GEOLOGIC INVESTIGATION OF FAULT E, SOUTHEAST OF THE SAN ONOFRE NUCLEAR GENERATING STATION, SAN ONOFRE, CALIFORNIA

For:

Southern California Edison Company
Rosemead, California 91770

By:

Fugro, Inc.,
Consulting Engineers and Geologists
3777 Long Beach Boulevard
Long Beach, California 90807

Project No. 77-206-05

May 12, 1978

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE

INTRODUCTION

Recent geologic mapping by Dr. Perry Ehlig in the vicinity of San Onofre Units 2 and 3 disclosed a previously unrecognized fault located about 1-1/4 miles east of the plant site (Ehlig, 1977, his Figure 6). This fault, informally designated Fault E, is approximately 2.5 miles long and has up to several hundred feet of predominantly vertical separation (northeast side down) of Miocene formations. Mapping by Ehlig (1977) showed only one location along Fault E's trace where it appeared to be overlain by a dateable geologic deposit suitable for demonstrating the minimum age of last displacement. This location is near the southern end of Fault E, where a remnant elevated marine terrace platform was believed to be covered by terrace deposits.

Due to the proximity (about 1-1/4 miles) to San Onofre Units 2 and 3, Fault E was investigated to evaluate its structure relative to 10CFR100, Appendix A, and its significance to the seismic design of San Onofre Units 2 and 3. This report presents the results of that investigation.

The following scope of work was performed to investigate Fault E:

1. Two trenches were excavated (Trench 1 and 1A) at one location where marine terrace deposits were mapped as overlying Fault E.

2. Excavation of a third trench (Trench 2) about 3/4 miles inland of the first location (Trench 1) to establish the continuity and observe the characteristics of Fault E.

3. Detailed logging of Trench 1 and 2.

4. Excavation of several small exploratory pits downslope from where the marine terrace deposits were mapped overlying Fault E. The purpose was to clarify the stratigraphic and structural relationships.

5. Analysis of vertical aerial photographs to identify photogeologic lineations in vicinity of Fault E.

6. Analysis of soil profile development at trench locations.

7. Geomorphic analysis of Fault E and vicinity.

The above scope of work relied on the previous geologic mapping by Ehlig (1977) for 1) the general identification and location of Fault E, and 2) for stratigraphic determination of the Monterey and San Onofre formations. Dr. Ehlig reviewed the results of trenching for consistency of lithologic identification and the regional geology associated with Fault E.

DESCRIPTION OF TRENCH 1

Two trenches (1 and 1A) were excavated with a backhoe on a remnant marine terrace platform at an approximate elevation of 350 feet. The mapped trace of Fault E underlies the marine terrace deposits that were believed to be preserved on this platform (Figure 1). The purpose of the excavation was to locate Fault E and expose its relationship to the marine terrace platform and deposits. Trench 1 was 180 feet long, traversed nearly the entire marine terrace platform, and was logged at a scale of 1 inch equals 5 feet. Trench 1A was less than 40 feet long and was dug within 20 feet and parallel to Trench 1 (adjacent to stations 80 through 120) to further trace and expose a fault observed in Trench 1. Trench 1A was not logged since the same relationships were exposed in Trench 1. The geologic relationships observed in Trench 1 and the surrounding area are depicted in Figures 2, 3 and 4.

The Monterey and San Onofre formations compose the stratigraphy observed in Trench 1 and have been identified by Ehlig (1977, and personal communication, 1978). The excavated exposures of the Monterey Formation consist of two conglomeratic facies of the basal Monterey Formation. These conglomeratic facies are comprised chiefly of reworked breccia deposits of the San Onofre Formation and are overlain by sandstone and diatomaceous deposits of the Monterey Formation at the eastern end of the trench. The San Onofre Formation in Trench 1 consists of a chaotic assemblage of highly sheared metamorphic lithologies (Figure 2). Though no matrix is observed in this assemblage, similar units within the San Onofre Formation have been identified elsewhere in the San Onofre Mountains by Dr. Ehlig (1977, and personal communication, 1978). The contact between the San Onofre and Monterey formations is exposed between horizontal stations 65 and 85. This contact appears to be an undulating unconformity, however, some shearing is apparent in the San Onofre Formation along a part of the contact.

At least two faults were identified in Trench 1 that probably represent Fault E. Both faults juxtapose different units of the Monterey Formation with the northeast side down. One fault, located at station 100 (Figure 2), strikes North 20 degrees west, and dips northeast at 44 degrees. This fault juxtaposes two conglomeratic units of the Monterey Formation and consists of a zone of light gray sandstone 4-12 inches wide. Several planar surfaces are contained within the zone but no slickensides, gouge, or significant shearing was observed. The characteristics of this fault were also observed in Trench 1A adjacent to Trench 1 (Figure 4).

The other fault associated with Fault E in Trench 1 is located at station 150 and juxtaposes conglomerate and sandstone units of the Monterey Formation. It strikes about North 35 degrees West, dips vertically, and consists of a zone about 2 inches wide. The zone contains numerous planar surfaces in a braided pattern and within this zone one shear surface has an associated clay gouge about 1/4 inch wide.

Three other possible faults were identified at stations 112, 153, and 158. The faults are queried in Figure 2 because no stratigraphic offset is apparent. The fault at station 112 consists of a zone similar to the fault zone at station 100 but is not as distinct, has fewer planar surfaces, does not juxtapose different lithologies, and does not extend laterally since it was not observed in Trench 1A (located within 20 feet of Trench 1). The faults at stations 153 and 158 are thin (1/4 inch or less) shears filled with brown clay gouge. These faults do not juxtapose different lithologies and have a vertically sinuous trace. In addition to these possible faults, the apparent shearing observed in Trench 1 at the contact of the Monterey and San Onofre formations (between stations 65 and 85) may have accomodated some offset. Evidence for fault movement along these shears is vague.

Lag gravels of a marine terrace deposit are scattered on the surface of the marine terrace platform, but in Trench 1 and 1A no inplace marine terrace deposits were observed. The presence, however, of the marine bedrock platform and the absence of any perceivable disruption of the platform surface or abrupt change in the erosional slope indicates that Fault E has had no movement at least since beveling of the terrace platform. This data combined with other evidence compiled during this study, and in previous investigations, suggests a minimum age of last movement for Fault E of at least 300,000 years. This evidence is presented in a later discussion (see Age of Fault E).

A soil profile was observed in Trench 1 between stations 90 and 135 (Figure 2). The soil formed after development of the marine terrace platform and is characterized by an argillic B-horizon with thick clay films that surround the sand grains and fill the void spaces. A detailed description of the soil profile is provided in Appendix A, B, and C. The soil has developed in two conglomeratic facies of the Monterey Formation, and in the fault zone (located between stations 97 and 101) that separates these two conglomeratic units. Horizons within the soil profile are generally continuous across the fault (Figure 3), suggesting the soil profile has not been disturbed by faulting.

Fault E in vicinity of Trench 1 was originally located between natural outcrops of the San Onofre and Monterey formations. As indicated in Figure 4, the mapped trace separated natural exposures of the Monterey Formation on the east side from a large outcrop of San Onofre Formation on the west side. A fault located at station 150 in Trench 1 corresponds with the mapped trace of Fault E; however, a second fault was observed at station 100, about 50 feet west of the mapped trace. Neither fault juxtaposed the San Onofre Formation against the Monterey Formation, as was anticipated from the natural exposures adjacent to Trench 1 (Figure 4). In order to clarify this inconsistency, several hand dug pits were excavated downslope of Trench 1 to remove the few feet of colluvium which mantles the surface. The purpose of these excavations was to expose the rock types and contacts at selected locations in the immediate vicinity of Trench 1 (Figure 4).

All of the exposures (hand-dug pits, natural exposures, and trenches) showed that the contact between the San Onofre and Monterey formations outcrops in Trench 1 between stations 65 and 85 feet and extends easterly at a depth just below the bottom of Trench 1 until it is offset by the trace of a fault observed in Trench 1 at station 150 (see Figure 5). The trace of the unconformity is controlled by natural and man-made exposures as indicated in Figure 4; however, this interpretation is best visualized in a generalized cross-section (A-A', Figure 5) which aligns parallel to Trench 1 (Figure 4). The presence of the unconformity on the west side of Fault E is consistent with geologic mapping of the surrounding region (Ehlig, 1977) because, based on projection of structural contours on the realtively planar unconformity, it should outcrop on the ridge where Trench 1 is located. The recognition of the shallow uunconformity west of Fault E's originally mapped trace (Figure 4) resolved why the San Onofre and Monterey formations are not in fault contact in Trench 1.

Even though the San Onofre and Monterey formations are not juxtaposed by faulting, as observed in Trench 1, the structural implications drawn from the natural, hand-dug, and trenched exposures indicates Fault E does transect Trench 1. In fact, based on previous mapping of Fault E (Ehlig, 1977) and on the geologic conditions observed in vicinity of

Trench 1, the trace of Fault E can not be placed anywhere except within the limits of Trench 1. As shown in Figure 5, Fault E in Trench 1 must consist of at least two structural elements; one at station 100 and another at station 150.

Of the two structural features in Trench 1 that represent Fault E, the fault located at station 150 must have accommodated nearly all of the vertical movement estimated on Fault E. This is because the unconformity (mentioned earlier) is generally continuous (within 10 to 20 feet in elevation) across the trace of the fault located at station 100. On the other hand, the fault at station 150 could account for several hundred feet of offset since the unconformity probably terminates at this fault and the San Onofre and Monterey formations appear juxtaposed downslope of Trench 1 along the fault trace.

In the area of Trench 1, the actual amount of separation on Fault E is not precisely known and can vary from about 450 to 600 feet (maximum) to about 20 to 100 feet (minimum) depending on the assumptions used. The maximum dip separation is estimated from structural cross-sections (Ehlig, 1977), oriented approximately at right angle to the trace of Fault E, that are based on field data control points located no closer to Trench 1 than about 1000 feet. Based on this data, the maximum amount of dip separation could range from about 450 feet to as much as 600 feet depending on the planarity of the San Onofre/Monterey contact and the variation of observed dips in the Monterey Formation (between 20 and 35 degrees southwest).

The geologic conditions in and adjacent to Trench 1 can accommodate these maximum ranges of offset, however, the exposures can also suggest minimum amounts of separation varying between 20 feet to just over 100 feet. The Monterey/San Onofre contact (Tm/Tso) identified in and adjacent to Trench 1 was observed at two locations; between stations 65 and 85 in Trench 1, and in a hand-dug excavation just downslope of the eastern end of Trench 1 (Figure 4). The hand dug excavation exposed the Tm/Tso contact, which was dipping gently northeast (between 15 and 20 degrees), for about 3 feet before either the depth of the excavation or overlying colluvial material inhibited any further exposure. The contact and exposed lithologies at this location are highly weathered and it is not clear if the contact represents 1) a gently dipping depositional unconformity or 2) a deformed contact due to faulting within a complex fault zone. If the contact is an unconformity of a depositional and undisturbed nature, the amount of slip on the fault projected from station 150 could be limited to as little as about 20 feet. On the other hand, if the contact is disturbed by faulting, which seems more reasonable, then no limit on the amount of separation is required, and the minimum amount expected would be the elevation difference between the terrace platform and the stream bed, about 100 feet.

In summary, the variance in the amount of separation on Fault E depends on the different use of interpretations and assumptions that can explain or be derived from natural as well as man-made exposures. The nature of the exposures is such that even though extensive studies and excavations were performed they are not conducive to a comprehensive understanding of the fault separation and geometry associated with Fault E. Even though the actual amount of separation is unresolved, it is important to note these studies demonstrate Trench 1 has crossed Fault E's trace. Two distinctive faults were observed in Trench 1 with one of these faults (located at station 150) having accomodated nearly all of the separation postulated on Fault E.

DESCRIPTION OF TRENCH 2

Trench 2 is located about 3,200 feet north of Trench 1 (Figure 1) along the mapped trace of Fault E (Ehlig, 1977). It was excavated to provide a second location where the characteristics of Fault E could be observed. No terrace deposits were expected or found at Trench 2. A detailed log of Trench 2 is presented in Figure 6.

As seen in Figure 6, the basal portion of the Monterey Formation is juxtaposed against the San Onofre Formation along an east dipping fault. This fault is interpreted to be Fault E (Ehlig, 1977). It strikes North 20 degrees West, (within 15 degrees of the strike of the mapped trace), and dips northeast between 65 and 76 degrees. In trench 2 Fault E consists of a wedge shaped zone that ranges from less than one inch at the top of the zone to about 15 inches wide at the trench floor. The zone is comprised of color banded (red in the center, light gray at the margins) sand with no apparent gouge or shearing. East of Fault E, basal conglomeratic beds of the Monterey Formation (Ehlig, 1977) are conformably overlain by northeast dipping sandstones and diatomaceous deposits of the Monterey Formation. West of Fault E, a homogenous sedimentary breccia of the San Onofre Formation is exposed continuously to the end of Trench 2.

RESULTS OF TRENCHING

Exposures in Trench 1 and 2, and hand dug excavations near Trench 1 indicate the following results:

1. The orientation and location of Fault E in Trench 1 and 2 corresponds to the mapped trace of Fault E (Ehlig, 1977, Figure 6).

2. Fault E in the Trench 1 area is represented by two faults exposed in the trench. One of these faults, located as station 150, has accommodated nearly all of the separation estimated for Fault E.

3. No inplace terrace deposits overlie Fault E at Trench 1 or at other localities along its trace. However a marine terrace platform crosses Fault E at Trench 1, as well as a soil horizon over one of the two faults in Trench 1, with no apparent disruption.

AGE OF FAULT E

Inplace marine terrace deposits are not preserved on the terrace platform in Trench 1 and therefore cannot be used to date the last movement of Fault E. However, the following multiplicity of geomorphic, pedologic, and topographic evidence strongly suggests that Fault E is not capable, thus meeting the criteria of 10CFR100 Appendix A.

- A marine terrace platform at about elevation 350 feet extends across Fault E and shows no evidence of disruption. The approximate age of this platform is probably between 300,000 to 350,000 B.P. based on correlation with the deep sea oxygen-isotope record.
- A soil profile which has formed on the 300,000 to 350,000 B.P. marine terrace platform crosses one of two faults in Trench 1 (discussed earlier) and shows no apparent disruption by the fault.
- Remnant marine terrace deposits at about elevation 450 feet exist on both sides of Fault E. The approximate age of these terraces is probably between 370,000 and 440,000 B.P. based on correlation with the deep sea oxygen-isotope record. Their presence at similar elevations indicates there has been no appreciable amount of vertical movement, if any, on Fault E in approximately the last 400,000 years.

- Non-marine terrace deposits with an age of less than 125,000 B.P. are exposed in the seacliffs along the southeast projection of Fault E with no apparent disruption (Shlemon, 1977).

- Fault E has no geomorphic or topographic expression.

Numerous raised marine terraces have been observed and mapped in the San Onofre area (Ehlig, 1977). These terraces probably correlate with various interglacial high stands of sea level, with the terraces generally increasing in age with increasing elevation. In the San Onofre area, only the lowest, or first emergent terrace has been well dated and is approximately 125,000 years old (Fugro, 1975). Age determinations of the older marine terraces are based on degree of preservation, elevation, degree of soil-profile development, and correlation with the deep-sea oxygen-isotope record, as no absolute radiometric ages have been determined for them.

In the area of Trench 1, Fault E is beveled by a marine terrace platform at an elevation of 350 to 375 ft (Ehlig, 1977). This platform is at least the third emergent terrace mapped near San Onofre (Ehlig, 1977, his Figure 6), and probably correlates with oxygen-isotope stage 9. The age of stage 9 ranges from approximately 297,000 to 347,000 years old (Shackleton and Opdike, 1976). Though no marine terrace deposits are preserved on the platform, the near horizontality of the platform with no disruption of the platform surface or abrupt change in slope indicates that Fault E probably has not moved at least since beveling of the terrace platform, approximately 300,000 years ago.

Trench 1 (Figures 2 and 3) revealed a soil profile (Figure 3, and Appendix A, B, and C) that has no apparent disruption where it crosses one of two faults exposed in the trench. This soil consist of an argillic B-horizon with thick clay films which surround the sand grains and fill the void spaces. The near horizonality of the B2t horizons on both sides of the fault (Figure 3) and in different parent materials (both are part of the Monterey Formation) suggests that the fault has been inactive for at least the duration of soil development.

Two marine terrace platforms with preserved deposits appear to be correlative and are located immediately northwest and southeast of the southern portion of Fault E (Figure 1). These terraces, at an elevation of about 425 to 450 ft., probably correlate with oxygen-isotope stage 11, and hence should range in age between 367,000 to 440,000 B.P. (Shackleton and Opdike, 1976). Within the resolution of these terraces, any major offset along Fault E (on the order of 20 to 50 ft.) should be observed by elevation difference between these correlative terraces. Field examination by Fugro indicates their elevation ranges are within about 10 feet of each other. This suggests no movement on Fault E in at least the last 400,000 years.

About 50 feet of continental, nonmarine terrace deposits are exposed near the seashore along the southeast projection of

Fault E. No evidence of faulting has been observed in these deposits (Shlemon, 1977). A reconnaissance of the upland topography along Fault E was also made. No geomorphic or topographic evidence of recent activity such as landslides, scarps, linear ridges, aligning saddles, or springs was observed (Shlemon, 1977). Thus, the lack of geomorphic and topographic expression of Fault E, further confirms that Fault E has not moved in the last several hundred thousand of years during development of the landscape.

CONCLUSIONS

The results of this investigation indicate the following:

1. No inplace terrace deposits overlie Fault E at Trench 1 or at other localities along the trace; however, a marine terrace platform, approximately 300,000 to 350,000 years old, does cross Fault E at Trench 1 with no apparent disruption.

3. A multitude of geomorphic, pedologic, and topographic evidence suggest Fault E is at least 300,000 years old and is probably greater than 400,000 years old.

4. Based on the results of this investigation and on previous reports by Ehlig (1977) and Shlemon (1977), Fault E is considered not capable, according to 10CFR100 Appendix A, and thus is not significant to the seismic design of San Onofre Units 2 and 3.

REFERENCES CITED

Birkeland, P. W., 1974, Pedology, weathering, and geomorphological research: Oxford Univ. Pres, New York 285 p.

Ehlig, P. L., 1977, Geologic report on the area adjacent to the San Onofre Nuclear Generating Station northwestern San Diego County, California: in Geotechnical Studies Northern San Diego County, California, October, 1977 for Southern California Edison and San Diego Gas and Electric Company.

Fugro, Inc., 1975, Summary of geomorphic and age data for the first emergent terrace (Qt_1) at the San Onofre Nuclear Generating Station: report to Southern California Edison Co., September 12, 1975, 49 p.

Shackleton, N. J., and Opdike, N. D., 1976, Oxygen-isotope and paleomagnetic stratigraphy of Pacific Core V28-239 late Pliocene to latest Pleistocene: Geol. Soc. America Memoir 145, p. 449-464.

Shlemon, R. J., 1977, Geomorphic analysis of fault "E" Camp Pendleton, California: in Geotechnical Studies Northern San Diego County, California, October, 1977 for Southern California Edison and San Diego Gas and Electric Company.

Soil Survey Staff, 1960, Soil classification, a comprehensive system (7th approximation): U.S. Dept. of Agri., Soil Cons. Service, 265 p.

APPENDIX A

Soil Profile A, Station 94-96, Trench 1

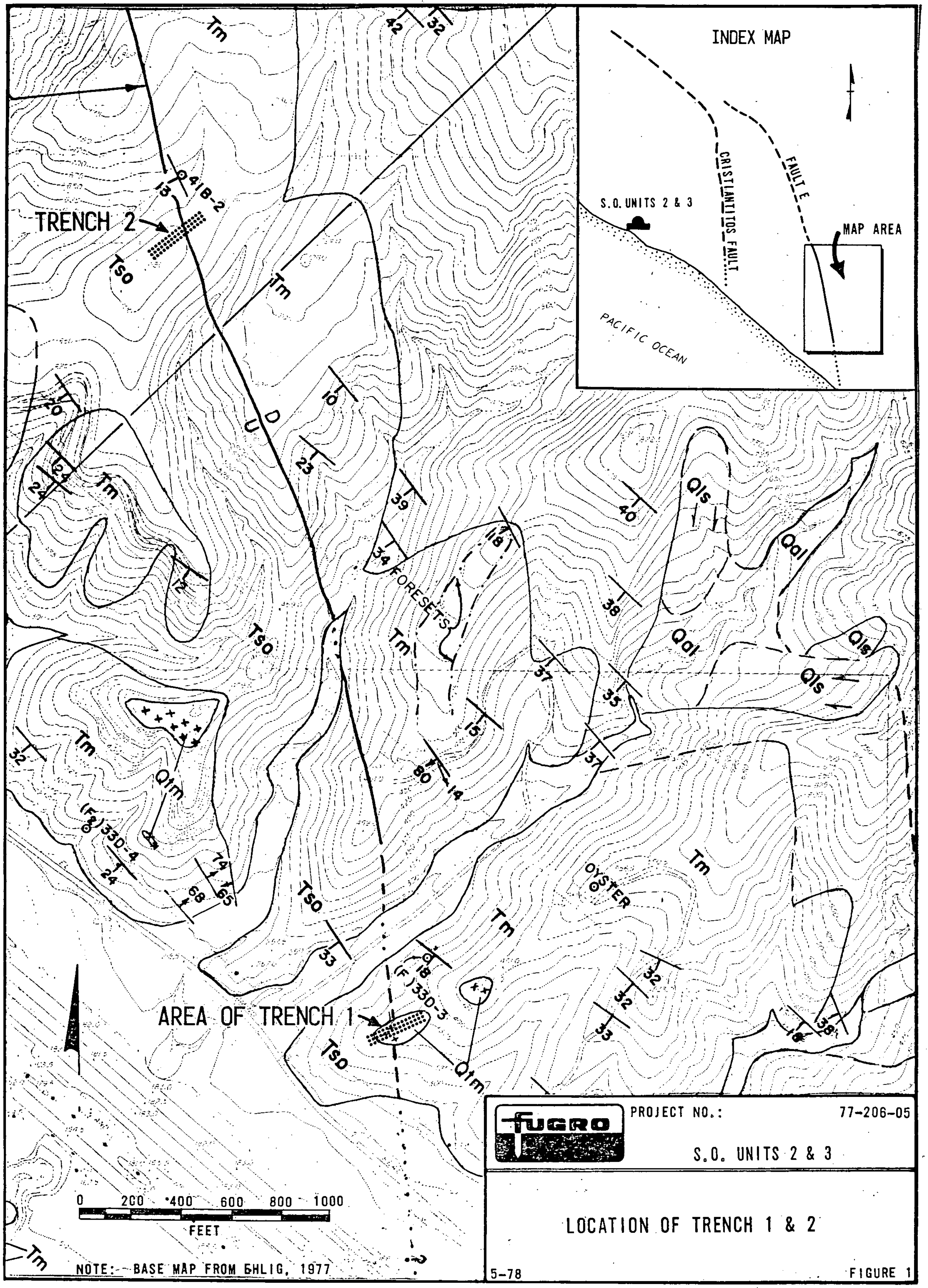
Approximate Depth (in.)	Horizon	Description
0-3	A 1	Brown (10 YR 4/3) sandy loam, single grain, 10% organic matter, possibly disturbed, very abrupt boundary to;
3-12	II B22t	Reddish brown to red (2.5 YR 4/4) to 4/6) sandy loam, slight plastic and slightly sticky, blocky structure, gravels compose greater than 50%, thick clay films, gradual wavy boundary to;
12-20	II B23t	Red (2.5 YR 4/6 to 5/6) sandy loam (-), slightly sticky, and plastic, granular structure, moderately thick clay films, gravels compose greater than 50%, gradual wavy boundary to;
20-43	II B3t	Strong brown (7.5 YR 5/6) sandy loam (-), very slightly sticky and plastic, granular structure, no obvious clay films, diffuse wavy boundary to;
43-61	II Cn or R	Yellowish brown (10 YR 5/6) loamy sand (-), single grain structure, no clay films, slightly oxidized. Bottom of trench.

Soil profile nomenclature modified from Soil Survey Staff (1960) and Birkeland (1974).

APPENDIX B

Soil Profile B, Station 101-103, Trench 1

Approximate Depth (in.)	Horizon	Description
0-3	Al	Brown (10 YR 4/3), sandy loam, single grain, 10% organic matter, possibly disturbed, very abrupt boundary to;
3-23	II B2t	Reddish brown (5 YR 3/4) sandy loam, blocky structure, sticky and plastic gravels compose greater than 50%, thick clay films, gradual wavy boundary to;
23-33	II B3t	Dark reddish brown to reddish brown (5 YR 4/4 to 3/4) sandy loam (-), massive structure, thin clay films gravels compose 40%, diffuse vary boundary to:
33-63	II Cn or R	Light olive brown (2.5 YR 5/4) sand, single grain, no clay films, slightly oxidized, bottom of trench.



PROJECT NO.: 77-206-05

S.O. UNITS 2 & 3

LOCATION OF TRENCH 1 & 2

5-78

FIGURE 1

LOG OF TRENCH 1

NORTHWEST WALL
N70°E

SCALE: 1' = 5"

FUGRO	PROJECT NO.: 77-206-05 S.O. UNITS 2 & 3

LOG OF TRENCH 1

5-78

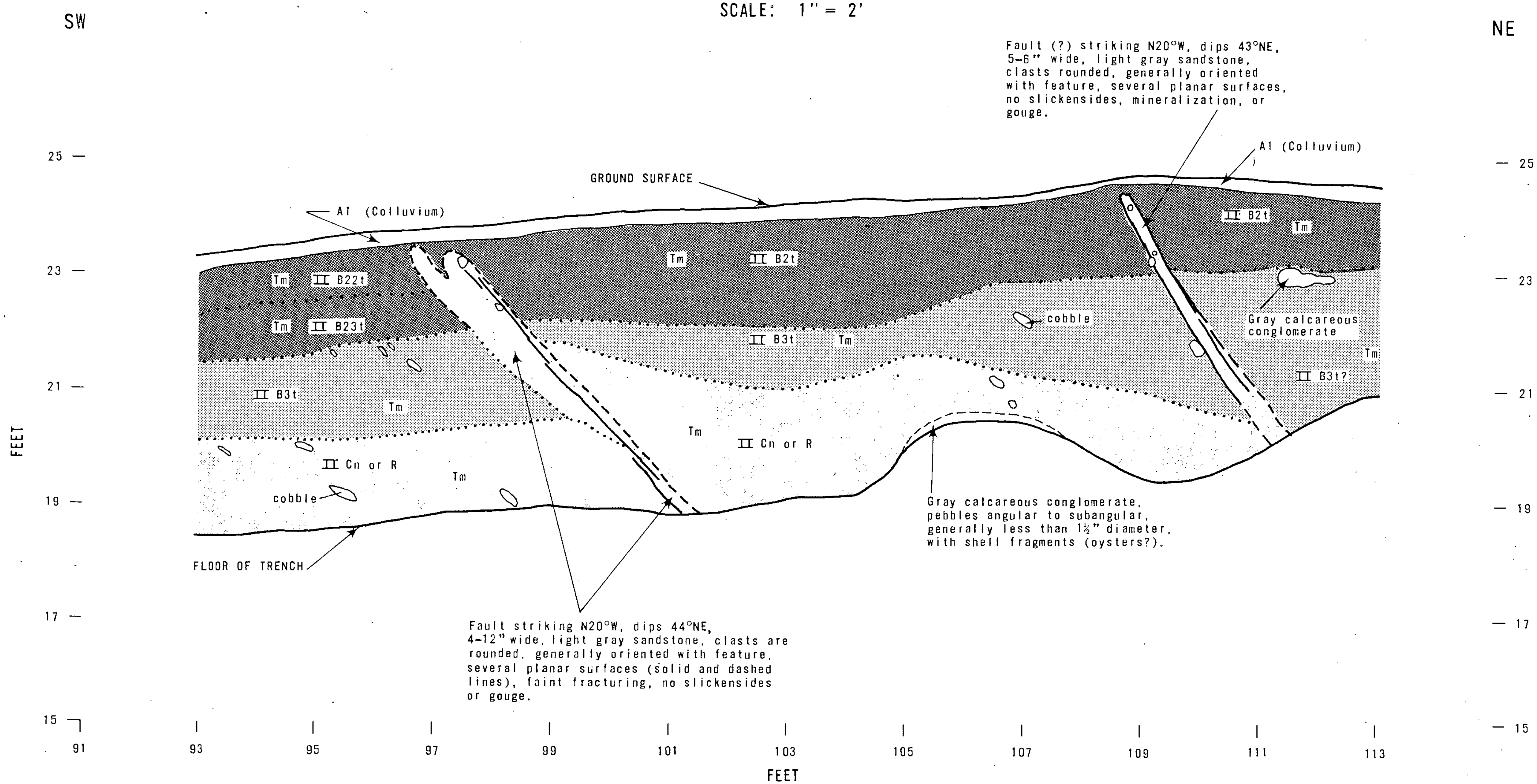
FIGURE 2

DETAILED LOG OF SOIL PROFILES, TRENCH 1

NORTHWEST WALL

N70°E ⟶

SCALE: 1" = 2'



NOTES:

—— ···· Pedologic boundary; solid where abrupt, dotted where gradual or difuse

II B2t Soil Horizon; see Appendix A for complete descriptions

Tm Monterey Formation (Ehlig, 1977)

Tso San Onofre Formation (Ehlig, 1977)

Location shown in Figure 2

FUGRO

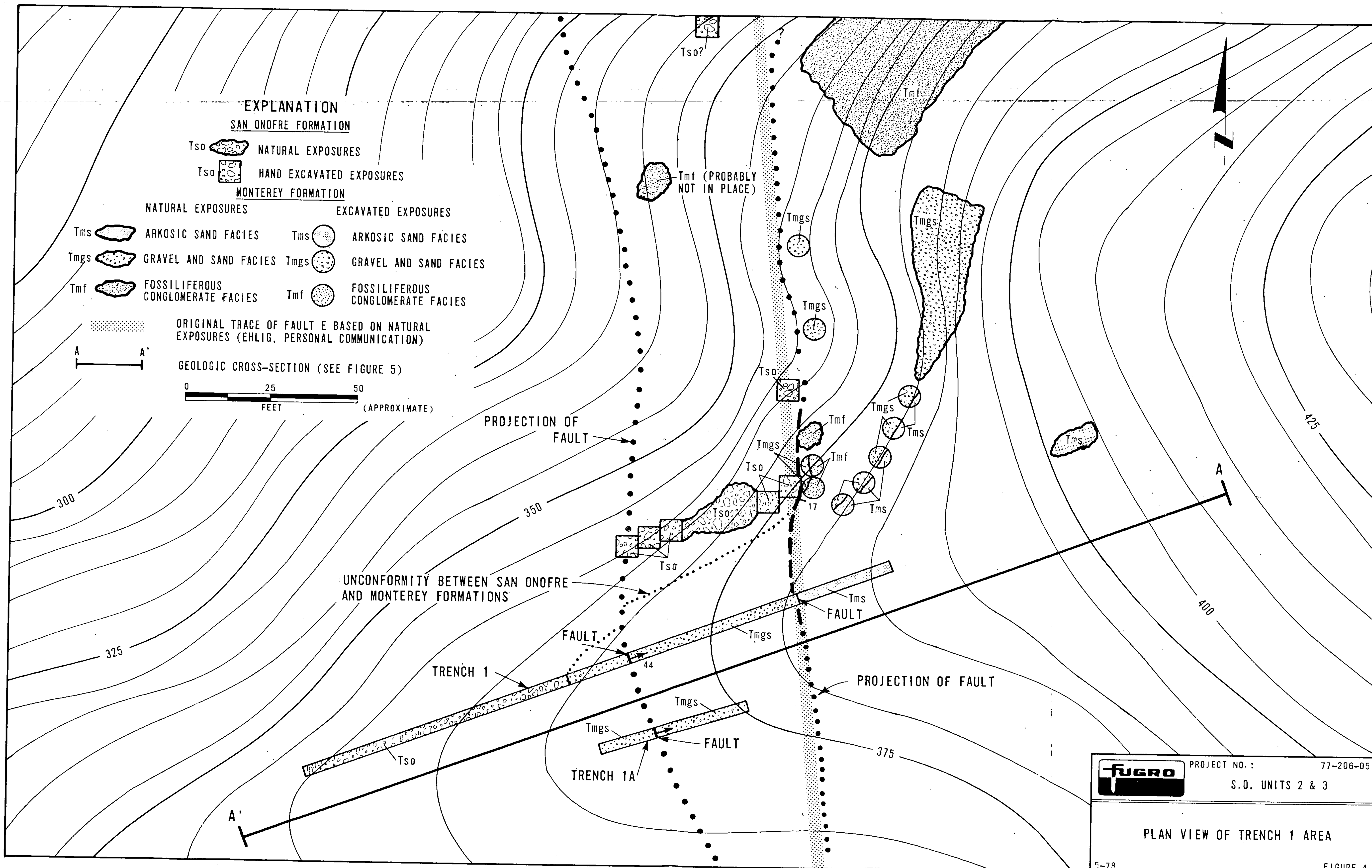
PROJECT NO: 77-206-05

S.O. UNITS 2 & 3

DETAILED LOG OF SOIL PROFILES, TRENCH 1

5-78

FIGURE 3



FUGRO

PROJECT NO.: 77-206-05

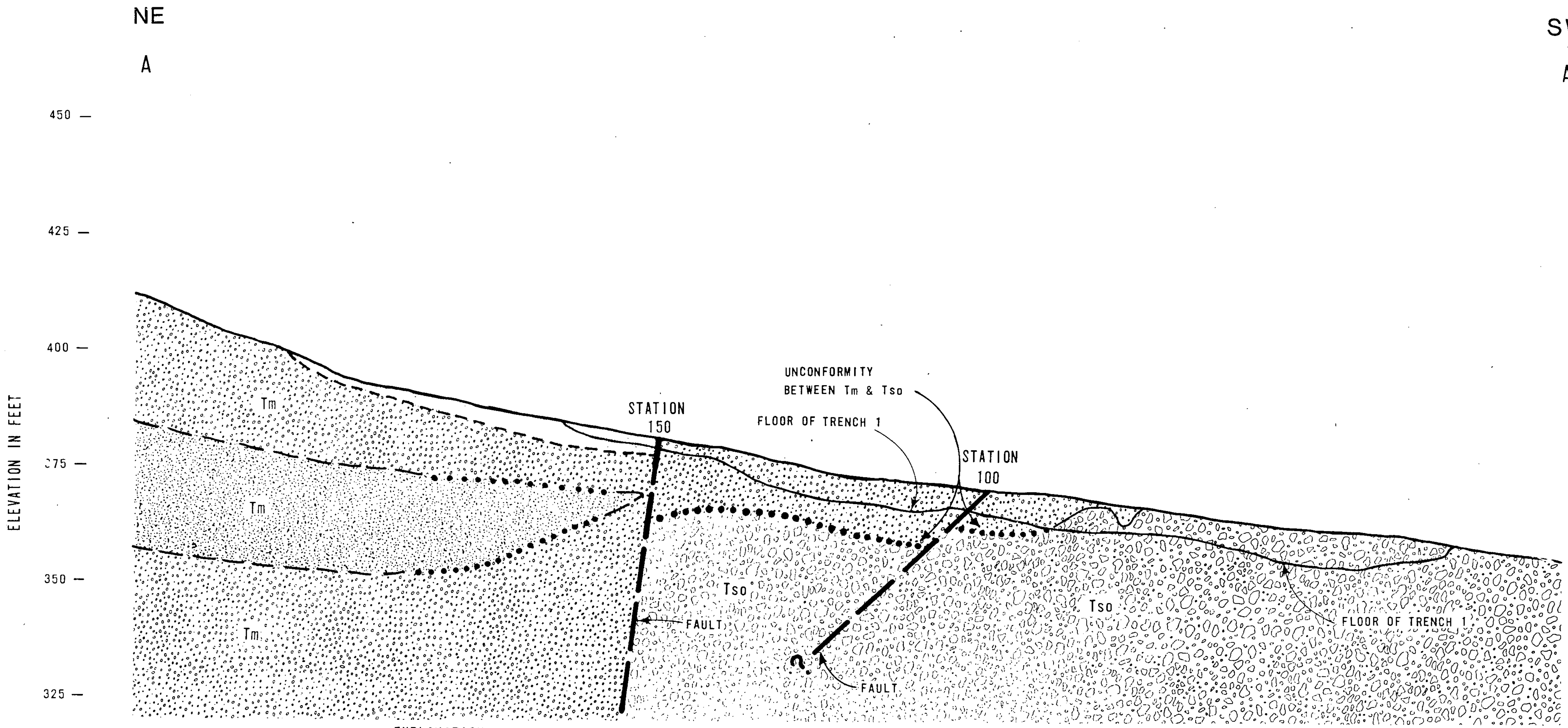
S.O. UNITS 2 & 3

PLAN VIEW OF TRENCH 1 AREA

5-78

FIGURE 4

DIAGRAMMATIC GEOLOGIC CROSS-SECTION IN VICINITY OF TRENCH 1



EXPLANATION

Tm	MONTEREY FORMATION ARKOSIC SAND FACIES
Tm	MONTEREY FORMATION GRAVEL AND SAND FACIES
Tm	MONTEREY FORMATION FOSSILIFEROUS CONGLOMERATE FACIES
Tso	SAN ONOFRE FORMATION

SCALE: 1" = 25'

NOTE: SEE FIGURE 4 FOR LOCATION OF CROSS SECTION

FUGRO

PROJECT NO : 77-206-05

S.O. UNITS 2 & 3

GEOLOGIC CROSS-SECTION A-A'

5-78

FIGURE 5

LOG OF TRENCH 2

NORTHWEST WALL
N60°E →

SCALE: 1' = 5"

FUGRO

PROJECT NO.: 77-206-05

S.O. UNITS 2 & 3

LOG OF TRENCH 2

5-78

FIGURE 6