley, as "pull-aparts" (Crowell and Sylvester, 1979, p. 145).

More or less continuous displacement along the Whittier-Elsinore fault during late Miocene, Pliocene and Quaternary is indicated by the following:

1. Diabasic intrusive rocks of early late Miocene age are associated with the Whittier fault and were probably intruded along the fault (Durham and Yerkes, 1964).

2. Locally along the south side of the Whittier fault in the Esperanza area folded late Miocene rocks are overlain unconformably by early Pliocene strata (Lamar, 1961). The folding dies out with distance from the fault and is interpreted to be the result of drag secondarily related to post late Miocene, pre-early Pliocene slip on the Whittier fault. Similar relations were observed near a possible branch of the Whittier fault in the Repetto Hills area (Lamar, 1970).

3. Several unconformities are present in upper Miocene strata in the Sansinena Oil Field adjacent to the Whittier fault in the Puente Hills; these unconformities and the distribution of coarser sediments in upper Miocene rocks strongly suggest fault movement or folding during late Miocene time (Woodward, 1958).

4. Foraminiferal studies in the Sansinena Oil Field indicate considerable Miocene landslide debris in Pliocene sediments in the down-thrown south block of the Whitter fault (Woodward, 1958); this could be explained by fault displacement during the Pliocene.

5. Kundert (1952) also suggests that unusual sedimentary clasts in the Repetto Formation (lower Pliocene) south of the Whittier fault may have been deposited by turbidity currents originating on a steep slope formed by movement along the Whittier fault.

6. An angular unconformity between the upper Pliocene Pico Formation and Pleistocene La Habra Formation (Kundert, 1952) may also be the result of post upper Pliocene movement and drag folding along the Whittier fault.

7. Basalts with an average age of 9.6 ± 0.7 m.y. (Kennedy, 1977) have been relatively down-dropped 1000 meters (3300 feet) in the Murrieta graben along the Elsinore fault zone (Mann, 1955).

8. Post Pleistocene displacement is indicated by the fault contact between the La Habra Formation and older rocks and by the steep dips in the La Habra Formation along the south edge of the Puente Hills (Yerkes, 1972). Mann (1955) and Kennedy (1977) also report folded and faulted Pleistocene strata along the Elsinore fault zone, southeast of Lake Elsinore, and Jahns (1954) shows northwest trending faults north of Lake Henshaw which cut valley fill.

9. Right lateral offset of stream courses of up to 2600 meters (8800 feet) have been reported by Durham and Yerkes (1964) on the Whittier fault along the south edge of the Puente Hills. Along much of its length, the Elsinore fault underlies long straight canyons so that right-slip would not be reflected in displaced minor drainage courses. However, right lateral offset of streams along strands of the Elsinore fault zone between the Santa Ana River and Lake Elsinore have been reported by

Lamar (1959) and Weber (1977), in the Wildomar-Temecula area by Kennedy (1977), and in the Julian area by Lamar and Merifield (1976), and along the southeastern part by Clark (1975).

10. Scarps and offset of colluvium and alluvium have been reported along the Whittier fault by Durham and Yerkes (1964), Nicoll (1970) and Hannan et al (1979), the Chino fault by Lewis (1941), Lamar (1959), Gray (1961) and Weber (1977a), and the Elsinore fault by Weber (1977a), Kennedy (1977), Jahns (1954), and Buttram (1962). Carbon 14 age dating of organic material within displaced alluvium indicates movement on the Whittier fault within the past 2185 ± 105 years (Hannan et al, 1979).
11. Sags or closed depressions have been reported along strands of the Elsinore fault zone by Jahns (1954), Engle (1959), Kennedy (1977), and Sharp (1978, p. 194).

Based on study of Los Angeles County Engineer level lines, Lamar and Lamar (1973) have noted that the synclinal area south of the Whittier fault between the Puente and Montebello Hills and Santa Fe Springs-Coyote Hills trend is subsiding at .3 to 1.2 cm/year (.01 to .04 ft/year). The relative motion across the Whittier fault could be caused by withdrawal of ground water or compaction of sediments rather than tectonic movement.

The tabulation of earthquakes of Richter magnitude 4.0 and greater between 1934 and 1961 and larger earthquakes since 1906 by the California Department of Water Resources (1964) indicates that a destructive earthquake has not occurred along the Whittier-Elsinore fault in historic time. However, Townley and Allen (1939) describe an earthquake which apparently centered in the Lake Elsinore region May 15, 1910, as follows:

> At Corona, Riverside County, a chimney was shaken down and plastering fell. In Cold Water Canyon in Temescal Mountains, the shock was exceedingly heavy. At Temescal it was the most severe for at least twenty years, toppling chimneys and overturning chairs. At Wildomar, rocks rolled down hillsides, bricks fell from chimneys, and books were thrown from shelves. Elsinore reported the "hardest earthquake in years, but no damage"--Corona newspaper.

Richter (1958, p. 533) has suggested that this earthquake originated on the Elsinore fault and estimated the magnitude as 6 or greater.

A net of portable seismometers was operated in the Puente Hills along the Whittier fault between July 1971 and April 1972 (Lamar, 1972; Lamar and Stewart, 1973). Epicenters of 31 microearthquakes with a maximum magnitude of 3.0 were determined. Sufficient data were available to determine hypocentral depths for 17 events. Assuming a range of 60 to 70 degrees north dip on the Whittier fault, 8 of the 17 hypocenters lie on the subsurface projection of the Whittier fault. Langenkamp and Combs (1974) also monitored microearthquakes along the Elsinore fault zone between Corona and just north of the Mexican border.

PRESENT INVESTIGATION

Proposed Trench Locations

The Alquist-Priolo Special Studies Zones Act of 1972 requires engineering geology seismic hazards reports for development on property situated on strands of the Elsinore fault zone (Hart, 1980). Such reports on file with Riverside County were reviewed for trench and other data on recent displacement. The pertinent data from these reports are summarized in Appendix A; the locations of the trenches relative to segments of the Elsinore fault are shown on Figures 3 and 4. Data on possible excavation sites for this study are summarized on Table 1 and located on Figures 2-4. The data were derived from a literature search and the review of engineering geology reports. Additional information was obtained during a field reconnaissance in July 1980.

Glen Ivy North Fault, Site 1:

Based on previous studies (Table 1) and our field observations, trenching at Site 1 (Fig. 3) has the potential of revealing disrupted Holocene sediments within an elongate sag pond along the Glen Ivy North fault. However, during our field reconnaissance in July 1980, the sag pond contained standing water which had overflowed from irrigation of adjacent orchards. Permission to trench has been obtained from the property owner. This site may be trenched if sufficient funds are available after two more promising sites are excavated and if groundwater conditions permit.

Previous investigators (GP-45, Appendix A; Sharp, 1978, p. 194) have suggested that cracks in the asphalt of Lawson Road at the eastern margin of the main sag pond area are due to fault creep. The cracks are located

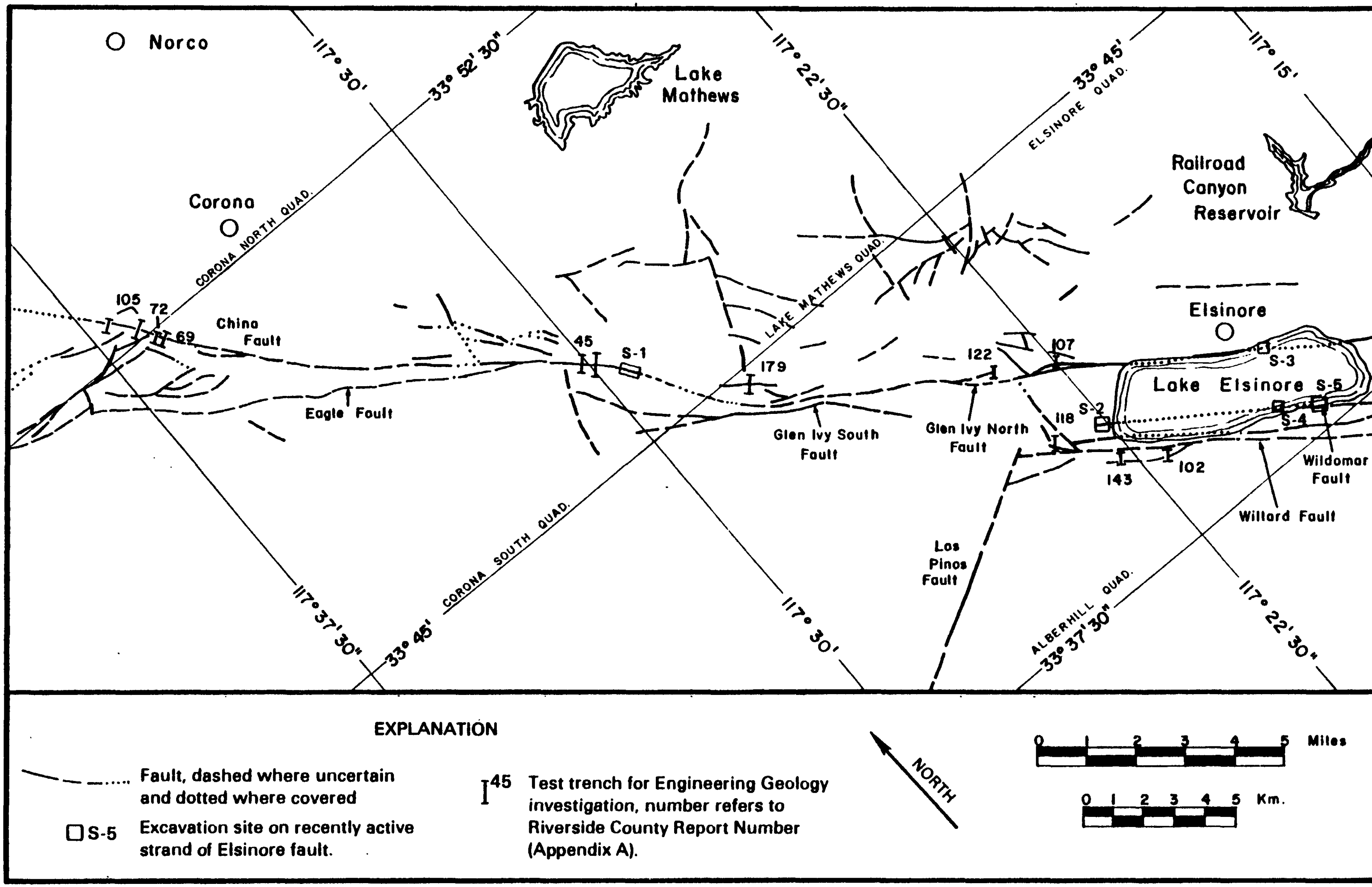

Fig. 3 - Map showing Elsinore fault zone between Corona and Lake Elsinore and excavation sites. From Rogers (1965) with modifications based on Weber (1977).

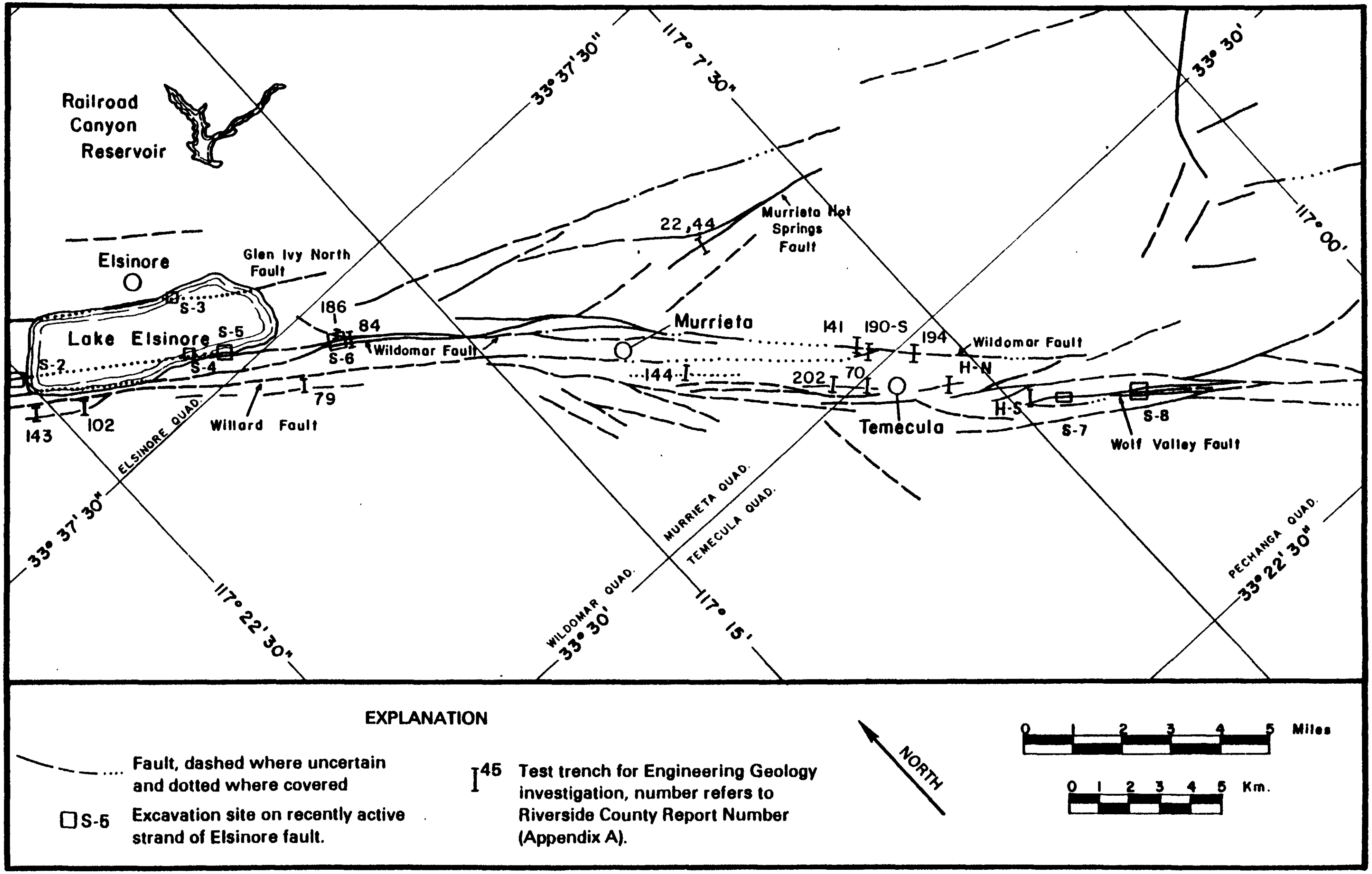

Fig. 4 - Map showing Elsinore fault zone between Lake Elsinore and Temecula area and excavation sites. From Rogers (1965) with modifications based on Weber (1977), Kennedy (1977) and Envicom (1976).

Table 1 - Data on possible excavation sites on recently active strands of Elsinore fault; locations are shown on Figs. 2-4. Riverside County Geology Reports (GP-) are listed in Appendix A.

Number	Description
1	Recent scarp and sag pond filled with trees and bushes along Glen Ivy North fault (Weber, 1977, p. 90; Sharp, 1978, p. 194). Pioneer Consultants (GP-45) report: (1) Fault gouge and slickensides in older fan deposits (Qof, Kennedy, 1977) in three trenches on proposed building sites along the northern portion of the sag pond area. (2) Water-line in vicinity of Hunt Road (northwest of main sag ponds and along strike) requires annual repair, possibly due to continual creep along the fault. (3) cracks in asphalt of Lawson Road at eastern margin of the main sag pond, also possibly due to fault creep.
2	Wildomar fault along southwest side of Lake Elsinore may displace lake sediments (Weber, 1977, p. 93).
3	Glen Ivy North fault may form southwest-facing scarp in relatively young lake sediments along northeast side of Lake Elsinore (Weber, 1977, p. 93).
4	Wildomar fault along southeast side of Lake Elsinore may displace lake sediments (Weber, 1977, p. 93).
5	Possible scarps in youthful lake sediments and steep north slope of Rome Hill suggest recent movement on Wildomar fault (Weber, 1977, p. 94).
6	Closed depressions and small sag ponds along Wildomar fault (Weber, 1977, p. 94; Kennedy, 1977, p. 9). Lohr (GP-84) reports "North" and "South" branches of Wildomar fault displace Pauba Formation to within 1-3 feet of surface; trenches are located directly southeast of largest depression.
7	Ground-water barrier along strand of Wolf Valley fault (Kennedy, 1977, Plate I).
8	Middle of three closed depressions along Wolf Valley fault zone (Kennedy, 1977, Plate I).
9	Prominent scarp in alluvium along south branch of Elsinore fault (Buttram, 1962, p. 59).

at, and westward from the cut-fill contact over a width of about 10 meters. About half of the cracks are oriented in a northwest trending en echelon pattern and the remainder are semi-circular or trend northeast. The cracks may be the result of differential settlement of road fill rather than aseismic creep.

Faults on Margins of Lake Elsinore, Sites 2-5:

As summarized on Table 1, previous work by Weber (1977) suggests that Sites 2-5 (Fig. 3) on the usual margins of Lake Elsinore would be favorable locations to find disrupted Holocene lake sediments. During July 1980, these sites were under water due to the abnormally high lake level caused by heavy rainfall. These sites will not be suitable until the lake and water table fall to previous levels.

Wildomar Fault, Site 6:

A previous engineering geology investigation (Table 1) revealed disrupted beds of the Pauba Formation (late Pleistocene, Kennedy, 1977) on branches of the Wildomar fault located on the northeast and southwest sides of a closed depression (Figs. 4 and 5). In July 1980, standing water was limited to the lowest part of the depression, and vegetation consisted of dry grass on the slopes and was absent on the bottom of the depression. Permission to trench across the depression was obtained from the property owner and was accomplished during September 1980. The results of the trenching are described in the next section.

Wolf Valley Fault, Site 7:

During our field reconnaissance, a small oval swamp of low relief containing standing water and thick vegetation was observed along a strand of the Wolf Valley fault at Site 7 (Fig. 4). The fault trace is expressed as an alignment of scarps and shallow depressions. A low scarp is located directly northeast of the swampy area between the site and Pala Road. This site is considered less favorable than other sites which will be investigated first.

Wolf Valley Fault, Site 8:

Kennedy's (1977) map and our reconnaissance indicate that faults bounding a closed depression are reflected in scarps and topographic saddles adjacent to the depression and along strike. Permission to trench Site 8

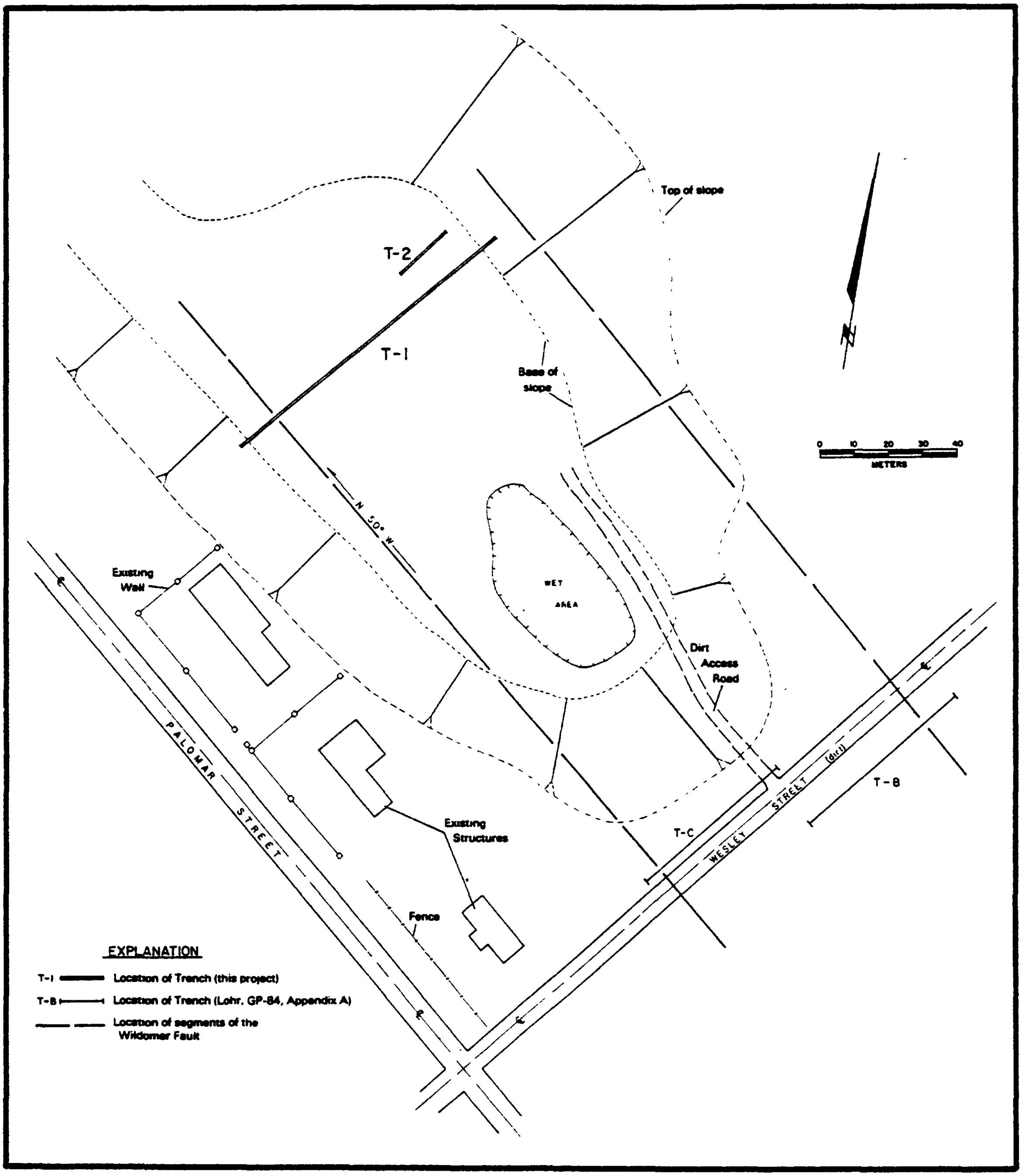

Fig. 5 - Map showing trenches across closed depression bounded by strands of Wildomar fault, Site 6. Location of site shown on Fig. 4.

(Fig. 4) has been obtained and work will begin in the near future.

South Branch of Elsinore Fault, Site 9:

Site 9 (Fig. 2) has not been visited during the present investigation. Trenching at this location has a low priority because of the great distance from urban areas.

Results of Trenching Across Wildomar Fault, Site 6

Field work was accomplished at this site during September 1980. Trenches were dug with a John Deere Model 540C "extendahoe" backhoe equipped with a two-foot wide bucket. A single trench trending N41°E was excavated at right angles to the N50°W trend of the Wildomar fault and was located so as to intersect the projected traces of the fault (Fig. 5). The trench was excavated to a depth of 2.5 meters over its entire 96-meter length. Nails and string were used to establish a one meter grid on the northern trench face; the southwestern end of the trench was defined as the 0.0 reference. Stratigraphic details were plotted relative to the grid. The trench was deepened to 5 meters between 12 and 16 meters to expose more details of the faulting.

A layered section of clay, silt, sand and gravel was exposed in the trench; this sequence is faulted and deformed between 7 and 14 meters (Figs. 6-9) near the southwest end of the trench. The sediments between 14 and 65 meters consist of horizontally layered sandy clay which overlies dense silty clay and appeared to be unfaulted and undeformed. Beyond 65 meters, the upper sandy clay unit graded into a slightly clayey coarse sand eroded and washed down from the hill (scarp) to the northeast. Groundwater was perched on the silty clay horizon at a depth of approximately 1.5 meters. Continuous seepage of groundwater caused filling of the trench and contributed to the complete collapse of the entire central portion of the trench between 27 and 75 meters.

A second trench was excavated parallel to and 10 meters north of the collapsed main trench (Fig. 5) in order to insure complete cross-section coverage. No evidence of faulting was observed at the northeast end of either trench. Projection of the north branch of the Wildomar fault northwestward from its mapped location in Lohr (GP-84, Appendix A) Trench No. B at a trend parallel to the south branch is shown on Figure 5. This projected trend lies beyond the northeastern end of our exploration trenches on a slope which is too steep for the operation of a backhoe.

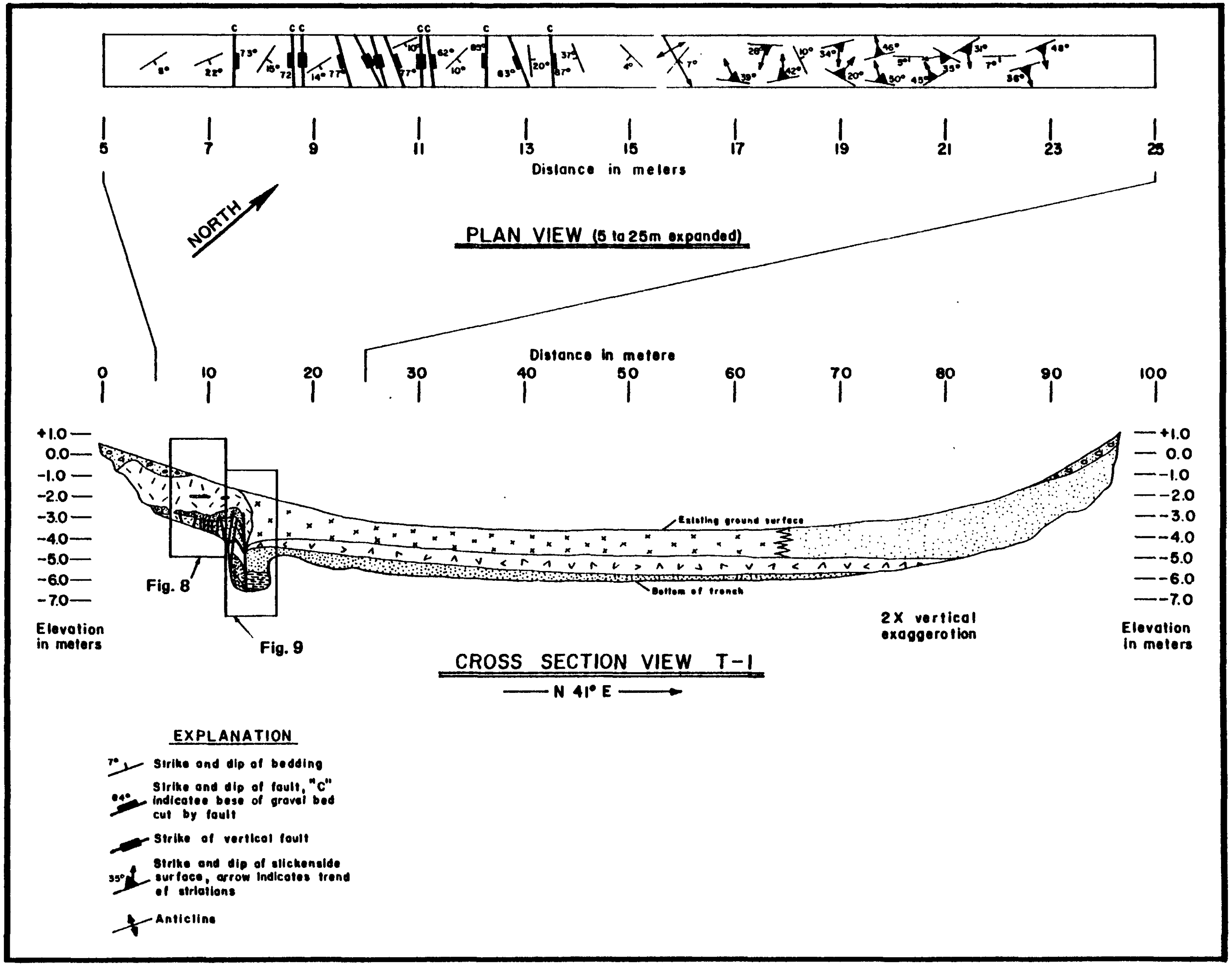

Fig. 6 - Generalized trench log and detailed plan view of fault zone, south branch of Wildomar fault. See Fig. 5 for location of trench and Fig. 7 for explanation.

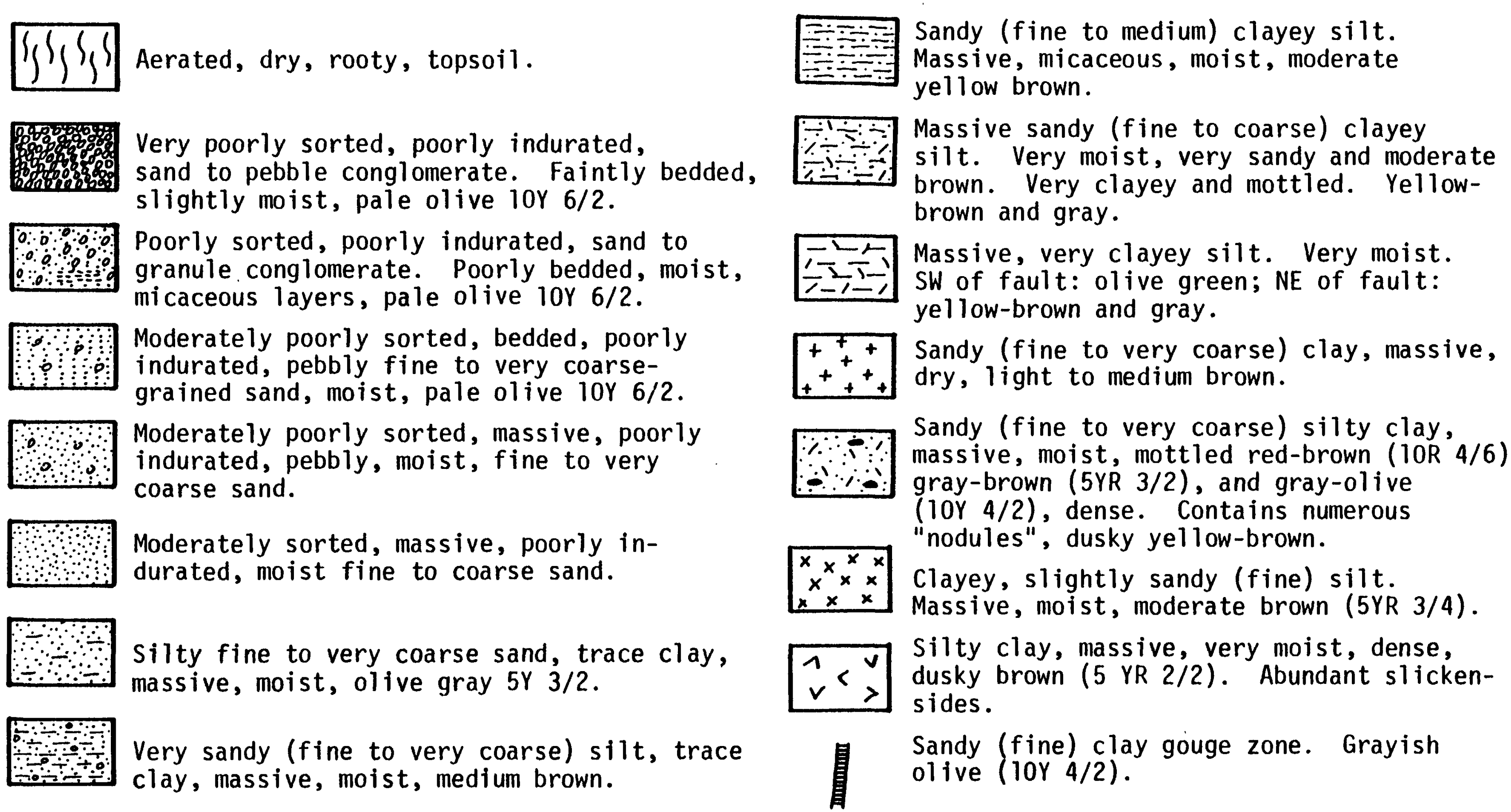

Fig. 7 - Explanation of lithologic symbols on Figs. 6, 8 and 9.

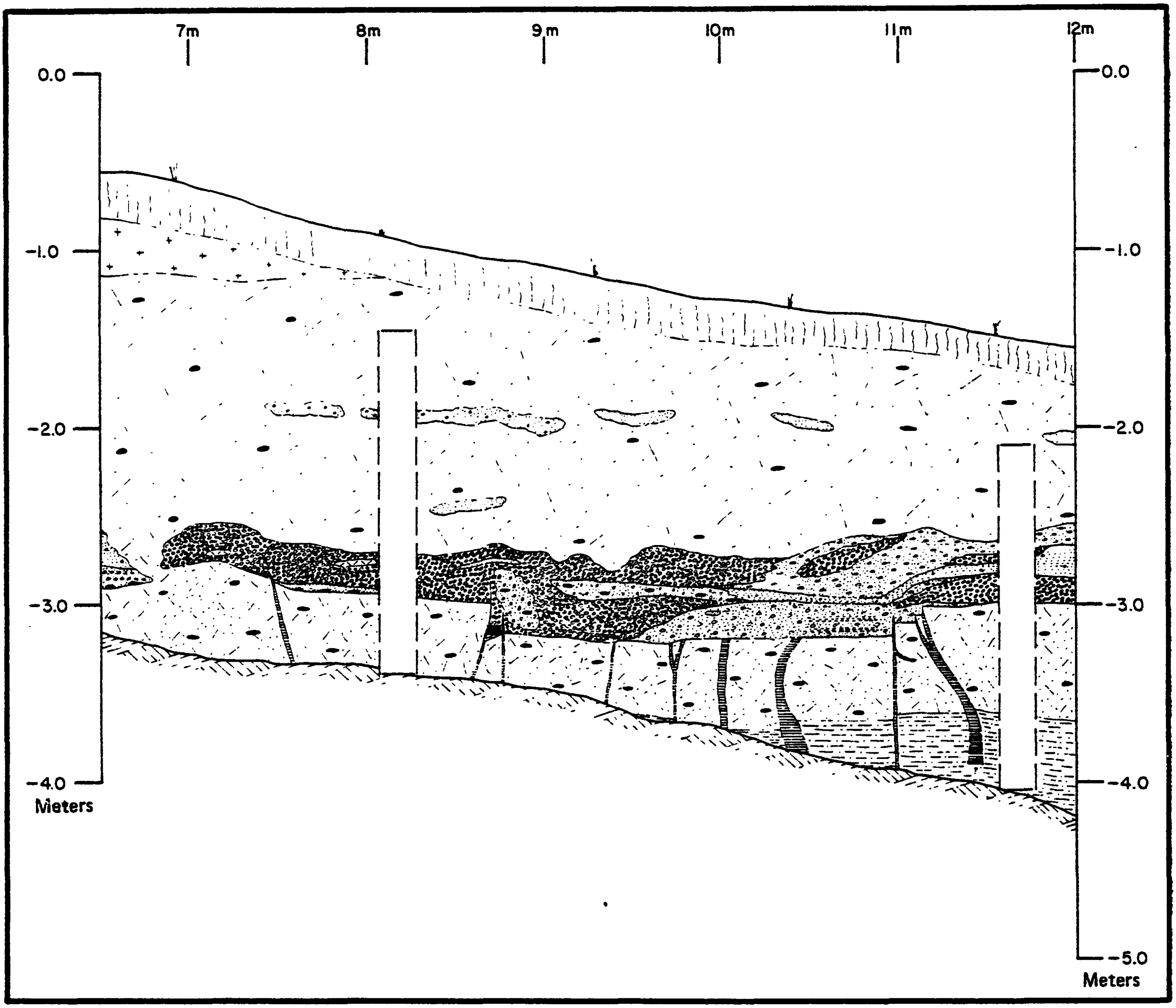

Fig. 8 - Detailed trench log between 6.6 and 12.0 meters.
See Fig. 6 for location and Fig. 7 for explanation.

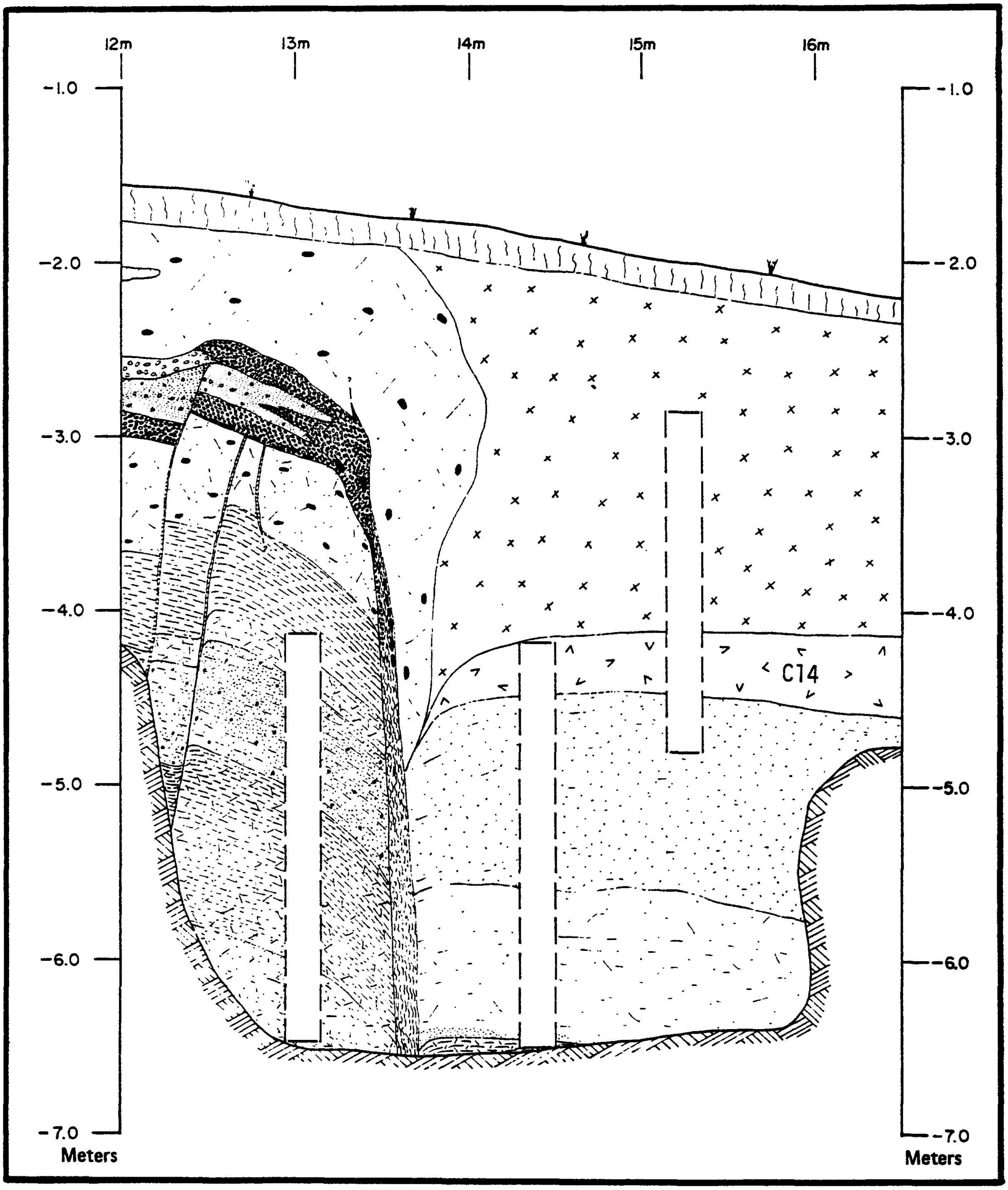

Fig. 9 - Detailed trench log between 12.0 and 16.5 meters.
See Fig. 6 for location and Fig. 7 for explanation.
C14: layer dated by radiocarbon method (Appendix B).

Details of the structure within the fault zone between 6.6 and 16.5 meters are illustrated in Figures 8 and 9. Completely different sedimentary sections occur on opposite sides of the principal structural break at 13.5 meters, which is interpreted to be the south branch of the Wildomar fault. The gouge zone is 5-10 cm wide, near vertical and truncates all sediments except the uppermost massive sandy clay within one meter of the surface. Sediments on both sides of the fault are dragged down. A gravel horizon on the southwest side of the fault (Fig. 9) shows approximately one meter of vertical drag. The lack of correlation of the sediments on opposite sides of the fault and the fact that beds are dragged down on both sides of the fault suggest a significant, but unknown, component of horizontal displacement.

The attitude symbols northeast of the main fault (Fig. 6) suggest a southeast plunging anticlinal axis trending about N75°W, at an angle of about 23 degrees to the fault. Such an orientation is consistent with drag folding caused by right-slip (Wilcox et al, 1973). Sediments northeast of the fault consist of gently dipping relatively undeformed clayey silts, silty clays, sandy silts and fine silty sands. Abundant slickensides were observed and measured in the massive dusky brown silty clay horizon between depths of 4.2 and 4.6 m (Fig. 6, plan view). Striations on most of the slickensided surfaces appear to be roughly parallel to the northwest trend of the breaks observed between 7 and 13.5 meters, thus strengthening the interpretation that the major displacement along the main fault was horizontal, rather than vertical.

Sediments southwest of the main fault break consist of a sequence of sandy clays and sandy silts with a prominent sand and gravel layer which occurs at a depth of 1 to 2 meters below the present ground surface. This unit provided a marker horizon for determining deformation between the 7 and 13.5-meter interval in the trench. Faults were identified within the sediments as steeply dipping or vertical light-green clay gouge zones ranging between 1 and 10 cm in width.

These faults are divided into the following two classes: (1) relatively older faults which are truncated by the base of the gravel; strikes: N64°W to N75°W; dips: 77°SW to 77°NE, and (2) relatively younger faults which displace the base of the gravel layer (denoted by C on Fig. 6) and appear to die out within the gravel; strikes: N47°W to N55°W; dips:

72°SW to 73°NE. No fault except the main break at 13.5 meters displaces the top of the gravel. However, the upper contact of the gravel shows minor deformation associated with faults located at 12.5 m, 11 m, 8.5 m and possibly 7.5 m (Figs. 8 and 9). The deformation may be the result of a "smoothing over" of the upper contact of the gravel subsequent to rupture. Redistribution of the clasts in the upper portion of the gravel could be accomplished if these sediments were at or near the ground surface at the time of rupture. A small (10-20 cm high) scarp produced during an earthquake could be eroded down after or at the time of deposition of the overlying sandy clay.

The main fault (13.5 m, Fig. 9) may have had the most recent displacement because a small gravel wedge projects upward from the gravel layer into the overlying clay within the fault zone. Above this wedge, the fault is not discernible within the massive sandy clay, which apparently continued to be deposited after displacement. It is also possible that the most recent displacement on the main fault was contemporaneous with formation of the youngest secondary faults described above and that, because of smaller displacement, the effects are not as obvious at and above the top of the gravel layer. It is concluded that the deformation was the result of two, or less likely three, earthquakes which originated on the south branch of the Wildomar fault.

Clearly identifiable organic material was not observed in any of the sediments exposed within the trench. However, the dense, dark gray, slickensided clay northeast of the main fault was sampled for C^{14} dating because its dark color suggested it might contain sufficient organic material for analysis. This material was sent to Teledyne Isotopes (Appendix B) and the following results were obtained: age in years (B.P.), humic acids: 4330 $\pm$ 400; carbon residue: 4120 $\pm$ 260. The clay unit sampled is truncated by the main fault and must predate at least one of the seismic events. Its relationship to the event which occurred prior to the deposition of the gravel is not clear, because units cannot be correlated across the main fault. Thus, we have no basis for deciding whether the clay predates one or both earthquakes caused by movement on the south branch of the Wildomar fault. We also have no basis for estimating the time which elapsed between deposition of the clay and its truncation as a result of fault displacement.

CONCLUSIONS

Radiocarbon dating of disrupted sediment indicates that the south branch of the Wildomar fault, southeast of Lake Elsinore, has been active within the past 4120 $\pm$ 260 years. The relationship of two distinct periods of secondary faulting to the dated sediments indicates that one or two seismic events occurred during this period; an additional and more recent displacement event on this fault is also possible but is considered less likely. Because of a lack of correlation of sediments on opposite sides of the main break, the amount and sense of displacement are unknown. This lack of correlation and secondary structures suggest an important, but unknown, component of right-slip. A vertical component of displacement, northeast side down, would explain the topographic relief between the south edge and center of a depression which is bounded on the southwest by the fault.

FUTURE PLANS

Permission has been obtained to trench Sites 1 and 8 (Table 1). It is planned to begin work on these sites in the near future. It is probable that study of these two sites will exhaust the funds currently available on this project.

ACKNOWLEDGMENTS

Permission to trench on their property given by the following individuals is gratefully acknowledged: Site 1: Mr. John B. Hoeger, president, Temescal Properties, Inc., Corona; Site 6: Mr. Timothy W. Archer, Lake Elsinore; Site 8: Dr. Edward H. Boseker, Santa Ana. Mr. Anthony B. Brown, Engineering Geologist, Riverside County, was generous in the loan of reports on file in his office and provided helpful discussions. Dr. Mason Hill, Mr. David Douglass and Mr. Blake Schow assisted in the field work. The manuscript was typed and reviewed by Mrs. Ruth Merifield. The manuscript was also reviewed by Drs. Paul Merifield and Mason Hill. Miss Sandra Petitjean helped with the illustrations.

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APPENDIX A

Annotated list of engineering geology reports with trench data across strands of Elsinore Fault zone by Riverside County Geology Report Number:

H. Leighton, F. Beach & Assoc., 1973, Geologic investigation along the Elsinore fault zone near Pala Village Site, Rancho California, July 10, Job #73222.

Trenches, 8-13 feet deep, across strands of Wolf Valley fault zone (Kennedy, 1977) and Willard fault zone (Envicom, 1976). Near vertical joints with no offset in alluvium (Qal, Kennedy, 1977) across strand of Wolf Valley fault (Kennedy, 1977) in southernmost trenches (H-S on Fig. 4). Fault cuts old terrace deposits (Pauba formation, Qps, Kennedy, 1977) and does not displace alluvium along possible northern extension of Wolf Valley fault (Kennedy, 1977) or strand of Willard fault (Envicom, 1976)(H-N on Fig. 4).

22. Murphy, M. A. & Associates, 1974, Fault study of the Murrieta Hot Springs property, revised specific plan 103-C/W, November 29, revised July 12, 1975.

Trenches, average depth 5-7 feet, across Murrieta Hot Springs fault (Kennedy, 1977). "Fractures" in "Temecula Arkose" (Qus and Qps, Kennedy, 1977); no faulting in floodplain sediments (Qal, Kennedy, 1977).

44. Earth Research Associates, Inc., 1976, Seismicity evaluation of fault activity investigation, Area III, Murrieta Hot Springs, California, February 13, Job #195-75.

Trenches, depth 7-14 feet, across Murrieta Hot Springs fault (Kennedy, 1977). Gouge zone, in unnamed pre-Pauba formation (Qus, Kennedy, 1977); no faulting in alluvium (Qal, Kennedy, 1977).

45. Pioneer Consultants, 1976, Geologic investigation, Tract No. 7240, February 13, Job. #2316-001.

Trenches to a depth of 12 feet across strands of Glen Ivy North fault (Weber, 1977). Fault gouge and slickensides reported in older fan deposits (Qof, Weber, 1977). "Rift valley" (30 ft. deep, 100 ft. wide); water line in vicinty of Hunt Road requires annual repair; may be caused by continuous creep; parallel cracks in asphalt of Lawson Road.

69. Pioneer Consultants, 1977, Fault hazard investigation, Tract No. 8090, March 22, Job #2466-001.

Trenches up to 10 feet deep across Chino fault (Weber, 1977). Consultant reported that Chino fault cut alluvium (Qsc or Qof, Weber, 1977) in three trenches. The structures observed were dismissed as sedimentary features by Tony Brown (Riverside County geologist) upon examination of trenches in neighboring sites GR-72 and 105.

70. Pioneer Consultants, 1975, Soil and geologic investigation, proposed industrial park expansion in Rancho California. PM 14933 and PM 12549, March 21, Job. #1208-095.

Trenches, depth 12-14 feet, across strand of Willard fault (Kennedy, 1977). No faulting in alluvium (Qal, Kennedy, 1977).

72. Scullin, C. Michael, 1977, Engineering geological-seismic evaluation, Tract No. 7219, Lots 1-15, March 15, Project #77129.

Trenches up to 10 feet deep across Chino fault (Weber, 1977); no faulting in old alluvium (Qsc and Qof, Weber, 1977).

79. Rand, LeRoy E., 1977, Fault hazard investigation for tentative Parcel Map No. 9070, May 20.

Trench average depth 7 feet, within Willard fault zone (Kennedy, 1977). No faulting in alluvial fan debris (Qal, Kennedy, 1977).

84. Lohr, Lewis S., 1977, Fault hazard investigation for Parcel Map No. 9770, June 29, Job #31-77-6.

Three trenches, average depth 9 feet, across three strands of Wildomar fault zone (Kennedy, 1977). No faulting in Pauba formation (Quc and Qps, Kennedy, 1977) northernmost trench. "North branch" of Wildomar fault displaces Pauba formation within three feet of surface in middle trench. South branch of Wildomar fault displaces Pauba formation within one foot of surface in southernmost trench. Property is located directly southeast of closed topographic depression within Wildomar fault zone.

102. Stickel, J. F. & Assoc., 1977, Engineering geological seismicity study, school site, Grand Ave., Lakeland Village, November 14, Job #1877-001.

Trench, average depth 12 feet, across strand of Willard fault (Weber, 1977). No faulting in alluvium (Qiv and Qif, Weber, 1977).

105. Scullin, C. Michael, 1977, Engineering geological seismic evaluation, Tract No. 8830, Lots 1-20, December 17, Project #77217.

Trenches up to 9 feet deep across Chino fault (Weber, 1977); no faulting in colluvium and old alluvium (Qsc and Qof, Weber, 1977).

107. Stickel, J. F. & Assoc., 1977, Engineering geological seismicity study for tentative Tract No. 9837, Rice Road, Elsinore, December 1, Job #1918-001.

Trenches, average depth 13 feet, across strand of Glen Ivy North fault Weber, 1977). No faulting in alluvium (Qiv, Weber, 1977).

118. Lohr, Lewis S., 1978, Fault hazard investigation for Tract No. 10,828, April 11, Job #52-78-3.

Trench, average depth 10 feet, across strand of Willard fault (Weber, 1977); no faulting in flood plain and valley fill (Qiv, Weber, 1977).

122. Lohr, Lewis S., 1978, Fault hazard investigation for Parcel No. 2 of Parcel Map No. 8669, May 25, Job #54-78-3.

Trenches, average depth 9 feet, across possible strand of Glen Ivy North fault (Weber, 1977); no faulting in Pauba formation and flood plain and valley fill (Qp and Qov, Weber, 1977).

141. Leighton, F. Beach & Assoc., 1980, Geotechnical investigation (revised), Tract No. 3334, Lots 17 and 18, April 22, Job #678347-03.

Trenches, depths 7-11 feet, across trace of Wildomar fault (Kennedy, 1977). Possible fault in alluvium (Qal, Kennedy, 1977). Evidence presented for slightly different location than that shown by Kennedy.

143. Lohr, Lewis S., 1978, Fault hazard investigation for Tract #12406, August 22, Job #66-78-8.

Trench, average depth 9 feet, across strand of Willard fault (Weber, 1977). No faulting in alluvium (Qiv, Weber, 1977).

144. Lohr, Lewis S., 1978, Fault hazard investigation for property southwest corner of Guava St. and Washington Ave., Murrieta, September 6, Job #68-78-9.

Trench, average depth 10 feet, across possible strand of Willard fault (Envicom, 1976). No faulting in alluvium (Qal, Kennedy, 1977).

179. Scullin, C. Michael, 1979, Engineering geological seismic evaluation of tentative Tract No. 14684, Indian Trail Road, Temescal Valley, Riverside County, April 25, Job #79125.

Trenches up to 12 feet deep across trace of unnamed fault (Weber, 1977) parallel to and about one-half mile north of Glen Ivy North fault. Fault gouge reported in older alluvium (Qov, Weber, 1977); alluvial fan (Qfi) and stream channel deposits (Qsct) not faulted.

186. Lohr, Lewis S., 1979, Fault hazard investigation for property lying southeasterly of Walnut Street and Mission Trail, Elsinore Valley, July 8, Job #79-79-7.

Trench, average depth 9 feet, across branch of Wildomar fault (Kennedy, 1977). No faulting in Pauba formation (Qps, Kennedy, 1977).

190-S. Leighton, F. Beach & Assoc., 1978, Geologic seismic investigation, Tract No. 3587 and property southwest of intersection of Rancho California and Ynez Roads, March 7, Job #678043-01.

Trenches, 5-8 feet deep, across Wildomar fault (Kennedy, 1977). Alluvium faulted against Pauba formation (Qal and Qps, Kennedy, 1977).

194. Osborne, Kenneth G. & Assoc., 1980, Geotechnical investigation, Parcel 2, P.M. No. 6607, Pauba Road and Ynez Road, Job #2888-1,5,11, February 7.

Trenches, depth 5-13 feet, across Wildomar fault (Kennedy, 1977). Fault separates Pauba formation and alluvium (Qps and Qal, Kennedy, 1977). Pavement along Ynez Road (west of site) disturbed along alignment of Wildomar fault.

202. Pioneer Consultants, 1979, Geotechnical evaluation, Parcel Map No. 14933, January 19, Job #1208-156, 157, 158, 159.

Two trenches, 12-15 feet deep, across strands of Willard fault (Envicom, 1976). No faulting in alluvium (Qal, Kennedy, 1977).

APPENDIX B

TELEDYNE ISOTOPES

50 VAN BUREN AVENUE

WESTWOOD, NEW JERSEY 07675

(201) 664-7070

TELEX 134474 TDYISOT WTWD

5 January 1981

Mr. Donald L. Lamar
Lamar-Merifield
1318 Second Street,
Suite 27
Santa Monica, CA 90401

W. O. No. 3-9724-072

Dear Mr. Lamar:

We have listed below the radiocarbon ages we have determined on the samples you submitted for analysis.

ISOTOPES NUMBER	SAMPLE	$-\delta C^{14}$	AGE IN YEARS, B.P.
I-11,678A	No. 1, Humic Acids	417 ± 29	4330 ± 400
I-11,678B	No. 1 Carbon Residue	401 ± 19	4120 ± 260

The Libby half-life of 5568 years was used to calculate the ages. No correction was made for variation in the atmospheric ^{14}C.

The larger than normal uncertainty of measurement is due to the small amount of carbon in each sample.

If you have any questions concerning these results, please contact us. We shall be happy to help in any way possible.

We hope these results will prove helpful in your work, and we look forward to serving you again soon.

Sincerely yours,

J. Buckley

James Buckley
Radiocarbon Laboratory

JB:hp

enclosures