SPLAYS ASSOCIATED WITH THE MALIBU COAST FAULT ZONE AT WINTER MESA, MALIBU

Los Angeles County
California

by

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INTRODUCTION

The Malibu Coast Fault Zone is an east-west zone of transpressive faulting along the southern front of the western Santa Monica Mountains in the western Transverse Ranges geomorphic province (Figure 1). It is part of a longer zone of faults along the southern margin of the Transverse Ranges that includes the Santa Monica, Hollywood and Raymond faults to the east and the Anacapa-Dume, Santa Cruz Island and Santa Rosa Island faults offshore and to the west.

The Malibu Coast Fault Zone was evaluated in 1994 in Fault Evaluation Report FER-229 (Treiman, 1994). It was found that the fault zone had limited evidence of Holocene activity along its onshore portions, but some minor splays were sufficiently active and well defined in two areas to warrant zoning under the Alquist-Priolo Earthquake Fault Zoning Act (Hart and Bryant, 1997). Based on data presented in FER-229 an Earthquake Fault Zone was established in two small areas of the Malibu Beach 7.5-minute quadrangle (California Division of Mines and Geology, 1995).

This supplemental report to FER-229 (Treiman, 1994) has been prepared to assess new data pertaining to the age of faulting at Winter Mesa (Figure 2).

SUMMARY OF PREVIOUS WORK

Geologic studies for development purposes in the late 1980s (Converse Consultants, 1986 & 1988) uncovered evidence of several faults underlying a site on a coastal terrace about 1 mile west of Malibu Creek (Figures 2 & 3). The faults appeared to be bedding-plane faults within the hanging wall of presumed active near-shore splays of the Malibu Coast Fault Zone. Several onsite faults displaced the ~125,000 year-old (Stage 5e) marine abrasion platform, basal marine sands and overlying continental terrace deposits.

It was determined that at least one of the faults (F-1; Figure 3) also displaced what were judged to be Holocene colluvial soils (Converse Consultants, 1986 & 1988; Rzonca and others, 1991). Soil age was estimated based on relative soil development and a reconstructed geomorphic and alluvial history. Although F-1 was identified in several trenches and offsets late-Pleistocene deposits, it only appeared to offset inferred

Holocene deposits in one exposure -- T-101 (Figure 4)*. The description of the fault within presumed Holocene deposits in the original field log reads: "very fine hairline separation / close examination indicates prior offsets along mineral grains / soil on south side of fracture is red shade of brown than that to north / separation is dark brown" [*slashes are inserted at assumed breaks between clauses*]. Although the trench logs only showed a generalized upper colluvial unit, more detail was provided in a soil-stratigraphic section that was measured 5 feet north of the fault in T-102 (see Table 1).

Other trench exposures across the site limited the lateral extent of F-1 and did not show any other evidence of Holocene activity. Based on the published data, a relatively restricted Earthquake Fault Zone was established in 1995 to include the presumed active fault trace (F-1) and another trace (F-2) to the northeast that could not be excluded as Holocene (California Division of Mines and Geology, 1995 - see Figure 2 herein). A third unnamed fault was judged to not be active since it did not displace overlying sediments that were interpreted, based on soil profile development, to be 35-40 ka (Rzonca and others, 1991).

SUMMARY OF NEW DATA

Commencing in 1999, Earth Consultants International (ECI) undertook new studies to attempt to better constrain the age and extent of faulting at Winter Mesa, focusing in particular on fault F-1 (ECI, 2000). The consultants excavated a new trench (ECI-T-1) that obliquely crossed two key trenches from the earlier work (Figure 5). ECI-T-2 attempted to gain an additional exposure of F-1. A third trench (ECI-T-3) explored the eastward lateral extent of faults F-1 and F-2.

ECI-T-1

In trench ECI-T-1 the consultants found essentially the same units and relationships at F-1 as exposed by Converse Consultants in their trench T-102 that was approximately two feet west of the ECI exposure at the fault plane (Figure 6). Both exposures revealed a fault extending from within the Miocene bedrock upward through the late-Pleistocene marine sands and terrace deposits to a now-buried paleosurface developed on those deposits, but neither exposure showed clear faulting into the overlying colluvium. The abrasion platform and overlying faulted deposits showed approximately 6 inches or less of vertical separation. Both exposures (ECI-T-1 and T-102) showed a similar fissure along the fault that was filled with fine sand. ECI measured a soil-stratigraphic column in this trench 3 feet north of the fault (see Table 2).

Within the colluvial unit overlying the buried paleosurface ECI identified several horizons, with a notable sand (unit Qsb) at its base that they interpreted as a "blow sand" derived from liquefaction of a lower marine sand (Qtm2). ECI (2000) interpreted the fissure noted above as the source conduit for unit Qsb. Unit Qsb showed no clear evidence of faulting in the trench exposure, although ECI (2003; Figure 7 herein) did

* The log of the fault exposure as published in Rzonca and others (1991) was mis-identified as T-102 when, in fact, it is a somewhat stylized portrayal of the T-101 fault exposure. Subsequent reports by ECI perpetuated this error in identification. The correct identification and location of this exposure will be used in this review without repeated mention of the correction.

observe fine fractures fanning out from the mouth of the fissure within the basal portion of Qsb. No displacement was observed on these uppermost fractures. They interpreted the fractures to have resulted from liquefaction-related settlement. The inferred "blow sand" was important to ECIs evaluation of fault activity and they dated the deposit using Optically Stimulated Luminescence (OSL)(ECI, 2002a & 2002c), yielding an age of 14.3 ± 2.4 ka.

The "unnamed" fault of Converse Consultants (1986 & 1988) was exposed at the southern end of ECI-T-1 with similar relationships to those observed previously. ECI referred to this fault as F-3.

ECI-T-2

Trench ECI-T-2 exposed F-1 within the Miocene bedrock, but the fault was abruptly truncated by a colluvial-filled swale. ECI reported no signs of faulting within the colluvial fill.

ECI-T-3

Trench ECI-T-3 crossed the eastward projections of faults F-1 and F-2. Although the trench did not reach the abrasion platform no evidence of faulting was found within the late-Pleistocene marine sand or continental deposits.

Although ECI did not re-expose the original faulted exposure in Converse trench T-101 (Figure 4) they expressed their opinion that the features observed by Converse Consultants within the colluvium were not faults but instead were small strain features related to liquefaction-related subsidence (ECI, 2001b & 2003). ECI argued that F-1 was overlain by unfaulted unit Qsb and therefore had not moved in the past 11,000 years. Since it is not a Holocene fault according to their evidence they requested that the Alquist-Priolo Earthquake Fault Zone be removed (ECI, 2003). Furthermore, since there was no evidence for Holocene displacement along F-2, this fault should also not be considered active.

Dating Of Sediments

To get better age control on the latest fault displacement Earth Consultants International contracted with Dr. Lewis Owen (then at U.C. Riverside) to date buried sediments using Optically Stimulated Luminescence (OSL). The science of OSL dating is discussed in many sources (e.g. Murray and Olley, 2002; Wallinga, 2002). Owen performed the field sampling, collecting samples from four horizons in trench ECI-T-1: Qtm1, Qtm2, Qsb and Qtcg (ECI, 2001b). At least 12 age determinations were run on each sample utilizing the single-aliquot regenerative dose (SARD) method. Recuperation and mis-match criteria were used to eliminate samples that might not yield reliable ages and new tests were run to replace those rejected. Initial age results (ECI, 2002a) were consistent with the stratigraphic order and geologic interpretation of the units. Unit Qsb was found to be 12.8 ± 3.2 ka. Because the margin of error on these results overlapped the Holocene boundary ECI had Owen run an additional 80 tests on the remaining sample as well as running another sand sample to confirm the environmental dose rate. A revised age of 14.3 ± 2.4 ka was derived from a plot of the 26 tests that passed rejection

criteria (ECI, 2002c). Independent discussion of the OSL data with Shannon Mahan (USGS Luminescence Dating Laboratory, Denver, CO - personal communication 11/2/06) confirmed that the low end of the age range is probably an "absolute minimum age of the deposit".

FIELD OBSERVATIONS

Converse trench T-101

This writer accompanied California Division of Mines and Geology geologist Richard Saul to observe the fault in the field on November 21, 1986. Richard Saul's field notes indicate that a discontinuous and narrow zone of staining was visible in the soil to an elevation at least one foot above the late Pleistocene soil, and perhaps as high as 1 m from the ground surface (Figure 8). This discrepancy in his notes is not resolvable, but the lower elevation is in accord with the Converse log.

ECI Trench T-1

This writer visited the trench on September 1, 1999 and noted unit Qsb overlying the fault. I was unable to see any fault within Qsb and observed that the unit appeared to have been deposited on an irregular and eroded surface. Qsb was noted as a massive vesicular silty sand with some matrix-supported pebbles, consistent with an interpretation of a debris flow deposit. A staff geologist at the trench commented that the unit appeared to have more fines than the marine sand below[*]. Offset of the abrasion platform was not conclusive in this exposure. (Treiman field notes, 9/1/99)

DISCUSSION

Fault F-1

I disagree with several of the ECI interpretations, principally 1) that unit Qsb is a liquefaction-derived sand-blow deposit, 2) that it was not present in the Converse Consultants trenches, and 3) that the faulting predates deposition of this unit.

1) The liquefaction hypothesis is important to ECIs argument and is part of what supported ECIs interpretation of an older age of faulting because it required that the marine sand be unconsolidated and saturated at the time of disturbance. Liquefaction-induced settlement was also used to explain fine fractures in unit Qsb at the mouth of the fissure (ECI, 2001b, 2002d, 2003). However, a liquefaction explanation for unit Qsb is not necessary and is in some aspects problematic. Differential consolidation above an irregular surface rather than liquefaction might also be an explanation for these fine fractures. Some factors that argue against the inferred liquefaction of unit Qtm2 and ejection as a sand blow deposit (Qsb) include the presumed liquefaction vent fissure extending both above and below the source bed as seen in all three trench logs, possible

[*] ECI (2001b) stated that the Qsb sands were "indistinguishable with Qtm2 sands *after crushing*" [emphasis mine].

textural difference between the supposed source bed and the deposit, and the massive nature of unit Qsb. Concern about the downward extent of the fissure was shared by Geomatrix (2001) in their review for the City of Malibu.

With respect to the fabric of the fissure fill, ECI's explanation is confusing, variously attributing the horizontal layering to "vertical depositional settling of turbid sands into the open fissure", "horizontal movement of liquefied sands along the fissures" and "horizontally laminated sands injected horizontally as sills and settling vertically downward" (ECI, 2001a). In a liquefaction event the vent fracture would fill from the bottom with material rising up until it vents at the surface, and it seems unlikely that the fissure fill would have been deposited in a series of horizontally laminated deposits. The vent fill might be expected to have laminations parallel to the vent wall, and there are commonly horizontal laminae in the surface deposit (Obermeier, 1996). In contrast, unit Qsb was massive with no detectable laminations; this is consistent with a debris-flow origin. The laminations in the fissure fill are more likely evidence of surface material episodically blowing or washing into a pre-existing fissure.

Calling on liquefaction to explain the vertical separation of some of the late-Quaternary deposits across the fissure also does not explain the corresponding offset of the abrasion platform observed in the Converse trenches T-101 and T-102. Deposition of unit Qsb as a debris-flow deposit is considered to be more likely.

2) The claim that unit Qsb was not present in the earlier trenches is an unfounded inference from the absence of this unit in the earlier trench logs. Although the level of detail of the trench logs was different, the soil-stratigraphic columns prepared by Converse Consultants (1986) and ECI (2000) are remarkably similar (see Tables 1 and 2). These columns were only a few feet away from each other (east wall of T-102 and west wall of ECI-T-1 - see Figure 9) and it is likely that Qsb was present in both. The consultants differed in some terminology and interpretation, such as which zone they identified as an eluvial horizon. Unit Qsb (brownish-gray sand) lies where Converse showed their "E" horizon (brown loam). ECI logged an "E" horizon (yellow-brown sand to loamy sand) above Qsb, where Converse logged a brown fine sandy loam. It is our contention that the eluvial horizon of Converse Consultants is probably the same as unit Qsb; they are in the same stratigraphic position with an abrupt smooth lower contact and have similar color and texture, even to the presence of scattered pebbles. Unit Qsb probably was unrecognized within the more generalized colluvial unit logged in T-101.

3) The vertical extent of faulting is perhaps the most critical factor to assess at this site with respect to recency of faulting. We have data on the vertical extent of faulting from three closely spaced trenches -- T-102, T-1 and T-101 (see Figure 9). In all three trenches the fault extends out of bedding planes in the Miocene Monterey Formation, displaces the Stage 5e abrasion platform, the overlying marine sand and subsequent continental deposits. A colluvial unit (including unit Qsb) overlies an unconformity eroded onto the continental deposits (Terrace Deposit or Qtc), with soil development (horizon 2Btb) indicating a hiatus in deposition prior to accumulation of the colluvial deposits. A fine sand (unit Qsb) lies at the base of the colluvium, at least in T-102 and T-1. In these two trenches the fault appears to stop at the unconformity with no faulting evident in the overlying colluvium. The implication from these two exposures is that

faulting is older than unit Qsb. However, in T-101, about five to ten feet to the east, the fault was observed to extend nearly 1.5 feet above the unconformity. Although at first these observations seem contradictory, a new comparison and analysis of the data helps explain the relationships.

To allow a new comparison, three key horizons were identified in each log and soil stratigraphic column: the Stage 5e abrasion platform cut on the Monterey Formation, the upper well-sorted marine sand (Qtm2 or unit 5), and the unconformity below the colluvial unit (including Qsb). Although the abrasion platform and the higher unconformity might be expected to have considerable irregularity, the marine sand can more easily be modeled to be relatively planar over the short distance between the trenches and, using the base of Qtm2 as a datum, the prior and recent logs can be aligned and used to construct a cross section along the fault (Figure 10). Inspection shows this construction to be fairly reasonable. When the observed vertical extent of faulting is plotted on this section it can be seen that the absolute height of faulting is consistent across the three exposures. About 10 feet further west (T-103), the direction in which the fault appears to be dying out, the fault was not observed to extend above the abrasion platform. The implication is that the last event (post unconformity) did not extend above the unconformity for much of its length but did extend higher in the stratigraphic column at T-101. It may be that the fine fractures at the mouth of the fissure in T-1 (if not due to consolidation) are also an indication of this event. Unit Qsb was not present approximately 30 feet to the east (in ECI-T-2) where it may have been removed by deeper erosion prior to accumulation of the Holocene colluvium in the then-developing east-draining swale. ECI, perhaps erroneously, has assumed that the colluvium in ECI-T-2 represents a more complete section than was exposed in T-101, but it may in fact be lacking the basal 14.3 ± 2.4 ka deposit that was faulted to the west.

This new interpretation allows the possibility that the last fault rupture event, albeit extremely minor, occurred since deposition of unit Qsb, and could even be Holocene. However, no evidence was present to document Holocene displacement and the earlier published age of less than 6000 years before present (Rzonca and others, 1991) is no longer supported.

Fault F-2

Fault F-2 has not shown any evidence of Holocene displacement in the studies by Converse Consultants (1986 & 1988) or in those by ECI (2000). It was originally included in an Earthquake Fault Zone because of its proximity to F-1 and the fact that it could not be demonstrated to not be Holocene and thus was presumed active by Converse Consultants (1986 & 1988).

Age of Qsb

This massive unit was initially logged as part of the young colluvial sequence (Converse Consultants, 1986 & 1988). Based on a qualitative discussion and reconstruction of the geomorphic history of the site it was estimated to be 4,000 to 6,000 years old (Rzonca and others, 1991). The more recent quantitative dating of Qsb gives it an age of 14.3 ± 2.4 ka (ECI, 2002a & 2002c). OSL dating, when performed with care and allowance for error, can be a reliable dating method within this age range (Murray and Olley, 2002; Walinga, 2002).

CONCLUSIONS

Fault F-1

Fault F-1 represents a short (~500') zone of closely spaced, perhaps en echelon bedding plane faults that have variably displaced overlying latest Pleistocene terrace deposits (Treiman, 1994) and perhaps a younger colluvial unit (Qsb). Unit Qsb can be inferred to extend east of the ECI-T-1 exposure. Although it was not recognized in the log of T-101 it probably lies, undifferentiated, within the colluvial unit logged by Converse, just as it apparently was in T-102. Fault F-1 may have had a displacement event some time after deposition of unit Qsb but the rupture was probably small and did not extend uniformly upward or laterally. In no observation did faulting or fracturing extend to the top of unit Qsb. OSL dating indicates that Qsb is 14.3 ± 2.4 ka. In spite of the near-Holocene age of unit Qsb, and although it is allowable, the faulting of this unit is not proof of Holocene fault activity sufficient to warrant zoning of a minor fault under the Alquist-Priolo Earthquake Fault Zoning Act. There is no evidence for Holocene surface faulting.

Fault F-2

There is no evidence to suggest Holocene surface displacement on F-2.

RECOMMENDATIONS

In view of the fact that this small Earthquake Fault Zone was established entirely on the merit of a single trench exposure (T-101) it is appropriate to reconsider this zoning decision based on the new information generated relative to that exposure. The prior evidence of Holocene fault displacement has been negated and these faults cannot now be considered "sufficiently active". Therefore, the small Earthquake Fault Zone on Winter Mesa, as indicated on Figure 11, should be deleted from the Official EFZ map for the Malibu Beach quadrangle.

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Table 1 - soil stratigraphic column from Rzonca and others (1991)

(geologic units in blue)

Table 1. *Soil stratigraphic measurement and description of Trench 102, Station 117, east wall (see Figure 6 for location).*

Horizon	Depth (ft)	Description
Ap1	0.0 - 0.5	Brown (10YR 5/3) to dark yellowish brown (10YR 3/4) when moist, sandy loam; strong medium angular blocky structure; hard, firm, non-sticky and non-plastic; common, medium random roots; common pores; abrupt smooth boundary.
Ap2	0.5 - 1.0	Brown (10YR 5/3) to dark yellowish brown (10YR 3/4) when moist, heavy sandy loam; weak, fine subangular blocky structure; hard, firm, slightly sticky and non-plastic; few fine vertical roots; diffuse smooth boundary.
Ap3	1.0 - 1.7	Brown (10YR 5/3) to dark yellowish brown (10YR 3/4) when moist, heavy fine sandy loam; weak medium subangular blocky structure; hard to very hard, firm, slightly sticky and non-plastic; few very fine vertical roots; base of artificial fill and plowpan; abrupt wavy boundary.
colluvium (unit 1) A1	1.7 - 2.4	Very dark greyish brown (10YR 3/2) to dark yellowish brown (10YR 3/4) when moist, sandy loam; moderate, fine subangular structure; slightly hard, firm, slightly sticky and non-plastic; few very fine vertical roots; many medium to fine pores; few disseminated charcoal fragments near top of horizon; surface of pre-fill profile; gradual smooth to gradual wavy boundary.
A2	2.4 - 4.1	Brown (10YR 5/3) to very dark greyish brown (10YR 3/2) when moist, fine sandy loam; weak fine subangular blocky structure; slightly hard, friable, non-sticky and non-plastic; common fine pores; few, very fine angular clasts to 0.5 in. diameter; gradual wavy boundary.
E	4.1 - 5.0	Brown (10YR 5/3) to light brownish grey (10YR 6/2) reduced and dark brown (10YR 3/3) when moist, loam; soft to slightly hard; very friable; non-sticky and very slightly plastic; common fine pores, mottled and leached (perched ground water table); eluvial horizon; few subrounded to angular clasts to 0.5 in. diameter near base; unconformity; base of colluvial-filled swale; geologic unit 1; abrupt smooth boundary.
2Bb unit 2	5.0 - 6.2	Buried Paleosol: Dark brown (7.5YR 3/2) moist, sandy clay; weak medium subangular blocky structure; very hard, very firm, sticky and slightly plastic; many thin, dark brown (7.5YR 3/2) clay films on ped faces and lining old root channels; base of argillic horizon; strongly developed buried paleosol; gradual wavy boundary.
2Cb unit 4	6.2 - 8.2	Yellowish brown (10YR 5/6) to dark brown (10YR 3/3) when moist, sandy clay; weak, fine subangular blocky structure; very hard, very firm, sticky and plastic; increasing sand near base; locally gradual transition to underlying clean (reworked), regressive marine sands; base of geologic unit 2; unconformity; abrupt wavy to abrupt smooth boundary.
3Cb unit 5 (Qtm2)	8.2 - 9.0	Strong brown (7.5YR 5/6) dry and moist, medium sand; massive structure; soft, very friable, non-sticky and non-plastic; regressive marine sand; base of geologic unit 3; unconformity; abrupt smooth boundary.
4C unit 6 (Qtm1)	9.0 - 10.2	Yellowish red (5YR 4/6) to brown to dark brown (7.5YR 4/2) when moist, sandy clay; massive structure; hard, firm, slightly sticky and slightly plastic; common to many angular clasts from Tertiary Monterey occur near base; few subrounded clasts to 1 in. diameter (stoneline) at base; reworked continental deposits; base of marine platform; base of geologic unit 4; abrupt irregular boundary.
Tm	10.2+	Geologic Unit: Tm. Bedrock: Tertiary Monterey Formation.

Note: Soil Profile described by Roy J. Shlemon, 13 November 1986.

Estimated ages: (as deduced from relative profile development and association with numerically-dated soils in comparable soil-climatic regimes [Harden and Taylor, 1983; Rockwell et al., 1985; and Shlemon, 1985]):

Geologic Unit 1: ca. 5,000-6,000 years at this locality; bears A/E horizon only; deposition in headward part of colluvial-filled swale.

Geologic Unit 2: ca. 35,000-40,000 years (isotope stage 3); buried paleosol here strongly developed and laterally traceable to relict paleosol elsewhere in site trenches; bears stage II-III carbonates (Gile et al., 1966).

Geologic Unit 3: ca. 100,000 years; stratigraphically is marine sand, possibly associated with marine oxygen isotope substage 5c?

Geologic Unit 4: ca. 120,000-125,000 years old; shoreline or near-shore cliff deposits overlying truncated marine platform cut on Tertiary Monterey Formation; cut ca. 125,000 years bp.

Table 2 - soil stratigraphic column from ECI (2000) at station 0+72 in ECI T-1

(geologic units noted in blue)

PROJECT NO.: 998117-002

SOIL DESCRIPTIONS EXPOSED IN MALIBU FAULT TRENCH T-1 @ 0+72'

SOILS DEVELOPED IN DEBRIS FLOW/LIQUEFACTION AND EOLIAN:

41-67cm

A_1 Soil Horizon (A_1): LOAMY SAND, dark grayish brown (10 YR 4/2) when dry, dark grayish brown (10 YR 3/2) when moist, weak to moderate medium to fine subangular blocky, slightly hard when dry, nonsticky and nonplastic when wet, no clay films, gradual to diffuse and smooth boundary with underlying horizon.

67-105cm

A_2 Soil Horizon (A_2): LOAMY SAND, dark grayish brown (10 YR 4.5/2) when dry, very dark grayish brown (10 YR 2.5/2) when moist, moderate fine subangular blocky to granular, slightly hard to hard when dry, nonsticky and nonplastic when wet, no clay films, gradual to diffuse and smooth boundary with underlying horizon.

105-132cm

E Soil Horizon (E): SAND to LOAMY SAND, yellowish brown (10 YR 5/2) when dry, very dark grayish brown (10 YR 3/2) when moist, strong medium subangular blocky, slightly hard when dry, nonsticky and nonplastic when wet, clear and smooth to wavy boundary with underlying horizon.

132-172cm

Qsb

C Soil Horizon (C): SAND, light brownish gray (10 YR 6/2) when dry, very dark grayish brown (10 YR 3/2) when moist, weak to moderate medium subangular blocky, weakly coherent when dry, nonsticky and nonplastic when wet, abrupt and smooth to wavy boundary with underlying horizon.

SOILS DEVELOPED IN TERRIGENEOUS SEDIMENTS:

182-201cm

2Btb Soil Horizon (2Btb): SANDY CLAY LOAM, dark grayish brown (10 YR 4/2.5) when dry, dark brown (10 YR 3/3.5) when moist, strong medium angular blocky to prismatic, very hard when dry, slightly sticky and plastic when wet, many thin to moderately thick clay films on bridges holding mineral grains together, many thin clay films lining tubular or interstitial pores, and few to common thin clay films on ped faces, abrupt and smooth boundary with underlying horizon.

201-229cm

$2Btb_2$ Soil Horizon ($2Btb_2$): SANDY CLAY LOAM to SANDY CLAY, strong medium angular blocky to prismatic, very hard when dry, sticky and plastic when wet, many moderately thick clay films on bridges holding mineral grains together, many moderately thick clay films lining tubular or interstitial pores, and many thin and common moderately thick clay films on ped faces, abrupt and smooth to wavy boundary with underlying horizon.

229-256cm

2Btkb Soil Horizon (2Btkb): SANDY CLAY LOAM to SANDY CLAY, strong coarse subangular blocky and strong medium prismatic, hard to very hard when dry, sticky and plastic when wet, many thin to moderately thick clay films on bridges lining mineral grains, common to many thin clay films lining tubular or interstitial pores, and many thin clay films on ped faces, clear and smooth to wavy boundary with underlying horizon.

256-280cm

Qtc

2BC Soil Horizon (2BC): SANDY CLAY LOAM, strong coarse subangular blocky to moderate medium columnar, hard when dry, slightly sticky to sticky and plastic when wet, common thin clay films on bridges holding mineral grains together, few to common moderately thick clay films lining tubular or interstitial pores, and common thin to moderately thick clay films on ped faces, abrupt and smooth boundary with underlying horizon.

SOILS DEVELOPED IN MARINE SANDS:

280-317cm

Qtm2

$3BC_1$ Soil Horizon ($3BC_1$): LOAMY SAND, yellowish brown (10 YR 5/4) when dry, dark yellowish brown (10 YR 4/4) when moist, moderate fine to medium subangular blocky, slightly hard when dry, nonsticky and nonplastic when wet, clay films stained on grains, few thin clay films on bridges lining mineral grains, clear to gradual and smooth boundary with underlying horizon.

317-339cm

Qtm2

$3BC_2$ Soil Horizon ($3BC_2$): SAND, light yellowish brown (10 YR 6/4) when dry, yellowish brown (10 YR 5/4) when moist, single grain to few medium subangular blocky, weakly coherent when dry, nonsticky and nonplastic when wet, clay film stains on grains, abrupt and smooth boundary with underlying horizon.

339-392cm

Qtm1

4Cox Soil Horizon (4Cox): LOAMY SAND, dark yellowish brown (10 YR 4/4) when dry, dark yellowish brown (10 YR 4/5) when moist, slightly hard to weakly coherent when dry, nonsticky to slightly sticky and nonplastic when wet, common to many, thin to moderately thick clay films on bridges lining mineral grains, common moderately thick clay films on ped faces, abrupt and wavy to irregular boundary with underlying horizon.

392-405cm

Qtmcg

5Cox Soil Horizon (5Cox): SANDY LOAM, dark brown (7.5 YR 4/3) when dry, dark brown (7.5 YR 3/3) when moist, strong medium subangular blocky, slightly hard when dry, nonsticky to slightly sticky and nonplastic when wet, common thin clay films on bridges lining mineral grains, and clay film stains on grains, abrupt and irregular boundary with underlying horizon.

TERTIARY MONTEREY FORMATION

Tm **405+cm** **Tm- Monterey Shale Bedrock** (R)

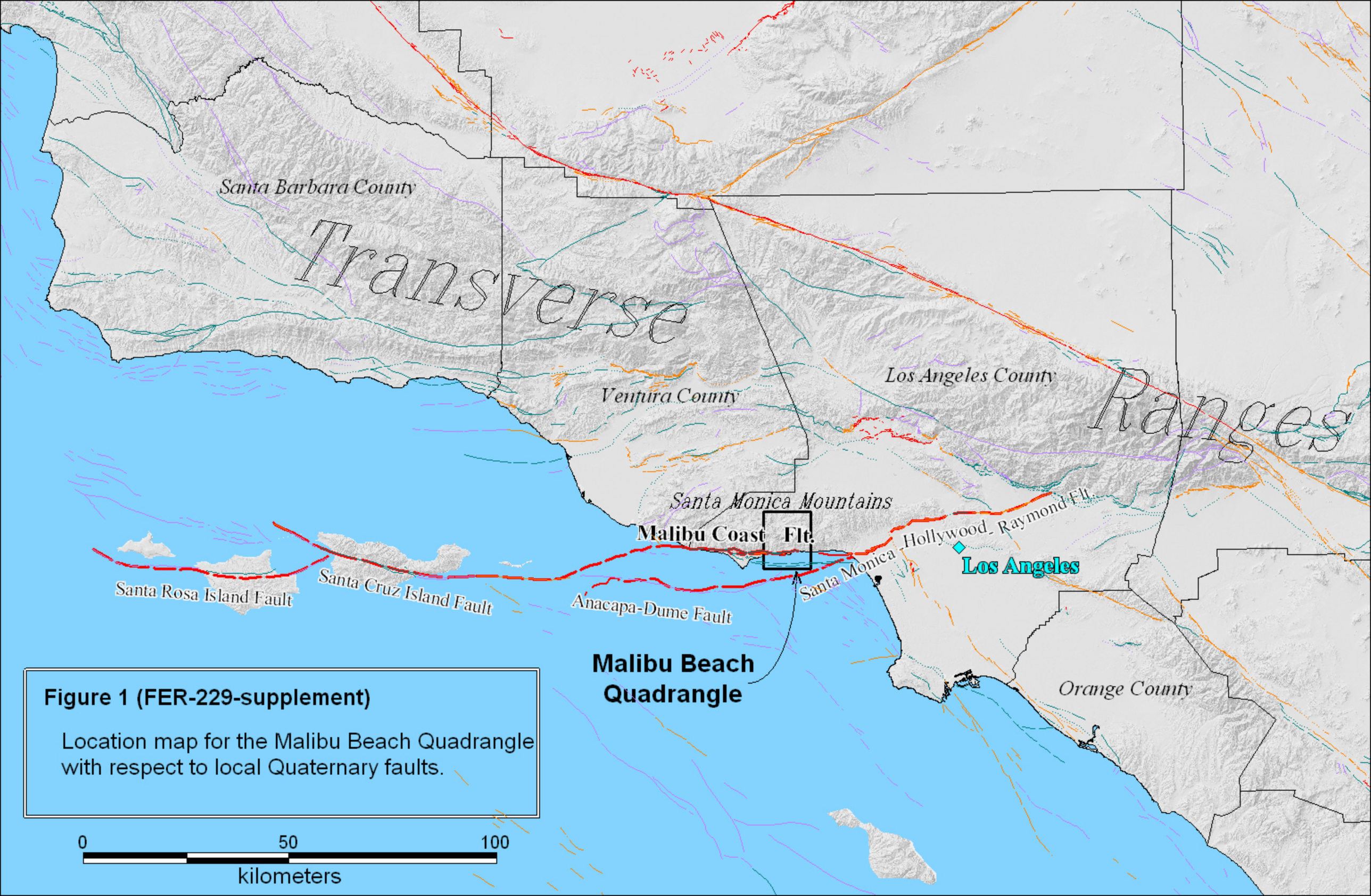


Figure 1 (FER-229-supplement)

Location map for the Malibu Beach Quadrangle with respect to local Quaternary faults.

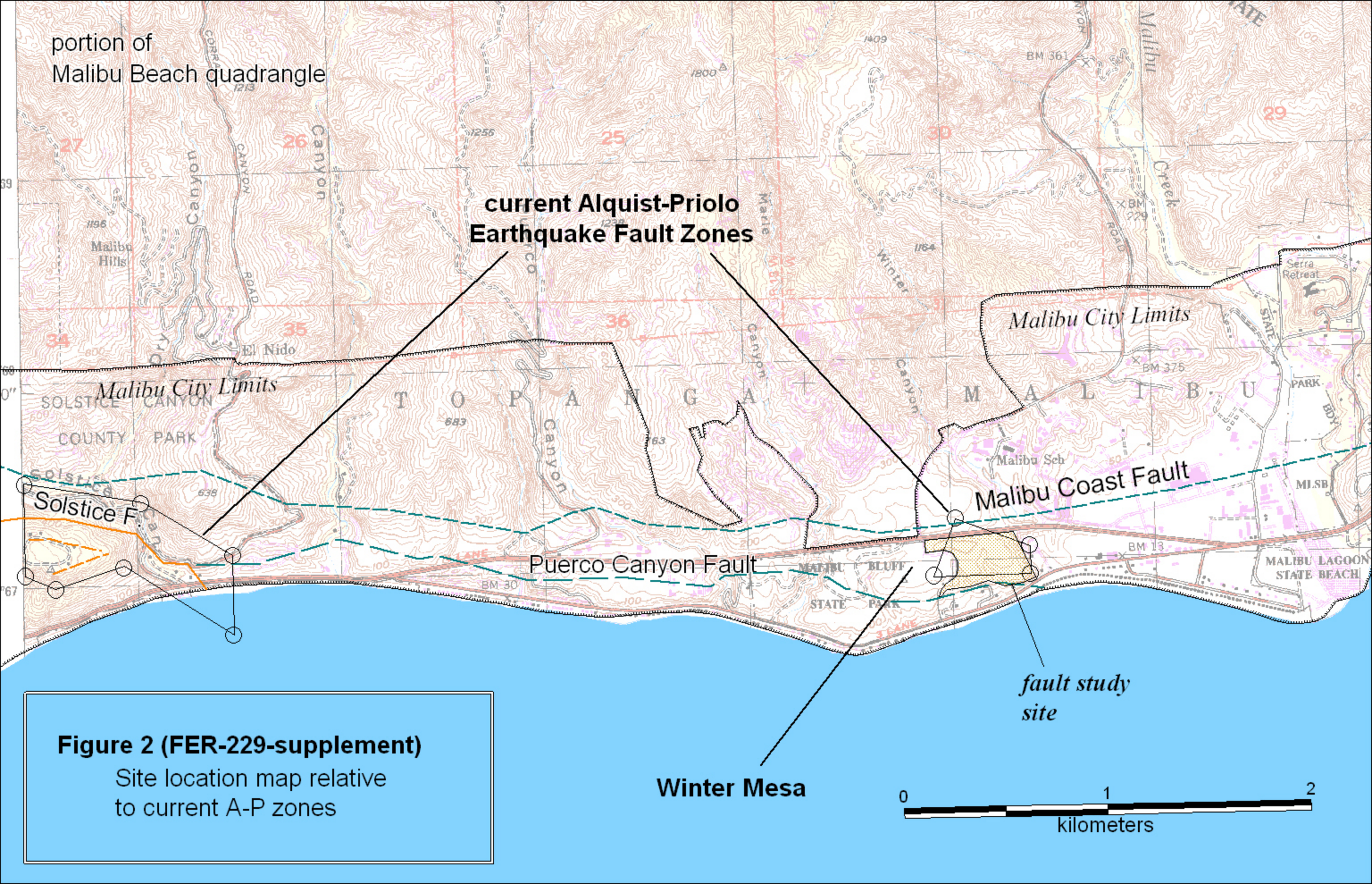


Figure 2 (FER-229-supplement)
Site location map relative
to current A-P zones

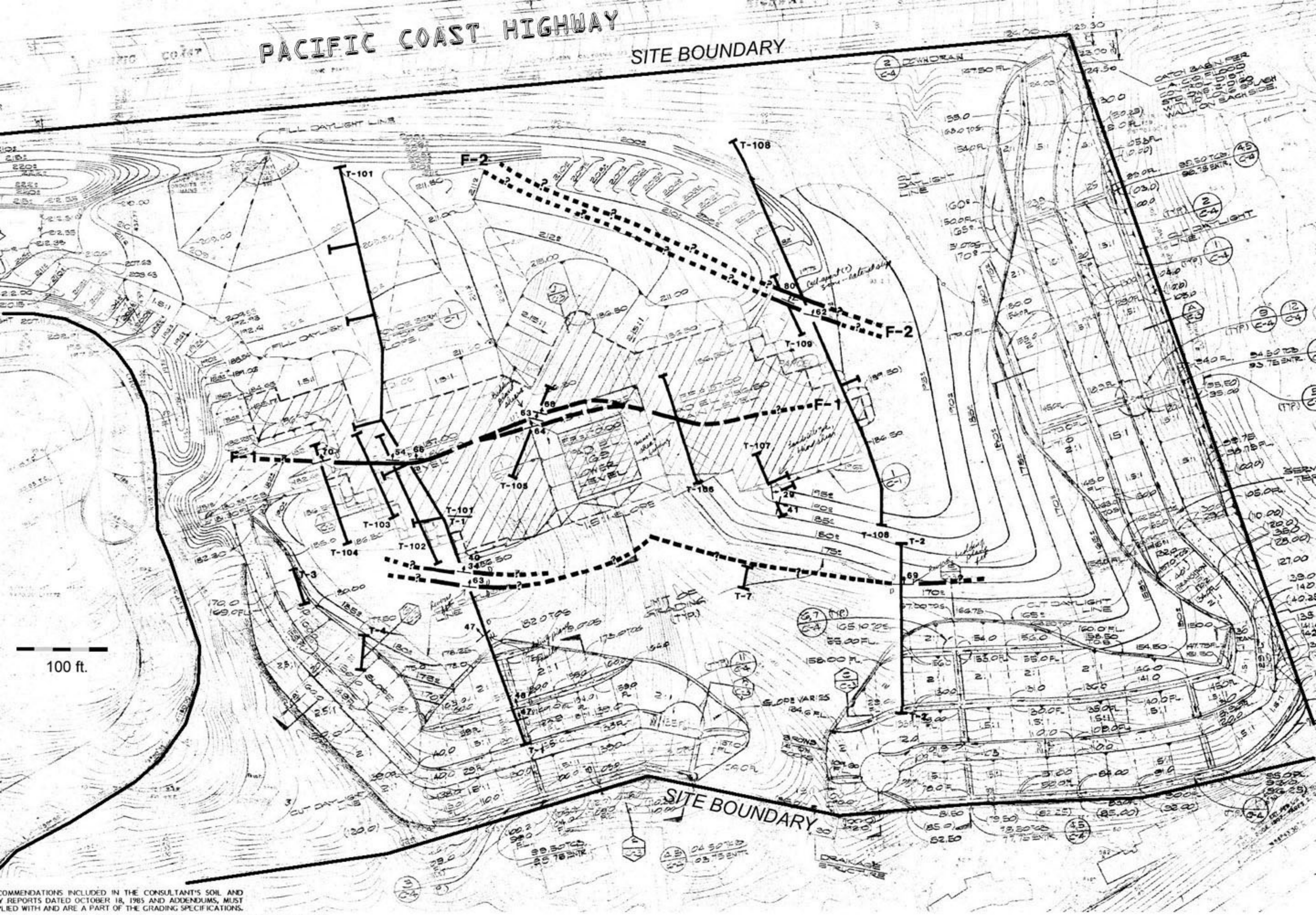
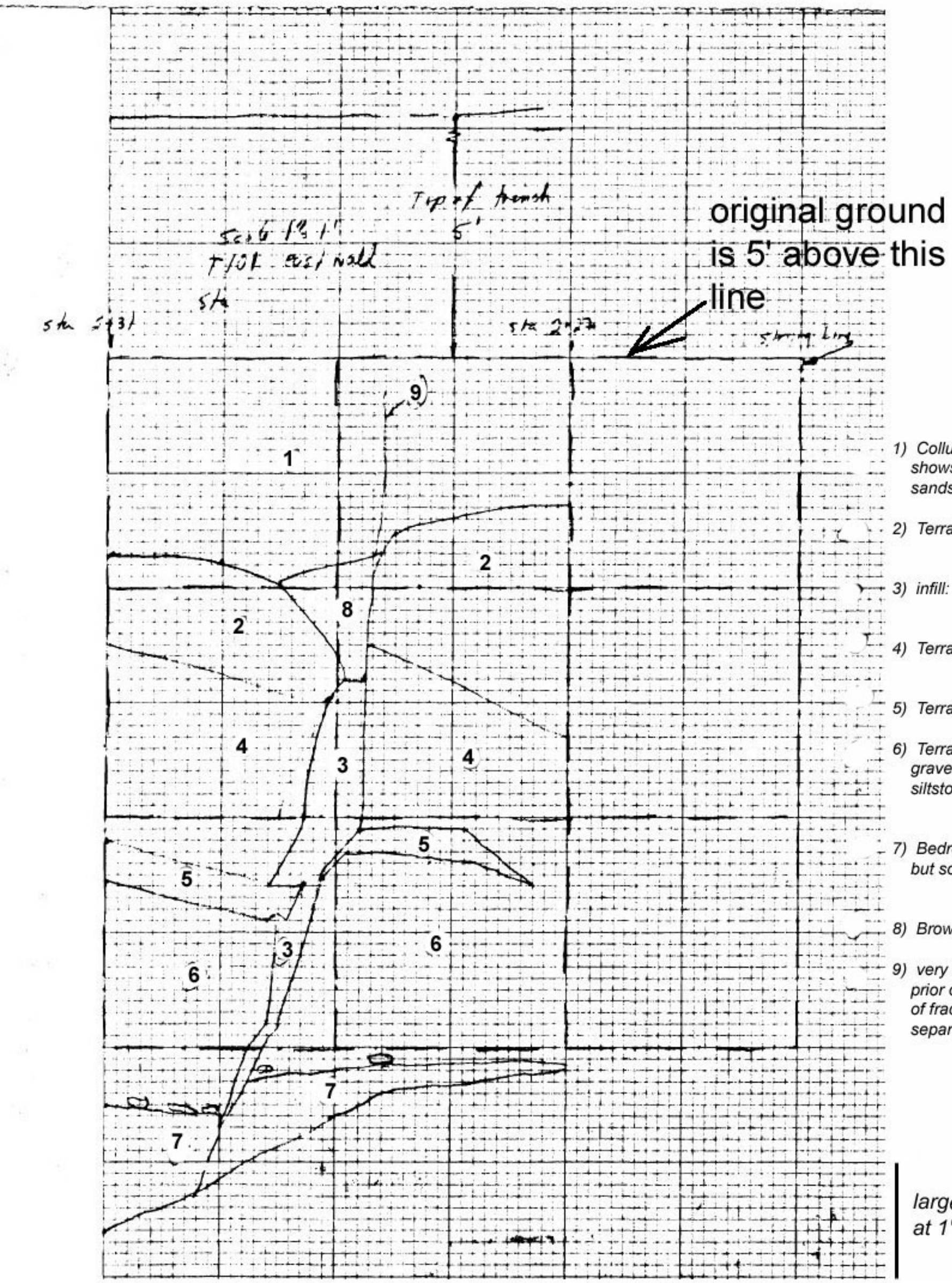


Figure 3 (FER-229 - supplement)

Map depicting trench and fault locations as established during original study (Converse, 1986). Conceptual grading was not done. See Figure 2 for site location



1) *Colluvium: Brown fine to med. silty sand with clay shows small voids with scattered subrounded gravel size sandstone fragments*

2) *Terrace Deposit: Brown fine to medium sandy clay*

3) *infill: Brown fine to medium clayey sand*

4) *Terrace Deposit: olive mottled orange clayey sand*

5) *Terrace Deposit: yellow brown fine to medium silty sand*

6) *Terrace Deposit: olive mottled orange clayey sand with gravel to cobble size subrounded igneouq and siliceous siltstone fragments at basal lag gravel*

7) *Bedrock: olive mottled orange siltstone well bedded but soft and punky local harder silicious interbeds*

8) *Brown fine to medium silty sand with minor clay*

9) *very fine hairline separation close examination indicates prior offsets along mineral grains soil on south side of fracture is red shade of brown than that to north* [sic] *separation is dark brown*

larger grid marks are at 1' intervals

Figure 4 (FER-229 - supplement)

Detailed field log of fault F-1 on east side of T-101 (Converse, 1986)

unit 2 corresponds to 2Bt of ECI (2000)
unit 5 corresponds to Qtm2 (marine sand) of ECI (2000)
unit 6 corresponds to Qtm1 (marine sand) of ECI (2000)
- see Figure 6 for complete ECI stratigraphy

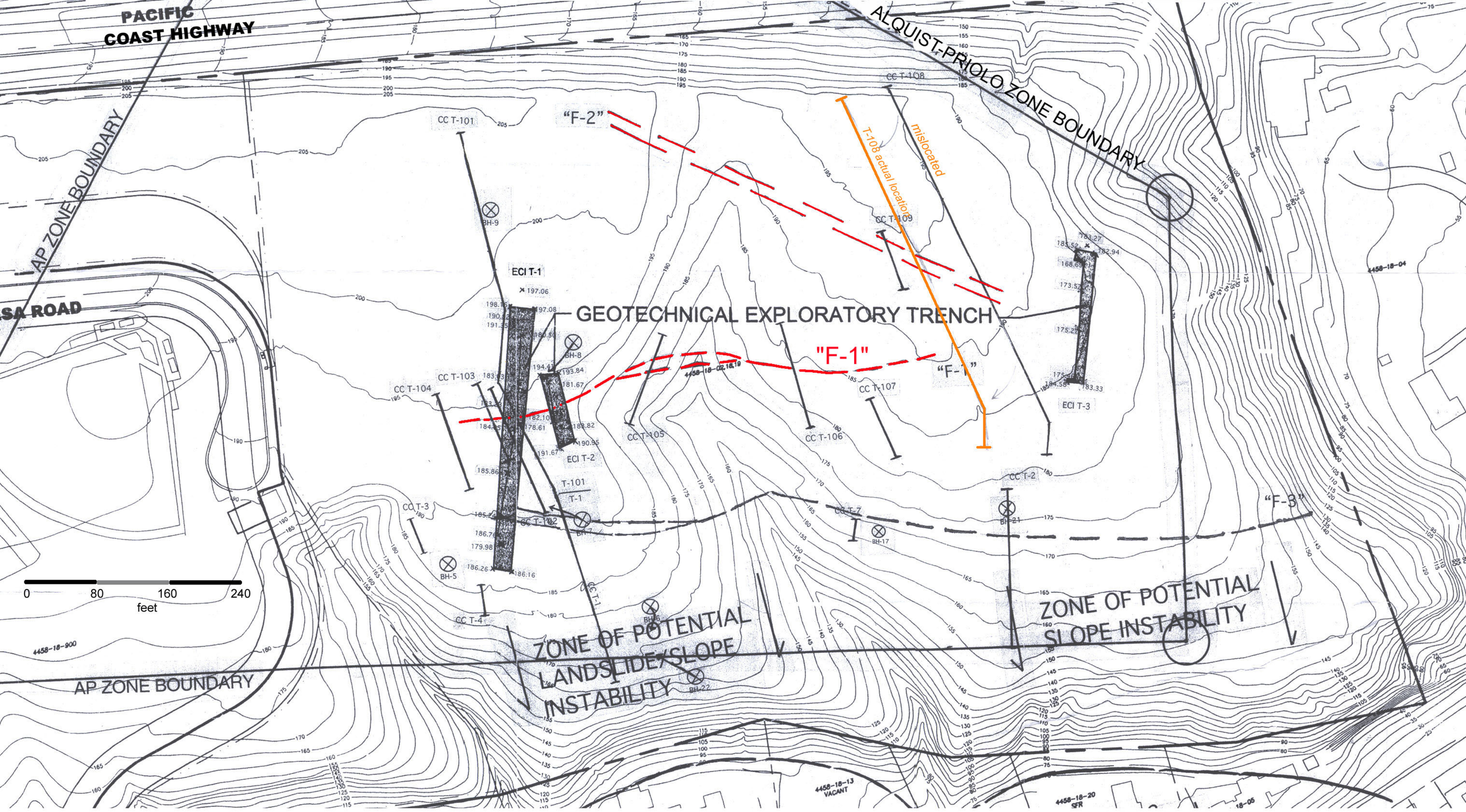
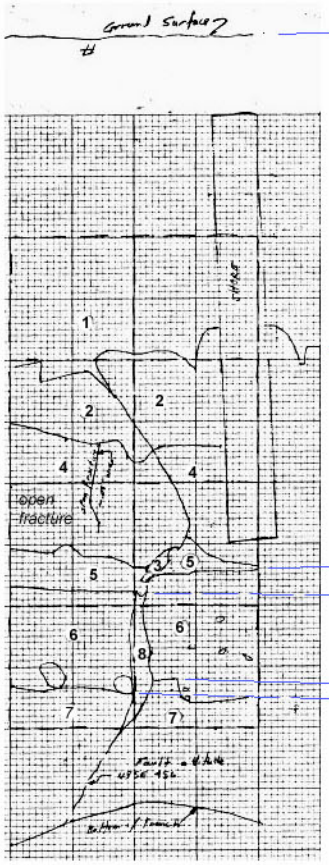


Figure 5 (FER-229 - supplement)

Map showing ECI trench locations relative to prior Converse trenches and faults (ECI, 2000).
See Figure 9 for detail of trench intersection (T-101, T-102 & ECI T-1).

Detail of
Trench T-102
east wall



original ground

base of colluvium

base of Qtm2 (south)

base of Qtm2 (north)

abrasion platform (south)

abrasion platform (north)

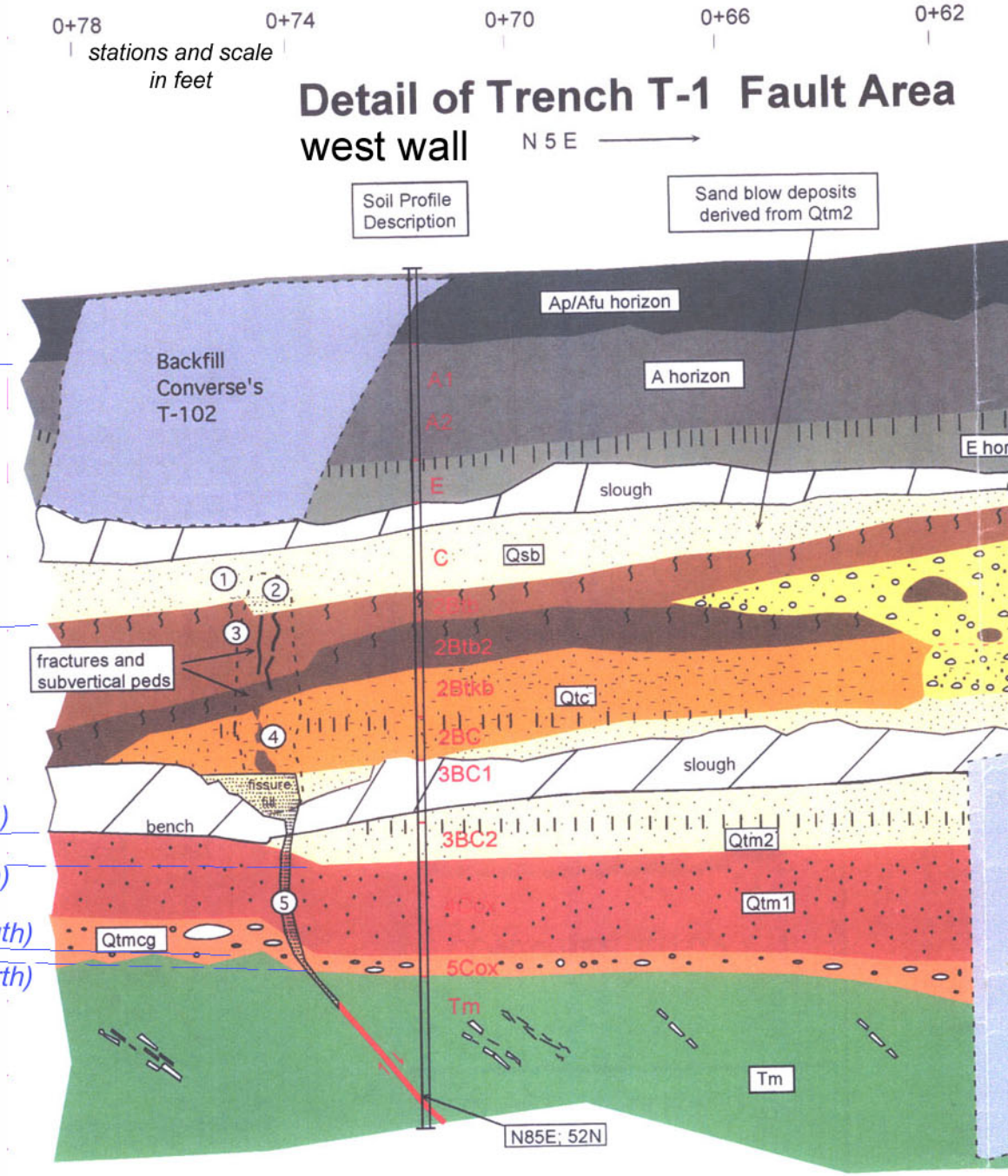
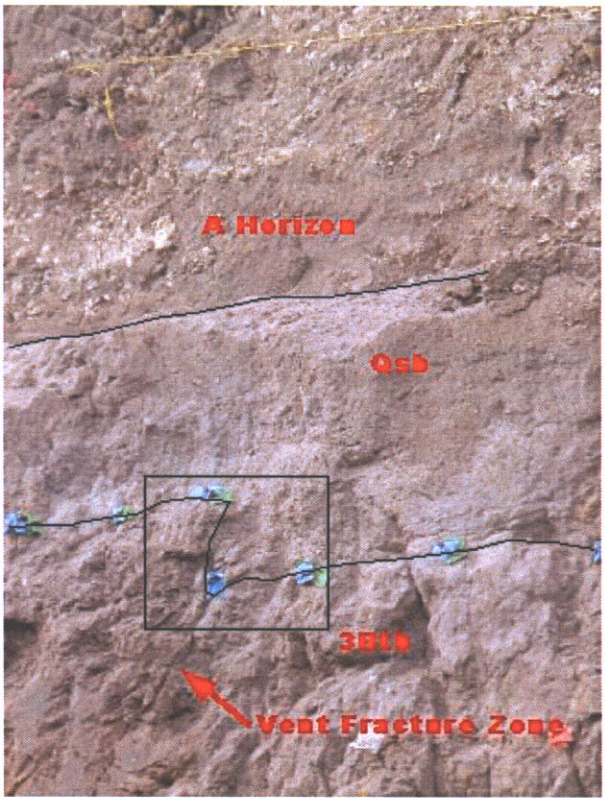


Figure 6 (FER-229 - supplement)

Comparison of fault exposures ~2 feet apart. Detail log on left is from Converse (1986) and log on right is from ECI (2000). Solid blue lines correlate horizons south of fault F-1 and dashed blue lines correlate horizons north of the fault. Units in Converse log are the same as in Figure 4. Fault F-1 was not visible in unit 1/Qsb in either exposure.



~~Figure 14~~ (left): This photo (ECI, 2001b) shows the burial of the Stage 3 ground surface (3Btb) by the sand blow deposit (Qsb). No fractures extend from the vent fracture zone into and through the sand blow deposit. However, proximal vent-mouth fractures are shown enlarged in Figure 15. The sand blow unit was OSL dated at 14.3 ± 2.4 ka (ECI, 2002c).

~~Figure 15~~ (right): This photo (ECI, 2001b) is an enlargement of the vent-mouth fractures from Figure 10, which might explain the fault-fractures shown on the log by Converse Consultants (Figure 4). These fractures form a horsetail fan arrangement and die out within inches of the vent apex. One interpretation is that they formed as small shear strains in response to the subsidence of the buried ground surface, while the bulk of the sand blow (Qsb) unit was still too fluid to preserve the strain.

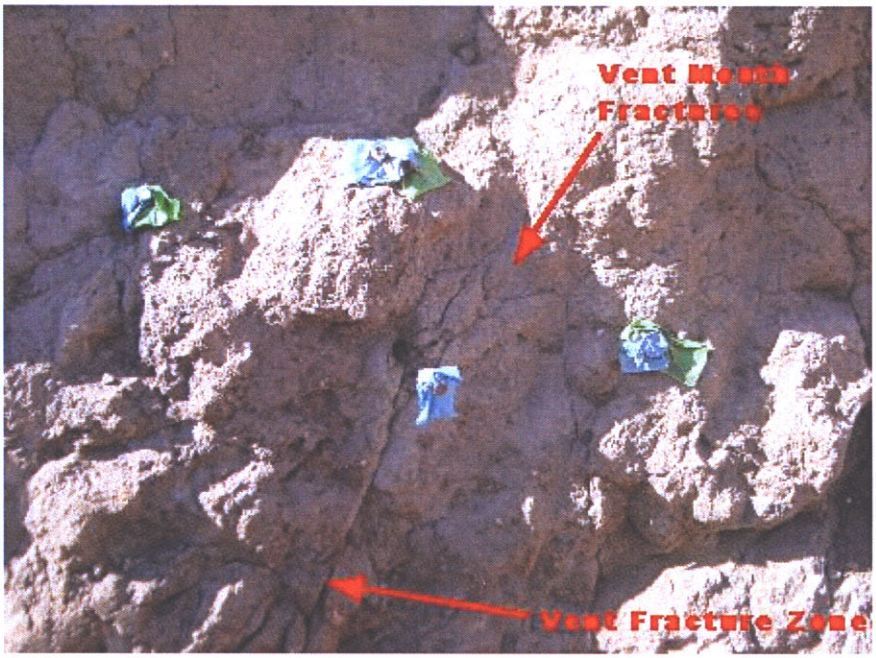


Figure 7 (FER-229 - supplement)

Figures from ECI (2003) document minor fractures at mouth of fissure, within basal portion of unit Qsb in trench T-1 at fault F-1

(reference in Figure 15 caption to "Figure 10" apparently should read "Figure 14")

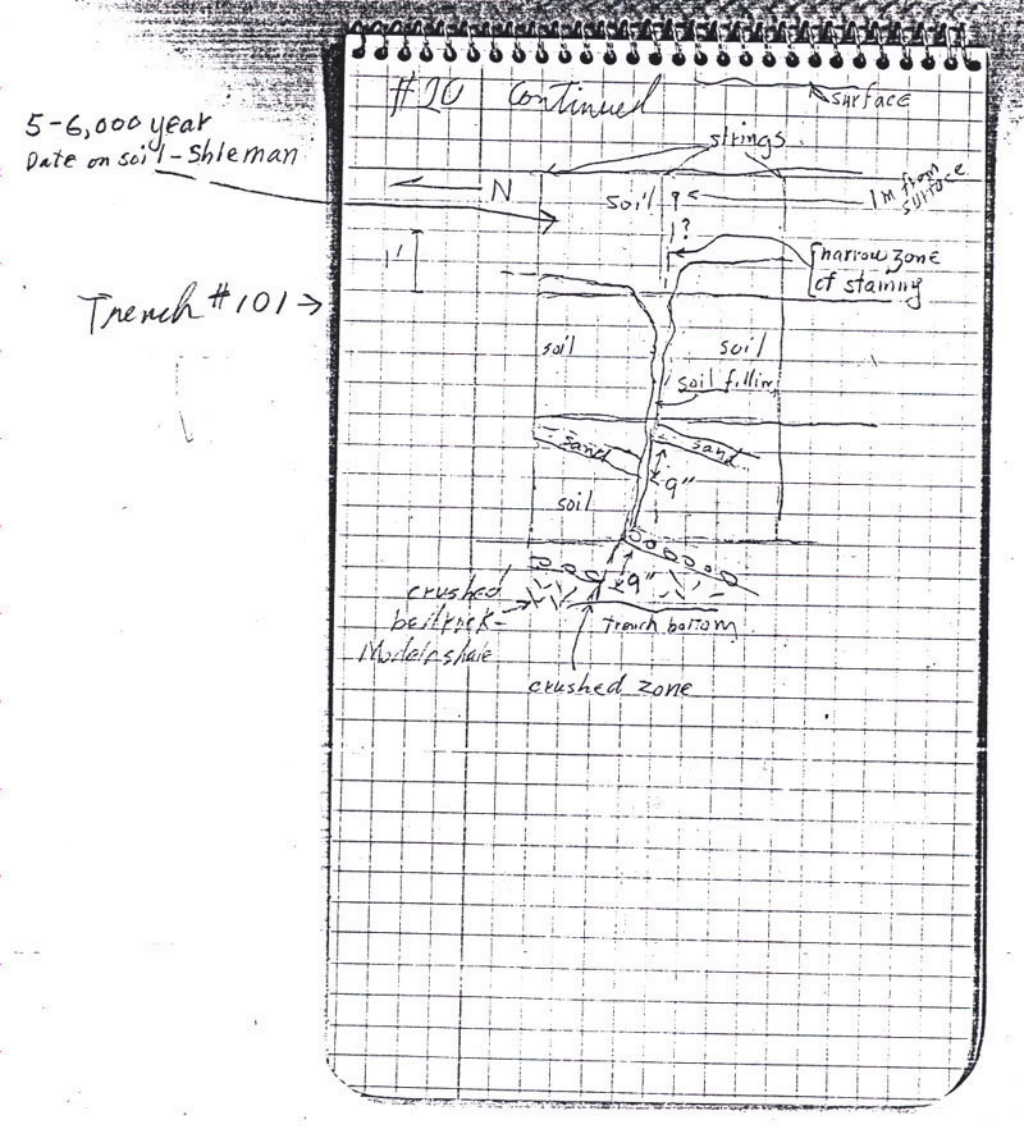
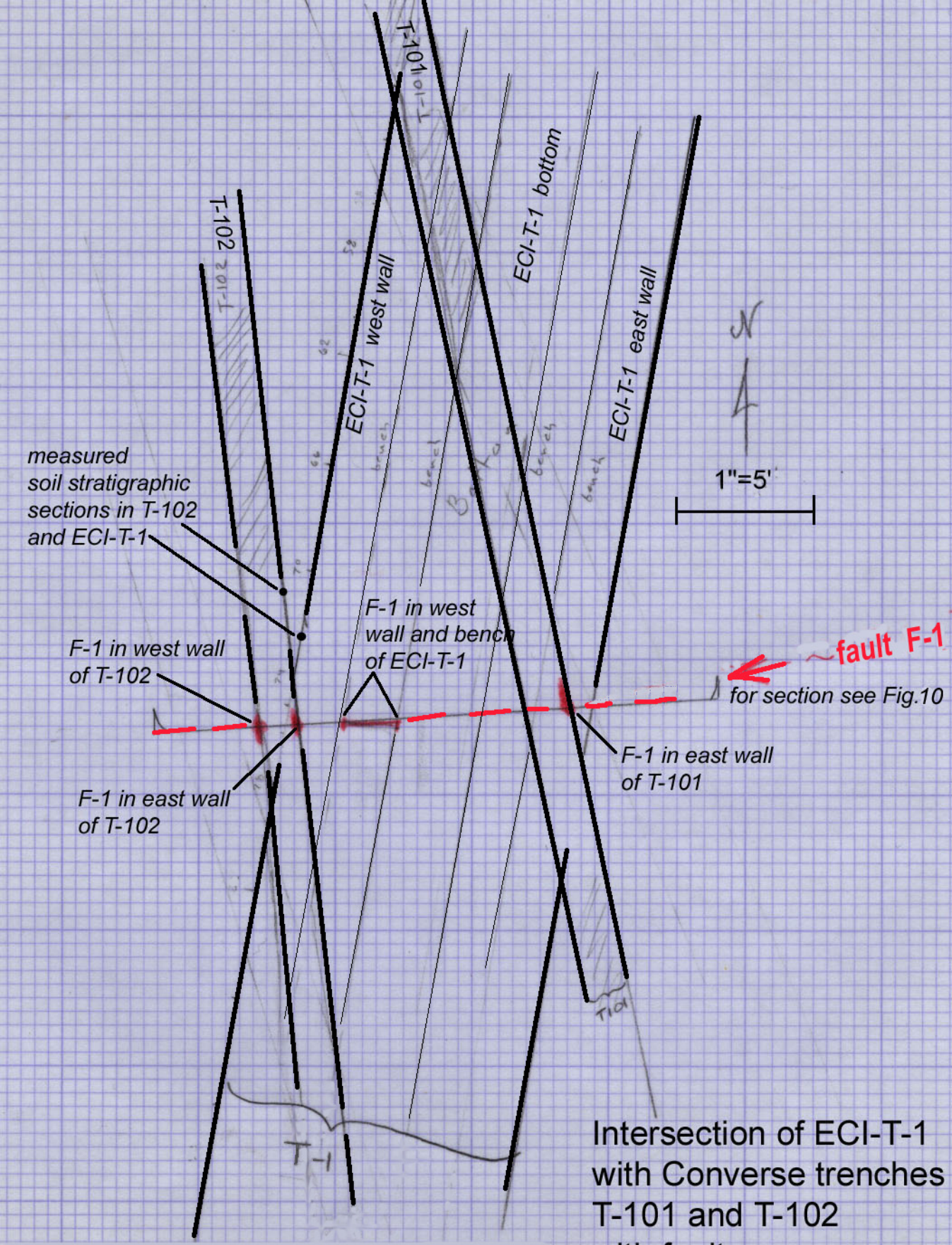


Figure 8 (FER-229 - supplement)

Original field notes and sketch of fault exposed in Converse trench T-101, showing fracture extending into soil.
(notes taken by Richard Saul on November 21, 1986)



Intersection of ECI-T-1 with Converse trenches T-101 and T-102 with fault exposures

Figure 9 (FER-229 - supplement)

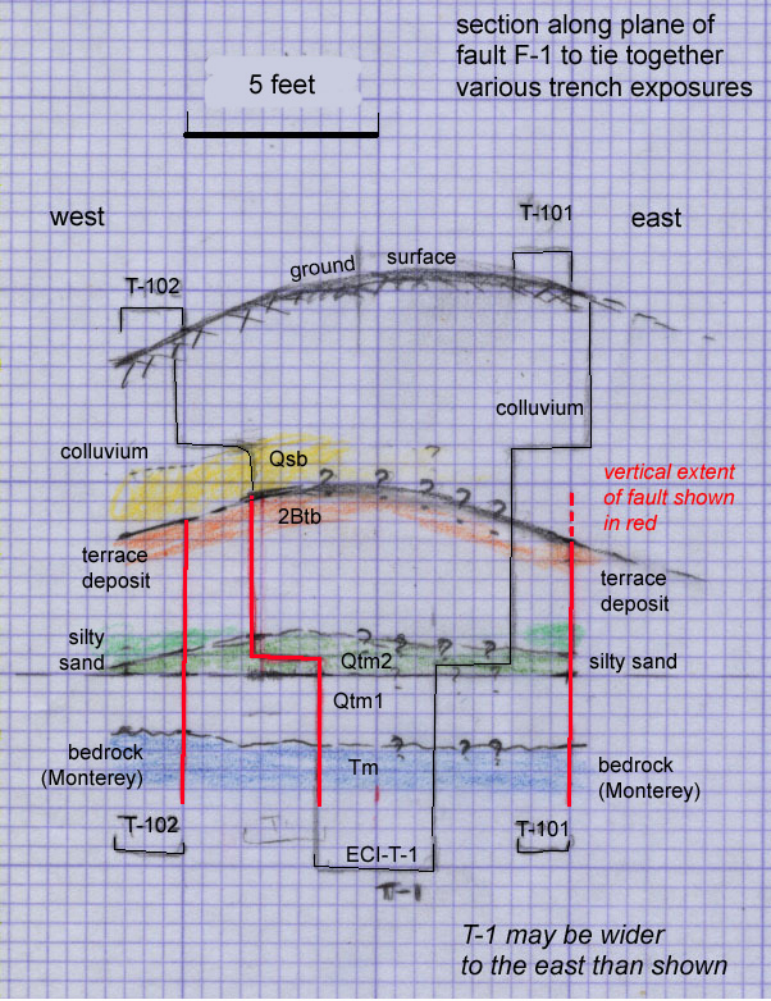


Figure 10 (FER-229 - supplement)

view is to the north; stratigraphic units from each source are shown
see Fig. 9 for location

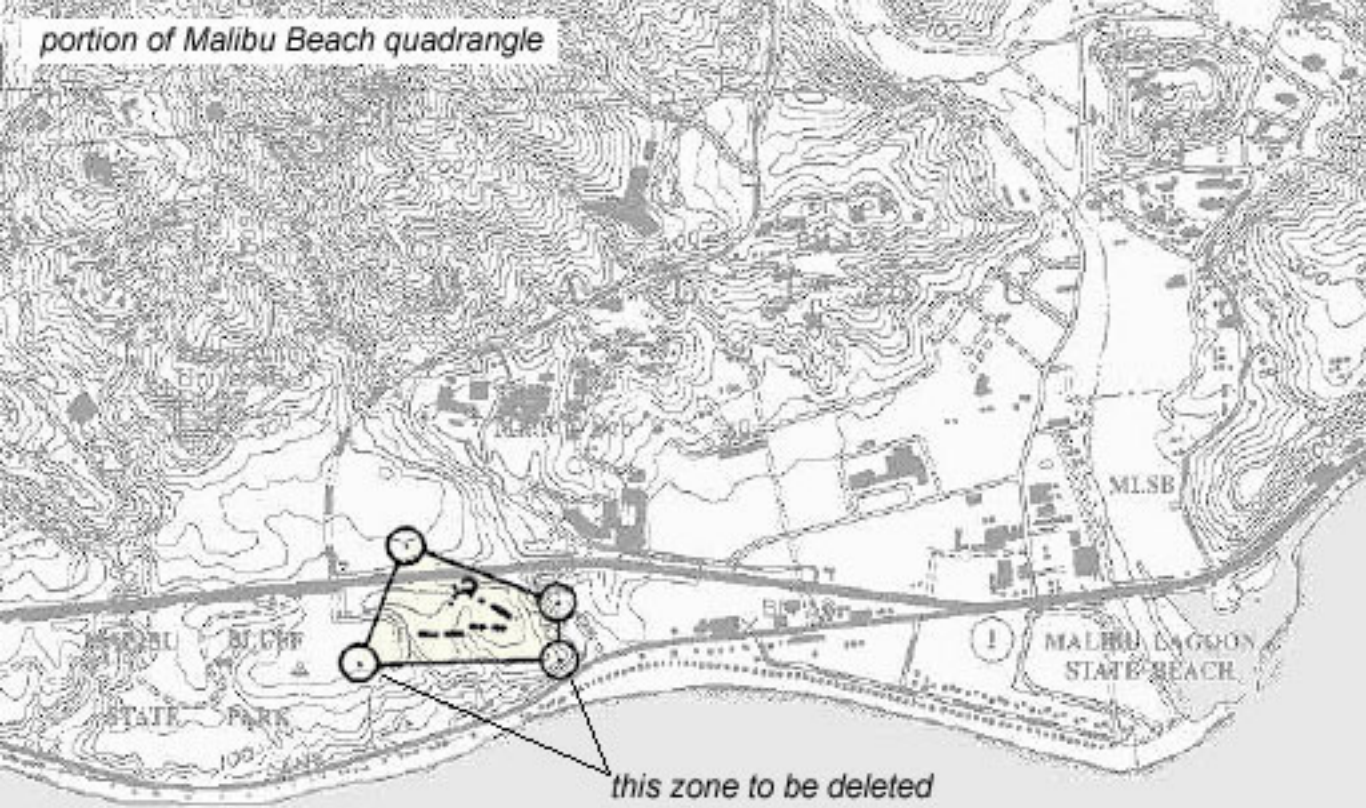


Figure 11 (FER-229 - supplement)

Proposed revision to Earthquake Fault Zone Map for the Malibu Beach quadrangle