SAN ONOFRE
NUCLEAR GENERATING STATION
UNITS 1, 2 & 3

9

GEOTECHNICAL STUDIES
NORTHERN SAN DIEGO COUNTY, CALIFORNIA

OCTOBER 1977

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Southern California Edison Company

SAN DIEGO GAS & ELECTRIC COMPANY

229

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GEOLOGIC STUDIES

NORTHERN SAN DIEGO COUNTY, CALIFORNIA

PURPOSE

This report documents the results of Southern California Edison Company's (SCE) geologic investigation of five areas to the southeast of San Onofre Nuclear Generating Station (San Onofre). These areas were the subject of field trips and meetings on May 25 and 26, 1977 among representatives of the NRC, Advisory Committee on Reactor Safeguards, California Energy Resources Conservation and Development Commission (ERCDC), U.S. Army Corp of Engineers, California Division of Mines and Geology, and SCE. The location of the five areas is shown in figure 1. This summary provides a description of the work performed and the resulting conclusions for each area.

DISCUSSION

Trail Six Landslide (Area 1)

As discussed in Enclosure 1, the landslide site was mapped in detail to determine the cause of fractures observed at this location. Mapping of surface exposures indicates that the undisturbed Quaternary nonmarine deposits continue laterally across the backscarp of Trail Six landslide. This indicates that the fractures do not extend beyond the landslide boundary. The fractures mapped in the slide mass have variable displacement, are curved, splay with depth and have fracture filling. This evidence indicates internal fracturing occurred within the landslide mass and caused the fractures observed at this location. The fractures are not of tectonic origin, thus they are not significant to the seismic design of San Onofre.

In addition to the above geologic mapping, the contact between the landslide and adjacent sediments was trenched to determine the extent of the fractures. However, because of delays associated with obtaining approval of the trenching, the work was not completed in time to be included in this report. A report describing this trenching will be forwarded to the NRC in November, 1977.

Horno Canyon Landslide (Area 2)

The south facing sea cliffs just south of Horno Canyon expose a displaced bedrock/marine terrace contact where two features create a graben structure. The area was mapped (Enclosure 1) to determine the origin of the graben and its relationship to the geologic history of the area.

The mapping of the Horno Canyon area demonstrates that several episodes of landsliding have occurred in the geologic past. The oldest landslide occurred before the marine terrace platform was cut. After the sea planed off the landslide surface and nonmarine sediments were deposited, another episode of landsliding occurred.

The landsliding caused substantial block deformation and created the features and graben exposed at the sea cliffs. Mapping the backscarp of the historic landslide demonstrated that continental nonmarine horizons of silts and gravels are continuous across the projected trend of the two features bounding the graben. Thus the features and graben are within the landslide mass and are not tectonic in origin. The features have no significance to the seismic design for San Onofre.

Target Canyon (Area 3)

As discussed in Enclosure 2, Target Canyon has been mapped in detail. This mapping includes several minor north trending offsets that extend upward from the bedrock into marine and nonmarine sediments. These features are considered insignificant based on the fact that their displacement length is less than 2000 feet and their displacement (maximum 14 inches) dies out before reaching the ground surface. Analysis of the features indicates that the offsets are probably the result of settlement or tectonic origin. Even if assumed to be of tectonic origin, the offsets would have no effect on the seismic design of San Onofre, since these offsets are insignificant in comparison to the hypothesized zone of deformation(1) and at least as distant from San Onofre.

Geology of the San Onofre Mountains, Northern San Diego County (Area 4 and 5)

Geologic mapping of the San Onofre Mountains by P. L. Ehlig (Enclosure 3) has disclosed that the oldest bedrock exposed is the dense, brittle, San Onofre breccia that is unconformably overlain by the Monterey Formation. The Monterey microfossil assemblages are Middle Miocene to Early Upper Miocene (Anderson, Warren 1977 Appendix A). These units in turn are overlain by marine sands and nonmarine continental deposits along the coast. The San Onofre breccia was deposited from a highland that existed offshore from the present coastline and laid down initially with an easterly dip. Subsequent to deposition, uplift occurred and the Monterey

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(1) Safety Evaluation of the San Onofre Nuclear Generating Station, Units 2 and 3, October 20, 1972

Formation was unconformably deposited on the west-facing slopes of the San Onofre breccia.

Periods of long term stability are demonstrated by the continuous marine terrace deposits at the southern area of the mapping that extend northward toward San Onofre Mountain. Marine terrace sediments are found at stepped elevations up to about elevation 1,275 feet. To the north, in the vicinity of San Onofre Mountain, terrace benches have been incised to approximately 1,500 feet but the marine gravels and armor have been eroded off. This evidence indicates long periods (200,000 years or greater) of stability in this region.

The mapping of fault F (Area 4) is shown on Figure 6 of Enclosure 3. The fault surface is well exposed in a small quarry just inland from El Camino Real. It strikes about 15 degrees west and dips about 78 degrees southwest where exposed in the quarry.

Mapping performed by Ehlig in the vicinity of fault F disclosed the previously unknown feature designated fault E on the geologic map of Enclosure 3. Fault E is approximately 2.5 miles long and has stratigraphic separation of about 330 feet down on the north side as shown in geologic section C-C' (Enclosure 3). Fault E, which was formed during the Miocene, is overlain by a remnant of marine terrace deposits that are at least 200,000 years old (Enclosure 4). These marine deposits will be excavated to confirm the age of last movement of fault E. This excavation is currently pending approval of the U. S. Marine Corps, Camp Pendleton. If approval is received within the expected time frame, a report of this excavation will be forwarded to the NRC in December, 1977.

To confirm the period of inactivity of Fault E, a geomorphic analysis was performed by R. J. Shlemon (Enclosure 4). The conclusions of this analysis are summarized as follows:

1. Marine terrace deposits at least 200,000 years old lie across the fault and appear not to be displaced within the resolution of their preservation.
2. The upland topography contains no landslides, spring lines, truncated spurs, saddles or similar geomorphic features. This evidence indicates that at least tens of thousands of years have elapsed since last movement.

The geologic mapping discussed in Enclosure 3 indicates that both faults E and F resulted from structural uplift of the brittle San Onofre breccia during the Miocene and are considered to have been inactive since that time. The age of faulting is older than the Miocene uplift and occurred after the deposition of the Monterey formation. The stability of this area is expressed by the essentially undeformed wave benches cut by receeding seas during high stands of sea level. The older, higher terraces are probably Pliocene in age and the region has been without major deformation since that time. Thus faults E and F are not significant to San Onofre seismic design.

CONCLUSIONS

1. The offsets observed in Trail Six landslide are the result of landsliding and are not significant to San Onofre seismic design.
2. The graben structure observed in the Horno Canyon landslide is of landslide origin and is not significant to San Onofre seismic design.

3. The origin of the features observed at Target Canyon cannot be specifically determined. However, even if they are assumed to be of tectonic origin, these features are not significant to San Onofre seismic design based on their length, distance from the site, and amount of displacement.
4. Faults E and F are considered to be incapable and thus are not significant to San Onofre seismic design.

LOCATION OF FIVE AREAS
FIGURE 1

ENCLOSURE 1

REPORT OF GEOLOGIC INVESTIGATIONS,
TRAIL SIX (AREA 1) AND
HORNO CANYON (AREA 2) LANDSLIDES
SOUTHEAST OF SAN ONOFRE
NUCLEAR GENERATING STATION

FOR:

SOUTHERN CALIFORNIA EDISON COMPANY
Rosemead, California 91770

BY:

FUGRO, INC.
CONSULTING ENGINEERS AND GEOLOGISTS
Long Beach, California

Project No. 77-206-01 and -02

October 15, 1977

REPORT OF GEOLOGIC INVESTIGATIONS, TRAIL SIX (AREA 1) AND HORNO CANYON (AREA 2) LANDSLIDES SOUTHEAST OF SAN ONOFRE NUCLEAR GENERATING STATION

For:

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2244 Walnut Grove Avenue
Rosemead, California 91770

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Project No. 77-206-01 and -02

October 15, 1977

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REPORT OF GEOLOGIC INVESTIGATIONS, TRAIL SIX (AREA 1) AND HORNO CANYON (AREA 2) LANDSLIDES

INTRODUCTION

This report presents results of geologic studies at two coastal areas southeast of the San Onofre Nuclear Generating Station Units 2 and 3 (Figure 1). These areas are informally termed Trail Six Landslide (Area 1) and Horno Canyon Landslide (Area 2), and are 3-1/2 and 5 miles southeast of San Onofre, respectively. At both locations, extensive landsliding has occurred, and the bedrock/marine terrace deposit contact (approximately 120,000 years old) is offset. The principal objective of the geologic studies was to evaluate the extent, nature, and origin of the offsets that disturb the bedrock/marine terrace deposit contact. The geologic studies at Area 1 are not yet completed and are pending completion of an excavation needed to expose a critical relationship of the offsets displacing the bedrock/marine terrace deposit contact and a slip-plane of the landslide. A supplementary Area 1 report will be submitted after the excavation is completed. The studies for Area 2 are complete.

Due to the unique characteristics of geologic conditions at Areas 1 and 2, this report is subdivided into two separate sections. The report of Area 1 is presented in Section I. The report of Area 2 is presented in Section II.

CONCLUSIONS

Area 1

Based on present exposures, results indicate the following general conclusions:

1. The displacements in the bedrock/marine terrace deposit contact in Area 1 occur and are confined within the southern boundary of a large landslide mapped by previous workers and investigated in detail by this study.

2. Continuity of the Quaternary non-marine terrace deposits in the backscarp of the landslide, indicates the offsets do not extend inland beyond the landslide boundaries.

3. The nature of the fractures (i.e. variable displacements within short distances, sinuousity, splaying with depth, and fracture fillings) are typical characteristics associated with the toe of a large landslide.

4. Evidence from this investigation strongly supports that the fractures resulted from landsliding rather than a tectonic origin.

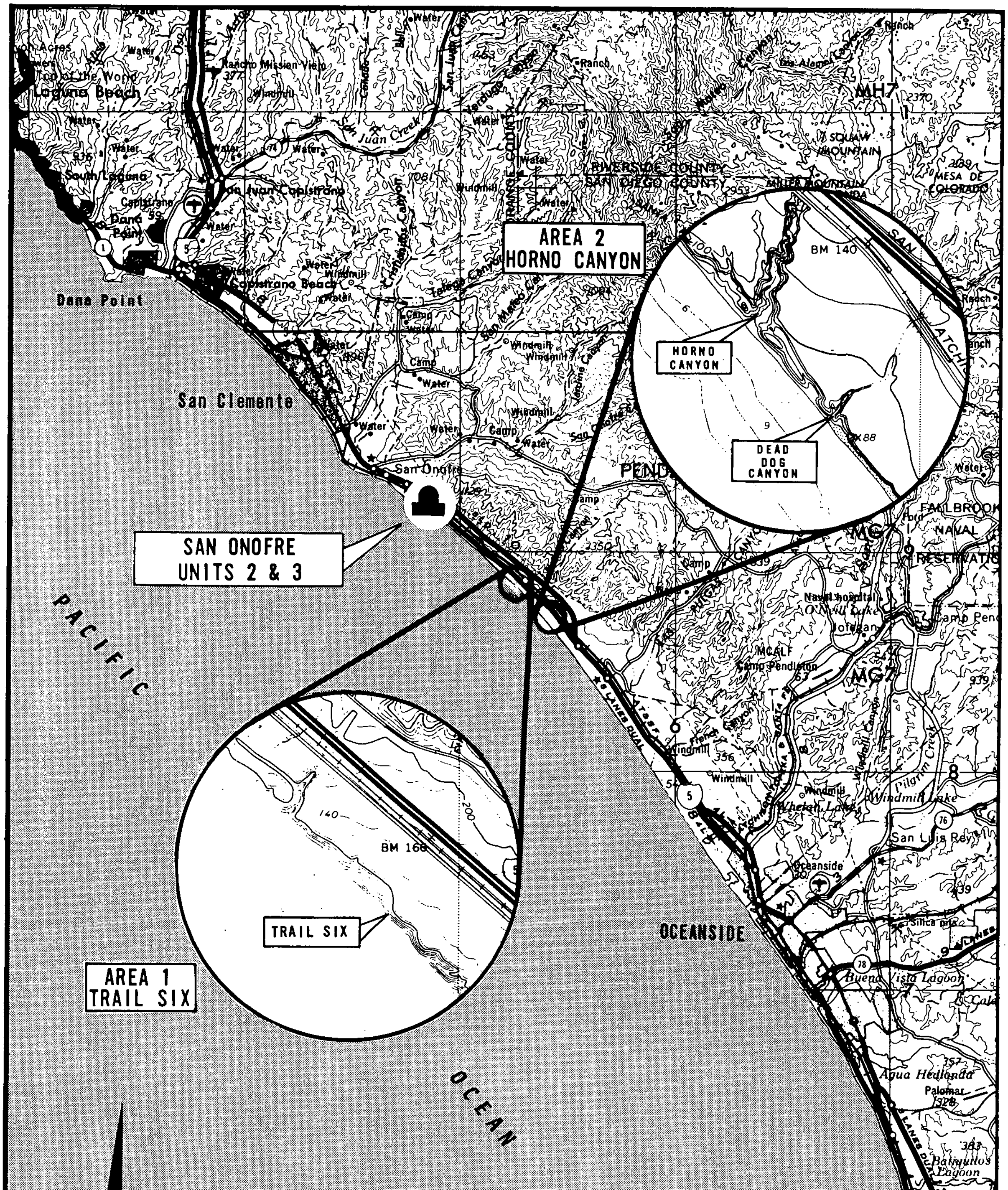
5. These conclusions are based on interpretation of present exposures. An excavation of colluvium is necessary to observe the intersection and relationship of fractures displacing the bedrock/marine terrace deposit contact with the sole of the landslide. A supplemental report presenting the results and conclusions of this excavation will follow after the excavation is completed.

Area 2

1. The subject area has undergone multiple episodes of sliding.

2. The fractures, which make up the boundaries of the graben at the seacliff, are restricted to the slide mass.

3. The graben, which offsets the bedrock/marine terrace deposit contact, was created by mechanisms of landsliding and is not tectonic in origin. Thus, the graben has no significance to seismic design at San Onofre Units 2 and 3.



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S.O. UNITS 2 & 3
AREA 1 & 2

VICINITY MAP

10-77

FIGURE 1

SECTION I

REPORT

OF

GEOLOGIC INVESTIGATIONS, TRAIL SIX LANDSLIDE
(AREA 1)

REPORT OF GEOLOGIC INVESTIGATIONS, TRAIL SIX LANDSLIDE (AREA 1)

INTRODUCTION

The following discussions present the results of geologic studies performed at Trail Six Landslide (Area 1), about 3-1/2 miles southeast of San Onofre Units 2 and 3 (Figure 1). In this area, the bedrock/ marine terrace deposit contact, which is approximately 120,000 years old (FUGRO, 1975), is offset in an exposure located within and near the southern edge of a large landslide mass. The boundaries of this landslide were recognized by earlier investigators and depicted on previous geologic maps of the area (Los Angeles Department of Water and Power, 1971; Moyle, 1973; and Cleveland, 1975). However, the offsets displacing the bedrock/marine terrace deposit contact were not indicated on previous geologic maps. In May, 1977, representatives of the California Energy Resources Conservation and Development Commission (ERCDC) examined the offsets displacing the bedrock/marine terrace deposit contact and questioned whether the offsets were due to tectonic or non-tectonic causes. Since then, the outcrop exposing these features was examined by representatives from the U.S. Nuclear Regulatory Commission (NRC) and the California Division of Mines and Geology, and by consultants to the U.S. Advisory Committee on Reactor Safeguards (ACRS). These representatives requested a geologic investigation be performed to evaluate the origin and safety significance of the observed features to San Onofre Units 2 and 3. As a result, a geologic investigation was performed with the following objectives: 1) identify and document the nature and extent of the disrupted bedrock/marine terrace deposit contact, 2) determine the origin of the displacements, and 3) determine the significance of the offsets relative to the seismic design for San Onofre Units 2 and 3. This investigation is near completion, but final results are pending on an excavation to remove the colluvium presently covering the actual intersection of the offsetting fractures and the sole of the landslide. This excavation has been delayed due to permit approvals. The site is under the responsibility of the California Parks and Recreation Department.

Scope of Study

To satisfy the study objectives, the scope of work included the following:

1. Geologic mapping at scales of 1"=20' and 1"=100' on specially prepared topographic maps (2 feet and 5 feet contour interval).

2. Detailed logging of the offsets and natural exposures of marine and non-marine terrace deposits.

3. Analysis of specially prepared large scale vertical and oblique aerial photographs.

4. Excavation of colluvial material to expose the intersection of the offsets and the sole of the landslide. This work will be performed when appropriate permits are received.

GEOLOGIC SETTING

The site occupies a portion of the southern California coast typified by a broad coastal plain terminating at steep cliffs along the shore. The steepness and height of the cliffs, and the seaward dipping bedrock deposits have resulted in numerous large-scale landslides which have been recognized and documented by a number of investigators (LADWP, 1971; Moyle, 1973; and Cleveland, 1975). Area 1 encompasses a major portion of such a documented landslide (Figure I-1). This geologic investigation has focused on a bedrock outcrop within the landslide boundaries. At this outcrop, the approximately 120,000 year old bedrock/marine terrace deposit contact is offset along several northwest trending fractures. A detailed discussion of these offsetting fractures and the surrounding landslide is presented in a following section of this report.

The oldest mapped bedrock unit in the general area is a sandstone member of the middle Miocene Monterey Formation (Tmss). This material crops out as a window at the southeast edge of a large landslide, and composes the lower 10 to 15 feet of the undisturbed seacliff to the south of the slide (Figure I-1).

The upper limit of the bedrock (Tmss) represents a roughly planar, wave-cut platform upon which marine terrace (Qtm) materials have been deposited. A sequence of non-marine terrace deposits extends from the top of the marine terrace (Qtm) to the present surface of the broad coastal plain about 120 feet above sea level (Figures I-1 and I-2).

LITHOLOGY

Monterey Formation (Tmss)

A sandstone member of the middle Miocene Monterey Formation is the main bedrock unit at Area 1. The unit consists of massive light brown, fine to coarse-grained sandstone with scattered lenses and clasts of green-gray shale. This sandstone member of the Monterey Formation was previously identified (LADWP, 1971) as an undifferentiated sandstone unit underlying the Monterey Formation and as the Pliocene San Mateo Formation (SCE, 1976). Recent analysis indicates that this unit is part of the middle Miocene Monterey Formation (Ehlig, 1977). Therefore, the designation (Tmss) used in this report is based on the most recent data.

Marine Terrace Deposits (Qtm). Quaternary marine terrace deposits typically consist of a basal gravel, 6 to 12 inches thick, overlain by clean, light-brown, thinly laminated, locally crossbedded, fine to coarse-grained sand. Several distinct subunits within these marine deposits can be identified at localized areas, as seen in Figure I-4. Thickness of the marine terrace ranges from a few inches (due to subsequent scour by stream beds) to approximately 20 feet. The basal contact is a very distinct, roughly planar wave-cut platform scoured in bedrock (Tmss). In contrast the contact of the marine terrace deposits with the overlying non-marine terrace deposits (Qtn) is gradational. Similar marine deposits along the California coast (including the San Onofre region) have been age dated.

These dates range from about 70,000 to 130,000 years B.P. but cluster at about 120,000 years B.P. (Fugro, 1975).

Non-marine Terrace Deposits (Qtn)

Non-marine Quaternary alluvial deposits consist primarily of clay , silt, and some sand and gravel. This material is brown to light-brown, massive to crudely-stratified, very stiff to hard, and contains some stringers of carbonate and interbeds of pebbles and cobbles (1/2 to 4 inches in diameter) composed predominantly of blue-gray to gray, and subangular to subrounded glaucophane schist. Thickness of the entire unit is about 70 feet. The non-marine terrace deposits include a basal transition zone of stratified reworked marine sand approximately 5 to 10 feet thick. A weakly developed soil has formed at the present surface of the non-marine terrace. Three subunits within the non-marine terrace deposits were differentiated (Figures I-2, I-3, I-5 and I-6). These units were separated on the basis of color; units Qtn_1 and Qtn_3 are reddish brown with gravel lenses near their top and the intervening layer (Qtn_2) is light brown with a gravel lense near its base.

Landslide Deposits (Qls)

Landslides (Qls) are abundant in the area and occur as either small slumps or as large blocks of material which have moved from a few inches to tens of feet. The deposits are composed primarily of marine (Qtm) and non-marine (Qtn) terrace deposits. Most landslides are of historic age and some are currently active. In order to determine the origin and nature of the fractures at the seacliff, geologic units have been mapped within the major landslide which is discussed in detail in a following section of this report.

Colluvium (Qc)

Deposits of colluvium mantle considerable portions of Area 1 (Figures I-2 and I-3). The deposits are thin (1 to approximately 5 feet), massive to indistinctly stratified, poorly sorted, and are composed of materials derived from nearby slopes.

Alluvium and Beach Sand (Qal, Qb)

Recent alluvium is found in ephemeral stream channels (Figures I-2 and I-3) and occurs as thin deposits of gravel, sand, and silt. Beach deposits (Qb) are present between the seacliff and ocean and are composed of wave-deposited sand and gravel.

Artificial Fill Deposits (af)

Artificial fill materials consist of mixtures of the non-marine terrace deposits which have been placed in conjunction with road building.

LANDSLIDING

The most prominent geomorphic and structural feature within the study area is a massive landslide (about 6 acres) with an estimated volume of over 1 million cubic yards (Figuge I-1). This massive landslide is informally referred to as "old" landslide on Figures I-2 and I-3. The boundaries of the slide are well defined from exposures and distinct morphologic characteristics, except at the extreme southeast margin, which is obscured by thin colluvium on the seacliff.

Geomorphic features resulting from the landslide are well preserved. A large pull-away zone and distinct scarp are present at the head of the slide. Several (at least three) large slide blocks have been downdropped and their surfaces rotated toward the scarp (Figure I-7). A hummocky topography typifies the surface of the disturbed blocks.

In general, the slide blocks within the landslide indicate a rotational sense of movement that hinged about the southeast extremity of the landslide boundary. As seen in Figure I-1, the slide blocks moved a greater distance in the northwest portion of the landslide than in the southeast portion. The surface of the non-marine terrace deposit has dropped about 100 feet (vertically) in the northwest and only about 15 feet (vertically) at the southeast boundary of the slide. The hinged effect may also explain the fact that the bedrock/marine terrace contact varies only inches in elevation between the inplace exposures immediately south of the landslide boundary and the exposure of disrupted bedrock and marine terrace deposits within and adjacent to the southeast boundary of the landslide (Figures I-2 and I-3).

Slide debris has obscured all but two outcrops of bedrock within the area of the slide. One outcrop occurs near the northwest end of the slide (near the head) and consists of a sandstone window dipping seaward at about 25 degrees, overlain by clayey shale. The other outcrop lies along the southeast boundary of the slide, consists of sandstone (Tmss), and possesses the offsets which were the focus of this study. At present, the intersection between the sole of the landslide and the fractures offsetting the bedrock/marine terrace deposit contact at the southeast edge of the slide are covered by colluvium. Excavation of the colluvium is in progress.

CHARACTERISTICS OF FRACTURES DISPLACING THE BEDROCK/MARINE TERRACE DEPOSIT CONTACT

The fractures displacing the bedrock/marine terrace contact were observed within the landslide near its southeast boundary. The fractures were logged at a scale of one inch equals one foot (Figure I-3), at six natural exposures (Figure I-4). From these exposures, the following characteristics were observed.

The offsetting fractures exhibit a high-angle reverse sense of offset. The amount of vertical offset is commonly between 12 and 24 inches, but the maximum and minimum amount of vertical displacement is 33 inches and 4 inches, respectively. The amount of offset at each logged exposure is variable. However, the two exposures with the least amount of offset (Figure I-4; Log 3 and 4) are situated furthest to the southeast; closest to the projected sole of the landslide (Figures I-1 and I-4).

The offsetting fractures are generally planar, with no associated gouge or brecciated materials. However, where two fractures are observed in one exposure, they converge upward and form a complex narrow (2-4 inches) zone that contains slivers of juxtaposed lithologies (Figure I-4; Log "1").

The strike of the fractures offsetting the bedrock/marine terrace deposit contact is commonly between N30°W to N45°W, but ranges from N60°W to N10°W. The dip ranges between 77°S and 98°S.

The traceable length of the offsets is about 80 feet (Figures I-3 and I-6). A northwest projection, along trend of the offsets, intersects the backscarp of the main landslide in the area of Profile A (Figure I-1 and I-5). The bedrock/marine terrace deposit contact is not exposed at the backscarp but a nearly complete section of inplace non-marine terrace deposits is observed. Numerous clay, silt, sand, and gravel lenses within the non-marine terrace deposits overlap with no observed disruption (Figure I-5). This demonstrates the non-marine terrace deposits are not disrupted along trend of the offsets that displace the bedrock/marine terrace deposit contact and indicates the offsets do not extend much beyond their exposed length. In addition, no faults or structures have been mapped or identified in the San Onofre Mountains (about two miles northeast of Area 1) directly along trend of the northwest projection of offsets exposed within the landslide (Ehlig, 1977).

The southeast continuation of the offsets abuts colluvial material. The sole of the surrounding landslide also projects toward and is buried by the same colluvium. It is planned to excavate this colluvium to determine the nature of the underlying intersection of the offsets and the landslide slip-plane. Immediately southeast of the colluvium and outside the projected sole of the landslide, no disruption of the bedrock and marine terrace deposits was observed.

RESULTS OF INVESTIGATION

The evidence suggests that the offsets which displace the bedrock/marine terrace deposit contact terminate toward the southeast at or before they reach the main slip-plane of the landslide and do not continue outside the limits of the landslide. This is based on the following evidence.

1. The fractures were not observed in bedrock or marine terrace deposits exposed immediately southeast (along their projection) of the landslide boundary.

2. The amount of displacement on the observed fractures is highly variable (33 to 4 inches) over a distance of less than 20 feet. The least amount of displacement occurs nearest the projected sole of the landslide.

3. The fractures, where observed, diverge downward suggesting extensional stresses at depth (typical of rotated slump blocks).

4. The average trend of the fractures projects northward toward undisturbed non-marine terrace deposits in the backscarp of the landslide.

5. Movement of the slide was probably rotational and hinged about the southeast extremity of the landslide.

6. The bedrock/marine terrace deposit contact is within inches of the same elevation in adjacent disturbed and non-disturbed exposures at the southeast boundary of the landslide.

CONCLUSIONS

The results of these studies indicate the following conclusions:

1. The displacements in the bedrock/marine terrace deposit contact in Area 1 occur and are confined within the southern boundary of a large landslide mapped by previous workers and investigated in detail by this study.

2. Continuity of the Quaternary non-marine terrace deposits in the backscarp of the slide indicate the offsets do not extend beyond the slide boundaries.

3. The nature of the fractures (i.e., variable displacements within short distances, sinuousity, splaying with depth, and fracture fillings) are typical characteristics associated with the toe of a large landslide.

4. Evidence from this investigation strongly supports that the fractures resulted from landsliding rather than a tectonic origin.

5. These conclusions are based on interpretation of present exposures. An excavation of colluvium is necessary to observe the intersection and relationship of fractures displacing the bedrock/marine terrace deposit contact with the sole of the landslide. A supplemental report presenting the results and conclusions of this excavation will follow after the excavation is completed.

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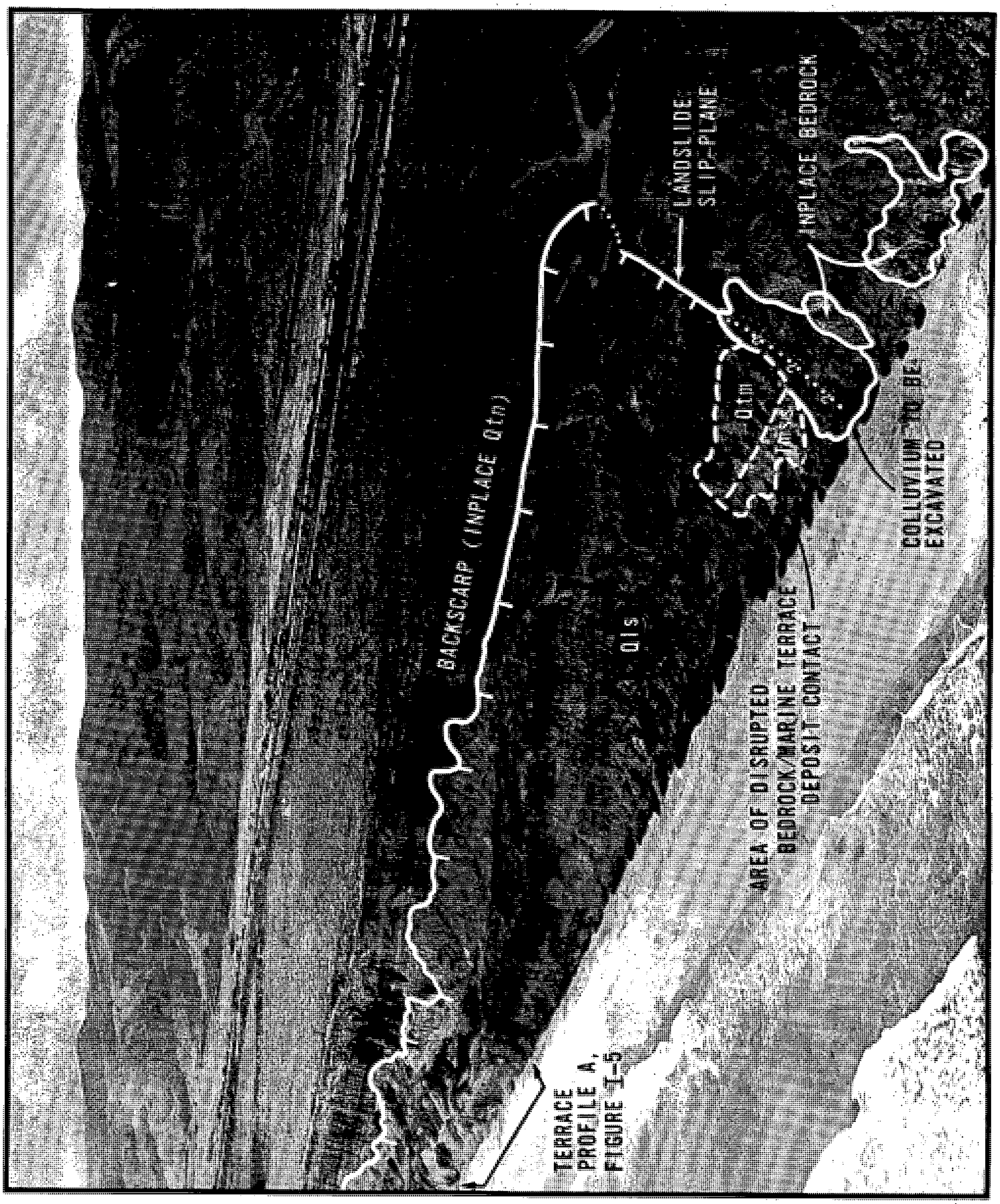

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S.O. UNITS 2 & 3
AREA 1

OBLIQUE VIEW OF TRAIL SIX (AREA 1)

10-77

FIGURE I-1

EXPLANATION

APPROXIMATE

0 100 200 300

FEET

CONTOUR INTERVAL 5 FEET

TOPOGRAPHY BY VTN, BASED ON PHOTOS TAKEN MAY 23, 1977.

ASSUMED MEAN SEA LEVEL

QUATERNARY

- af — ROAD FILL
- Qb — BEACH SAND
- Qal — ALLUVIUM
- Qc — COLLUVIUM
- Qls — HISTORIC TO ACTIVE LANDSLIDE DEPOSITS
- Qtn_3, Qtn_2, Qtn_1 — NON-MARINE TERRACE DEPOSITS
- Qtm — MARINE TERRACE DEPOSITS

TERTIARY

- Tmss — SANDSTONE MEMBER, MIDDLE MIOCENE MONTEREY FORMATION

CONTACT: DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED OR INFERRED.

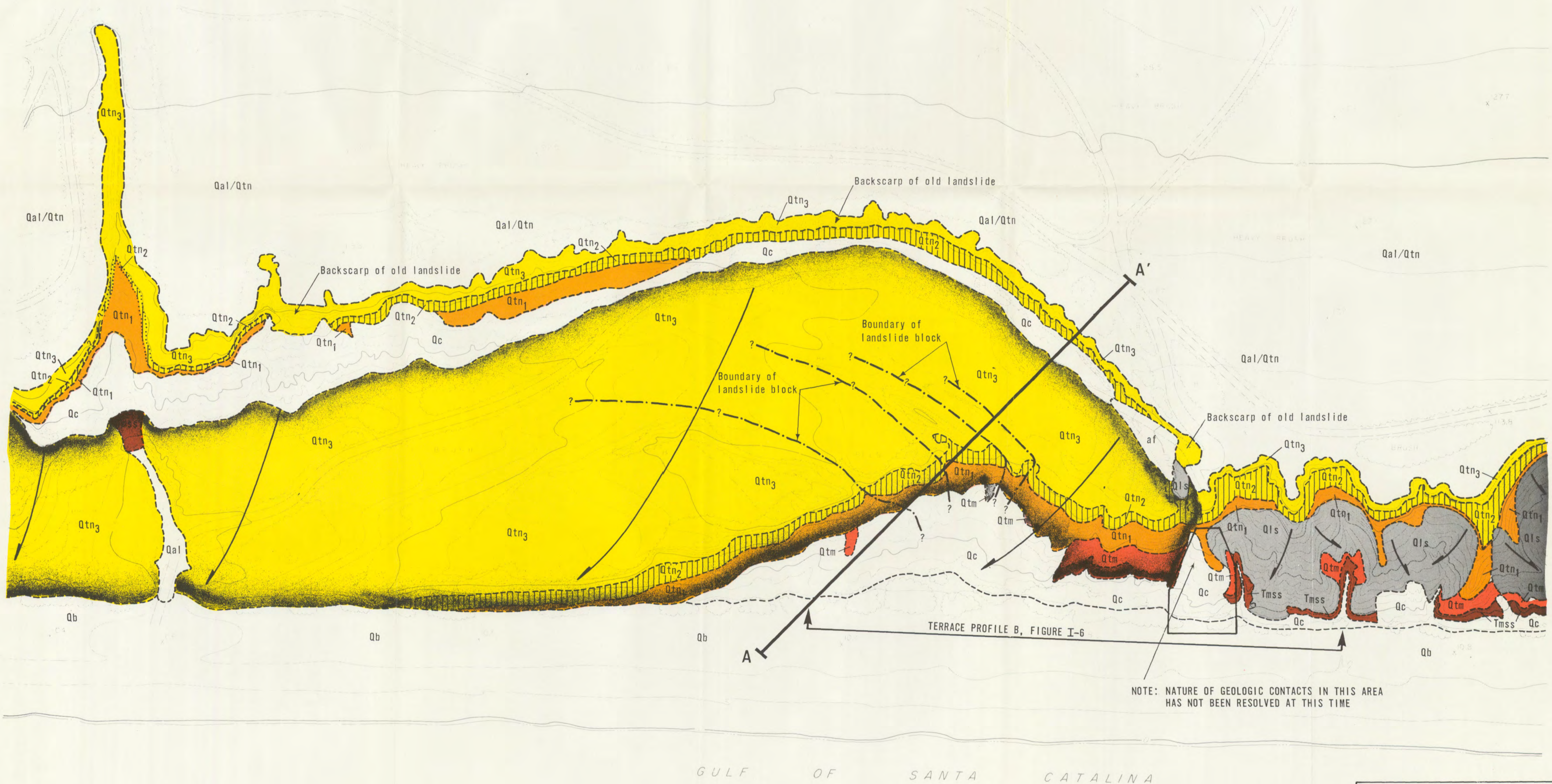
OLD LANDSLIDE DEPOSITS COMPOSED OF Tmss?, Qtm, Qtn_1, Qtn_2, AND Qtn_3

GENERAL DIRECTION OF LANDSLIDE MOVEMENT

A — A′ GEOLOGIC CROSS-SECTION, SEE FIGURE I-7

Qal/Qtn — NON-MARINE TERRACE SURFACE (P. EHLIG, 1977)

NOTE: SEE TEXT FOR DETAILED LITHOLOGIC DESCRIPTION OF GEOLOGIC UNITS



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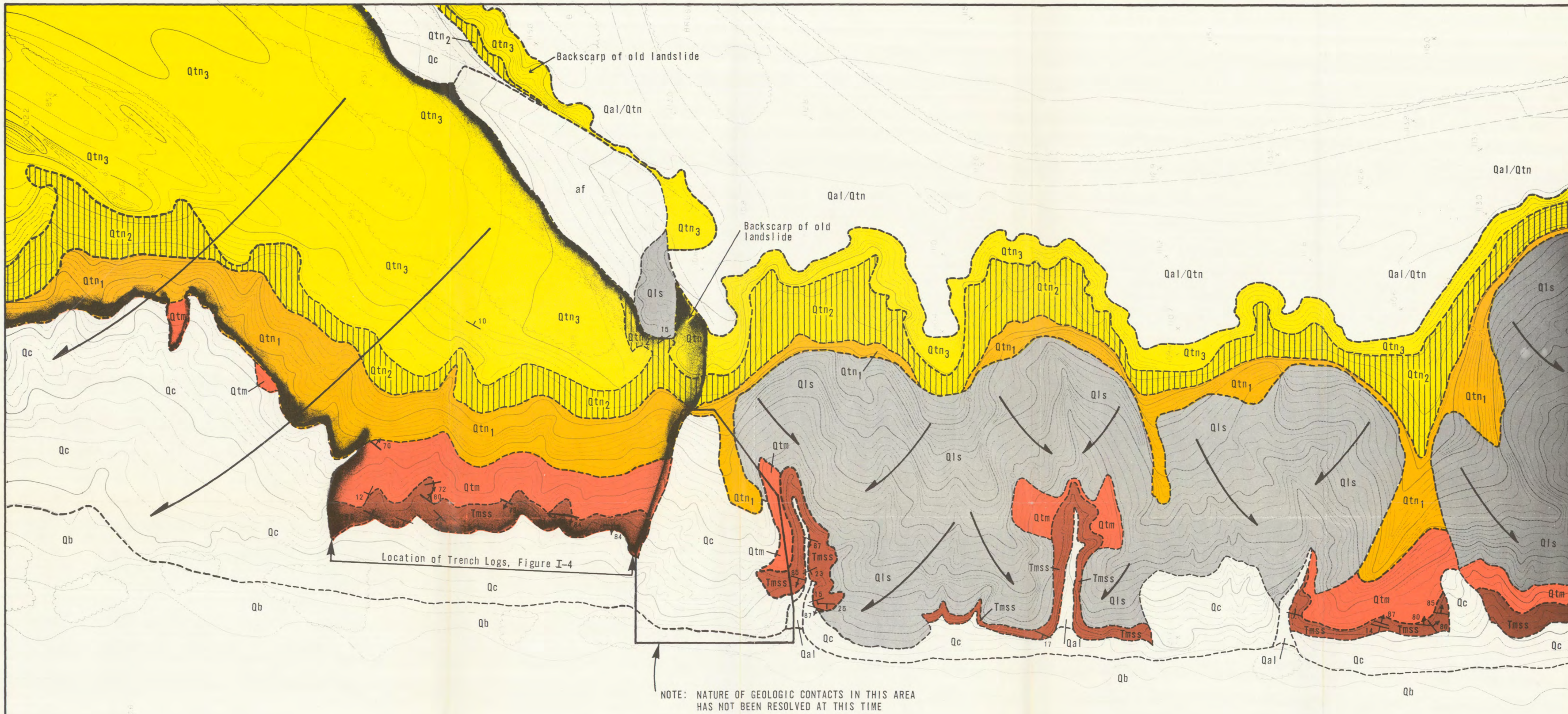
PROJECT NO.: 77-206-01

S.O. UNITS 2 & 3
AREA 1

SMALL-SCALE GEOLOGIC MAP

10-77

FIGURE I-2



EXPLANATION

af	ROAD FILL
Qb	BEACH SAND
Qal	ALLUVIUM
Qc	COLLUVIUM
	HISTORIC TO ACTIVE LANDSLIDE DEPOSITS
Qtn_3, Qtn_2, Qtn_1	NON-MARINE TERRACE DEPOSITS
Qtm	MARINE TERRACE DEPOSITS
	SANDSTONE MEMBER, MIDDLE MIOCENE MONTEREY FORMATION

QUATERNARY (af through Qtm); TERTIARY (sandstone member)

CONTACT: DASHED WHERE APPROXIMATELY LOCATED

OLD LANDSLIDE DEPOSITS COMPOSED OF Tmss?, Qtm, Qtn_1, Qtn_2, AND Qtn_3

GENERAL DIRECTION OF LANDSLIDE MOVEMENT

25 BEDDING PLANE ATTITUDE

84 DISPLACEMENTS WITHIN Tmss AND Qtm, INDICATES VERTICAL DISPLACEMENT

70 DISPLACEMENTS WITHIN Tmss, INDICATES VERTICAL DISPLACEMENT

Qal/Qtn NON-MARINE TERRACE SURFACE (P. EHLIG, 1977)

NOTE: SEE TEXT FOR DETAILED LITHOLOGIC DESCRIPTION OF GEOLOGIC UNITS

APPROXIMATE

0 20 40 60
FEET

CONTOUR INTERVAL 2 FEET
TOPOGRAPHY BY VTN, BASED ON PHOTOS TAKEN MAY 23, 1977.
ASSUMED MEAN SEA LEVEL.

FUGRO — PROJECT NO.: 77-206-01
S.O. UNITS 2 & 3
AREA 1

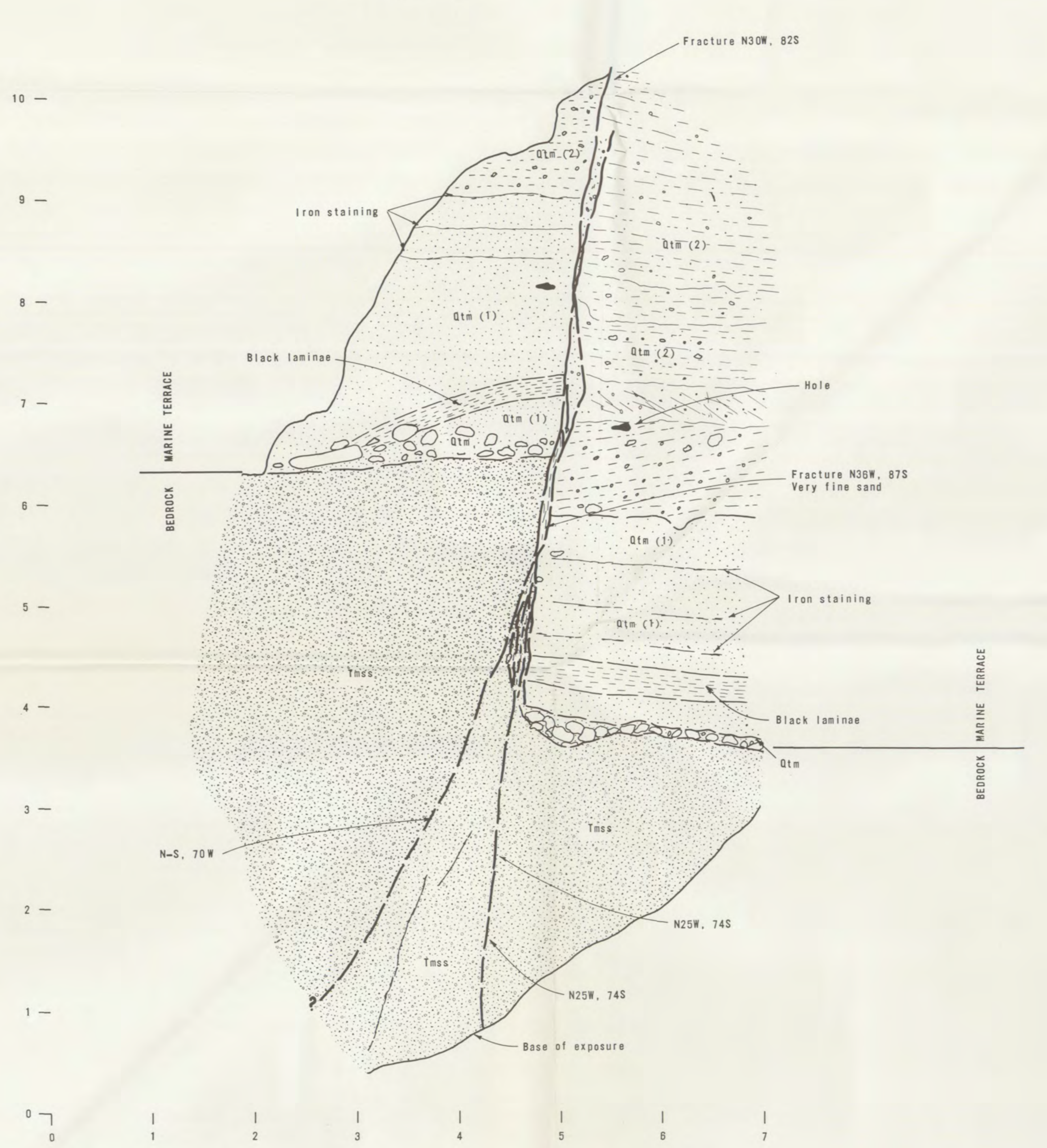
LARGE-SCALE GEOLOGIC MAP

10-77 FIGURE I-3

DETAILED EXPOSURE LOG "1"

LOOKING NORTHWEST

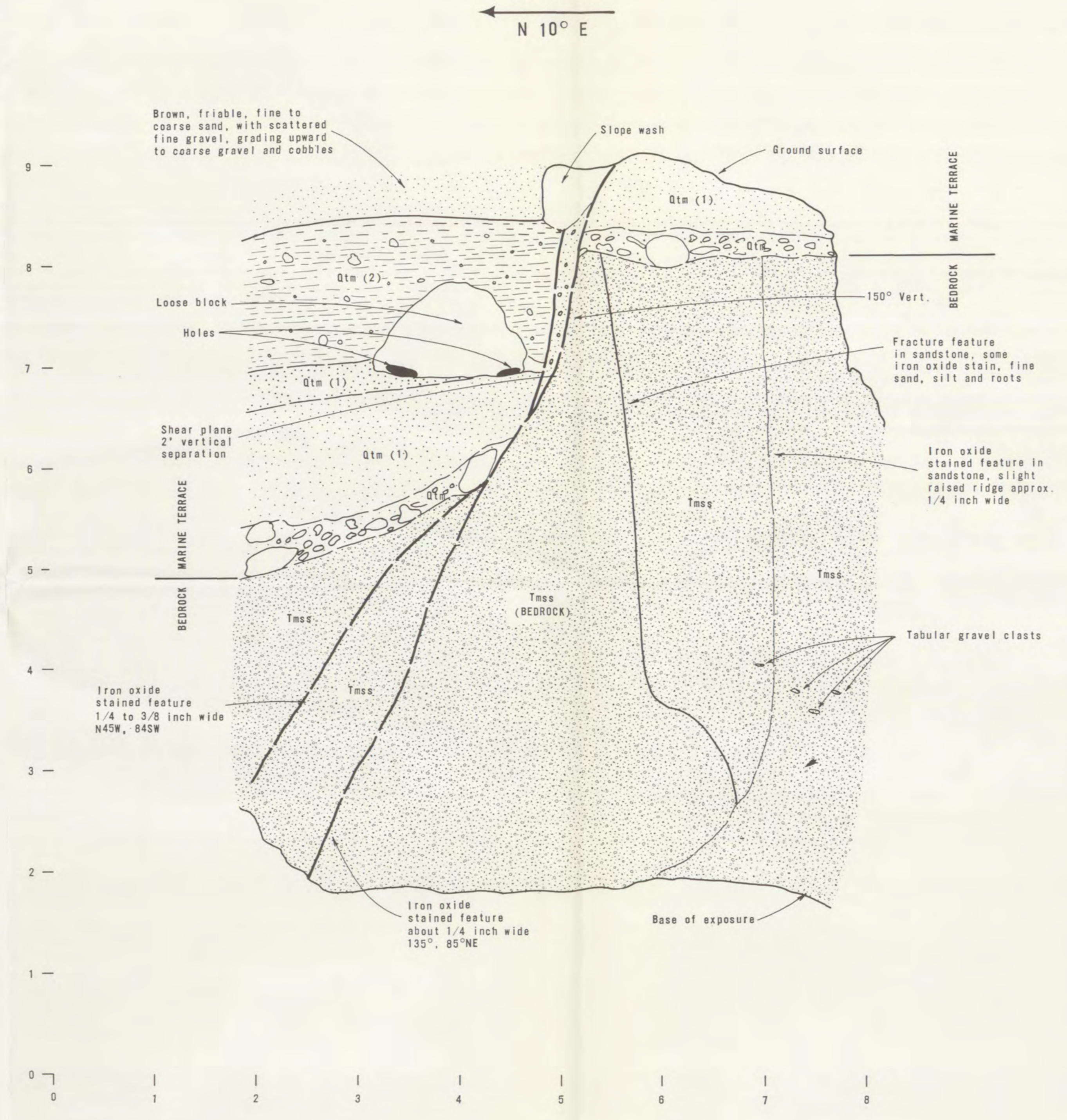
S 65° W



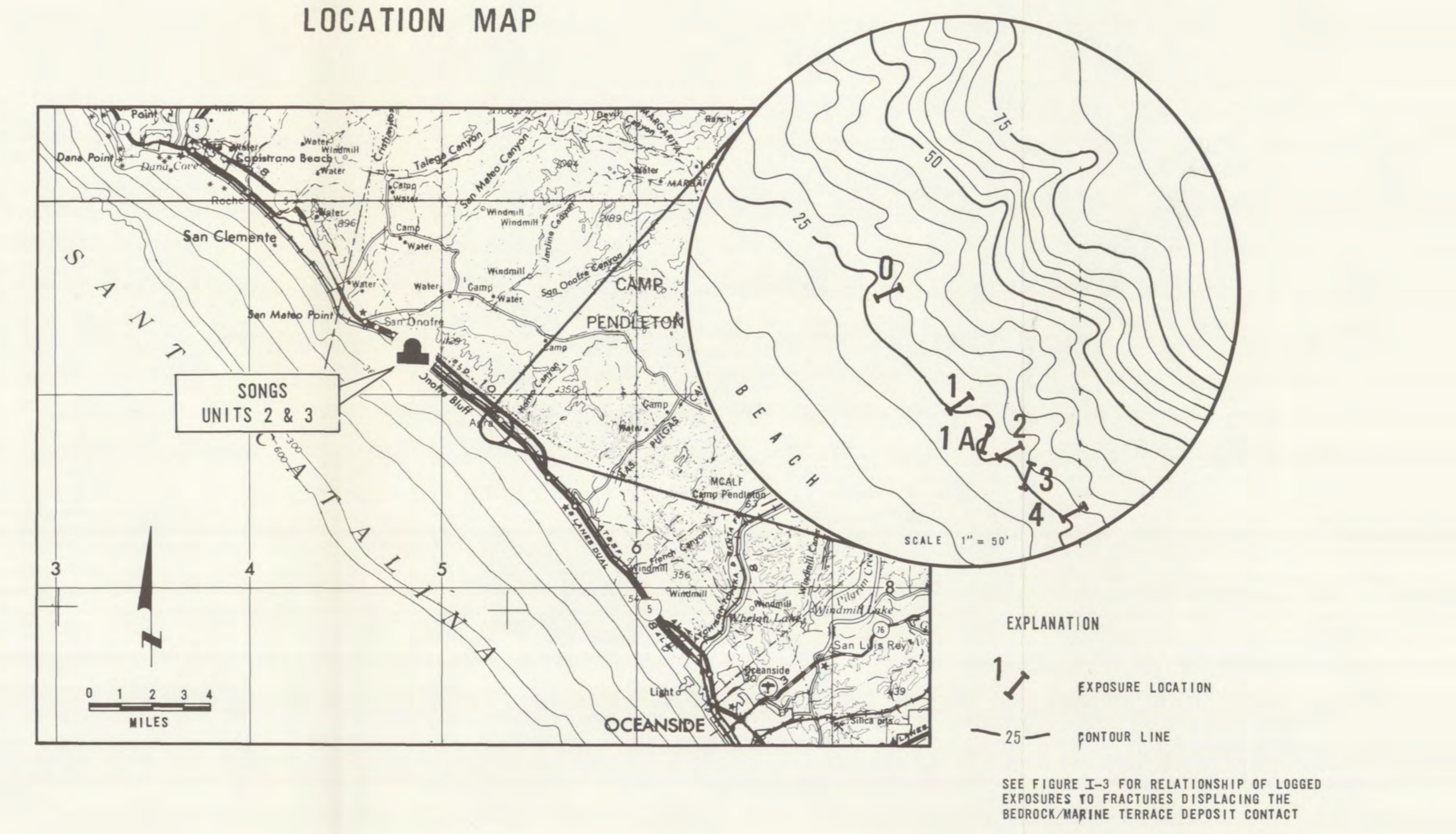
DETAILED EXPOSURE LOG "1A"

LOOKING EAST

N 10° E



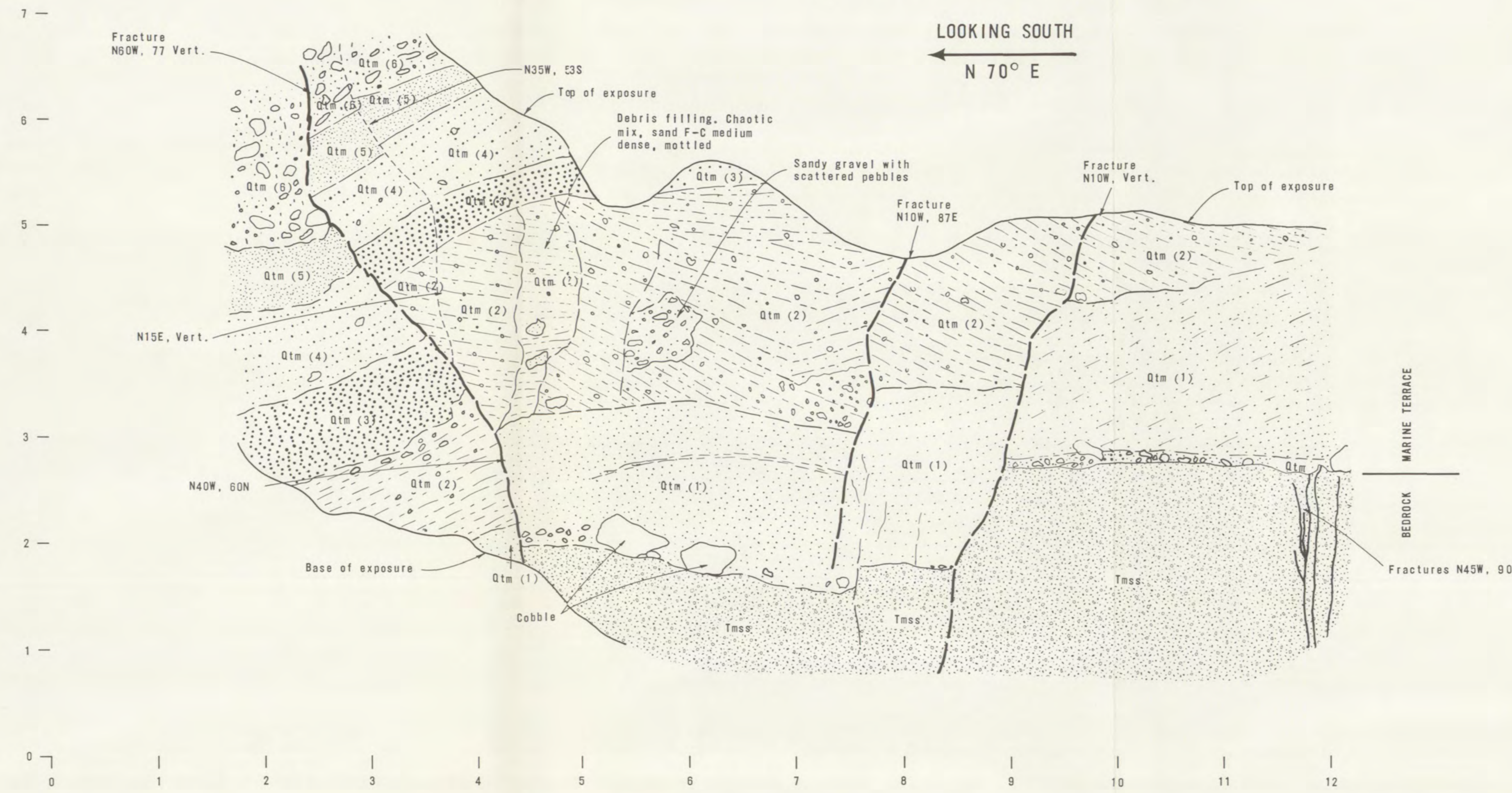
LOCATION MAP



DETAILED EXPOSURE LOG "0"

LOOKING SOUTH

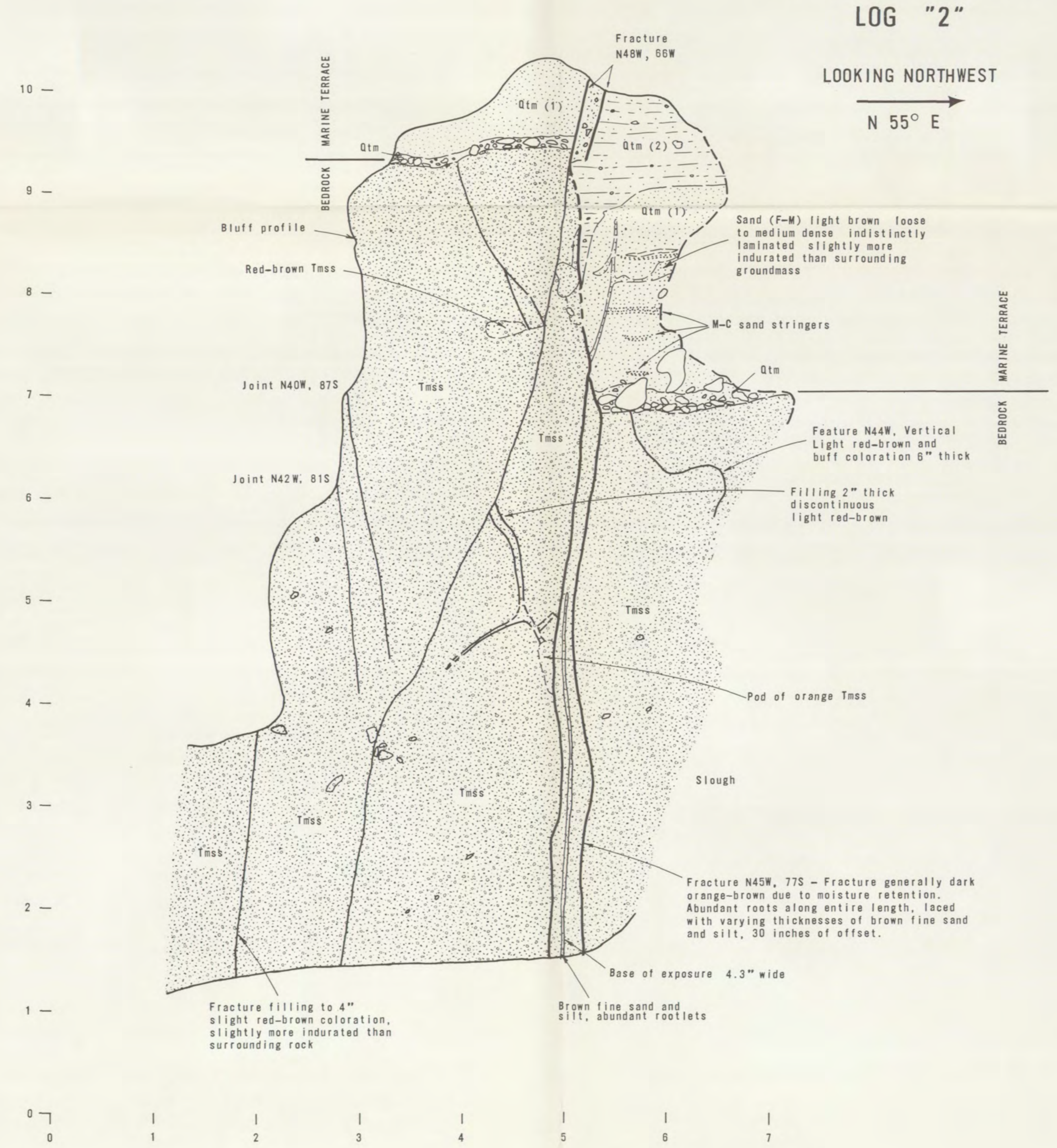
N 70° E



DETAILED EXPOSURE LOG "2"

LOOKING NORTHWEST

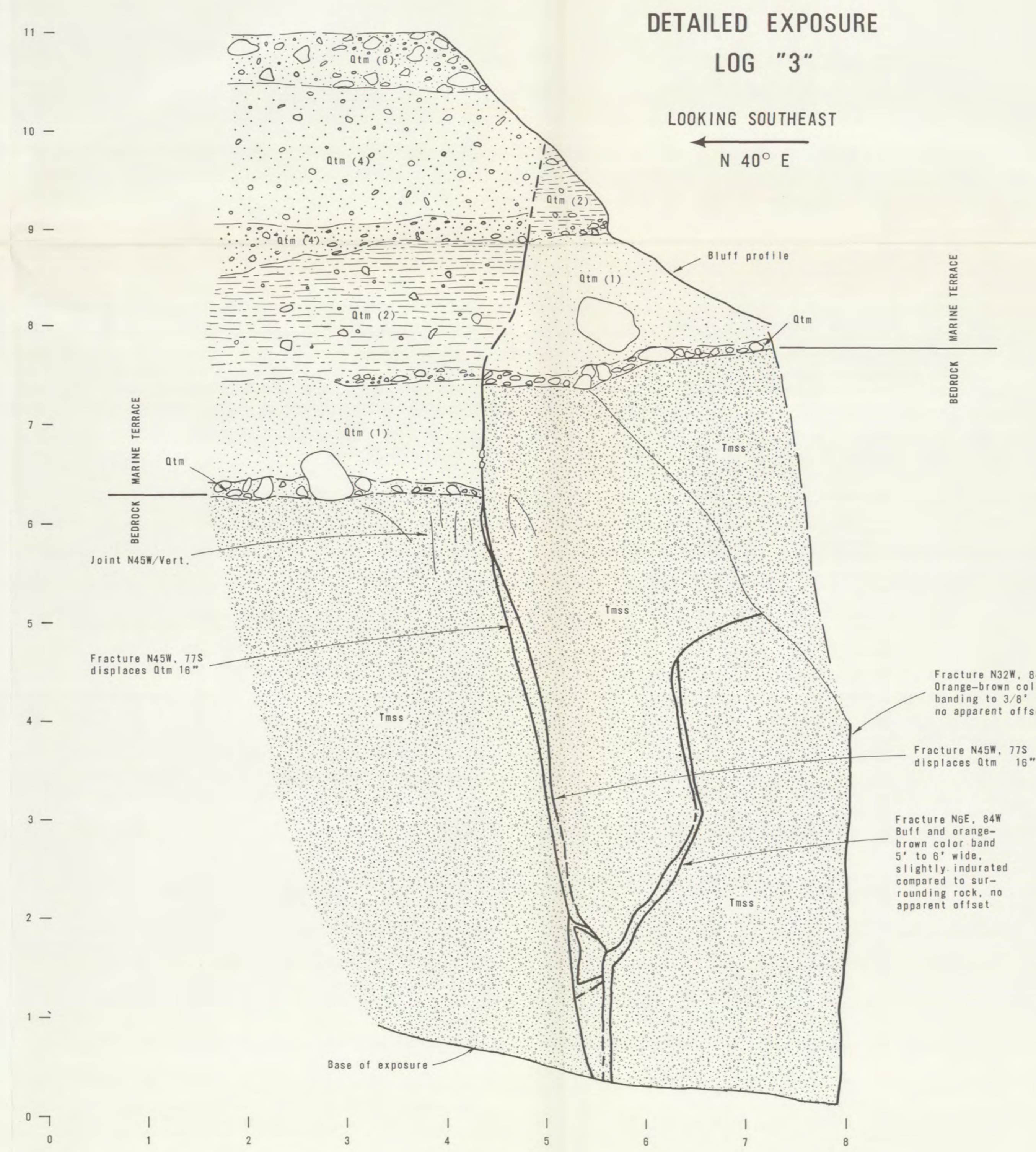
N 55° E



DETAILED EXPOSURE LOG "3"

LOOKING SOUTHEAST

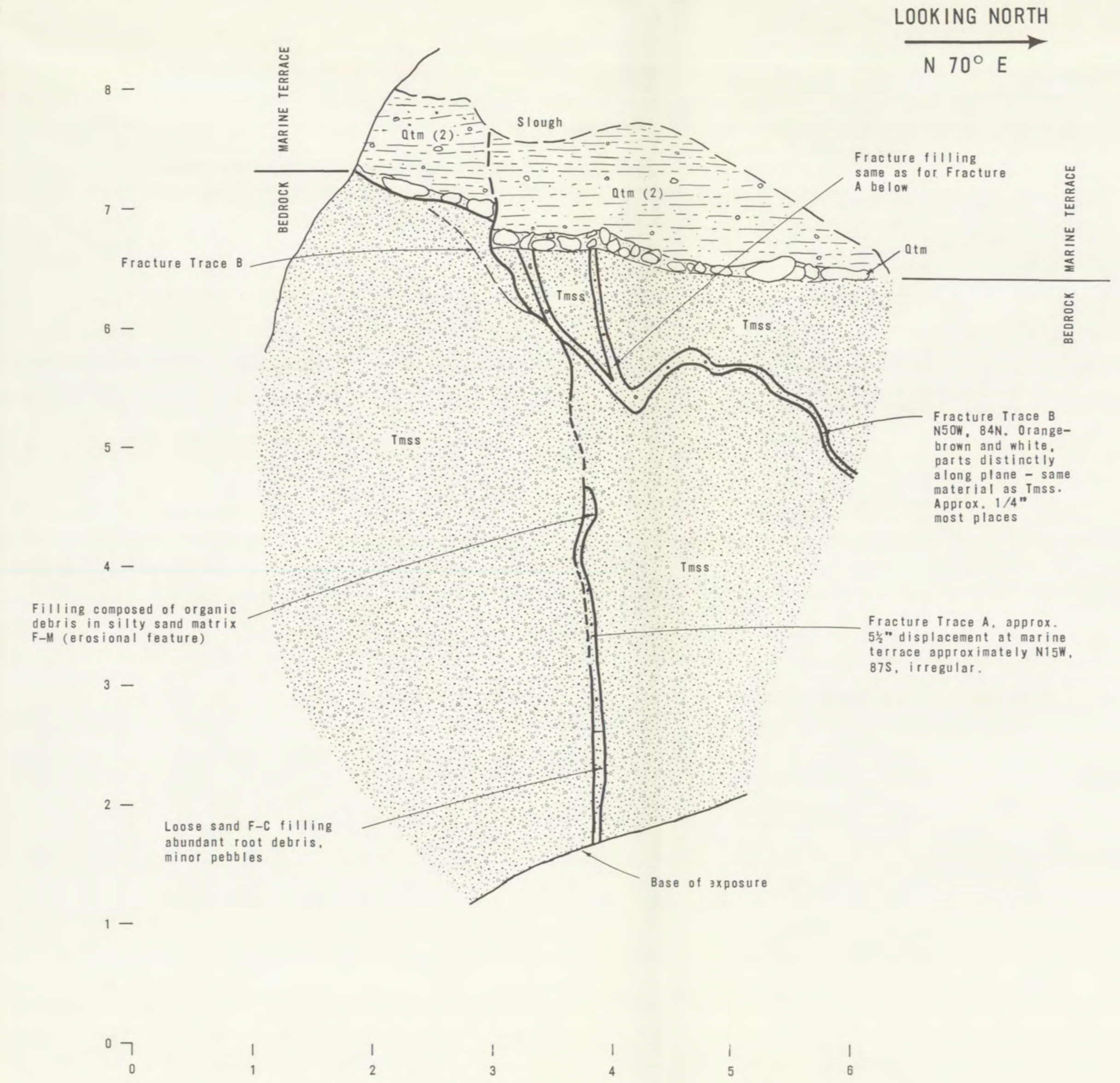
N 40° E



DETAILED EXPOSURE LOG "4"

LOOKING NORTH

N 70° E



Qtm (6) – GRAVELLY SAND AND COBBLES. Light brown, medium dense to dense, crudely stratified.

Qtm (5) – SAND (FINE TO VERY FINE). Light brown to gray, very dense, slightly cemented (Fe?) along scattered bedding planes.

Qtm (4) – SAND (FINE TO COARSE). Light brown to gray, dense to very dense, slightly cemented (Fe?) locally, with scattered pebbles to 1".

Qtm (3) – SAND (MEDIUM). Red-brown, medium dense to dense, thinly cross bedded.

Qtm (2) – SAND (FINE TO MEDIUM). Light brown to red-brown, dense to very dense, dry to slightly moist, thinly laminated, cross bedded, subangular to subrounded with scattered fine gravel.

Qtm (1) – SAND (VERY FINE). Light gray to light brown, very dense, dry to slightly moist, thinly laminated, with local cross bedding.

Qtm – SANDY GRAVEL (MARINE TERRACE BASAL UNIT). Gray, fine to coarse, loose to medium dense, crudely stratified, with scattered cobbles to 8" and boulders to 12".

Tmss – SANDSTONE (FINE TO COARSE). Light brown, moderately weathered, massive to indistinctly bedded, moderately hard, uncemented, friable with scattered pebble lenses. Sand subangular, pebbles subrounded.

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PROJECT NO.: 77-206-01

S.O. UNITS 2 & 3

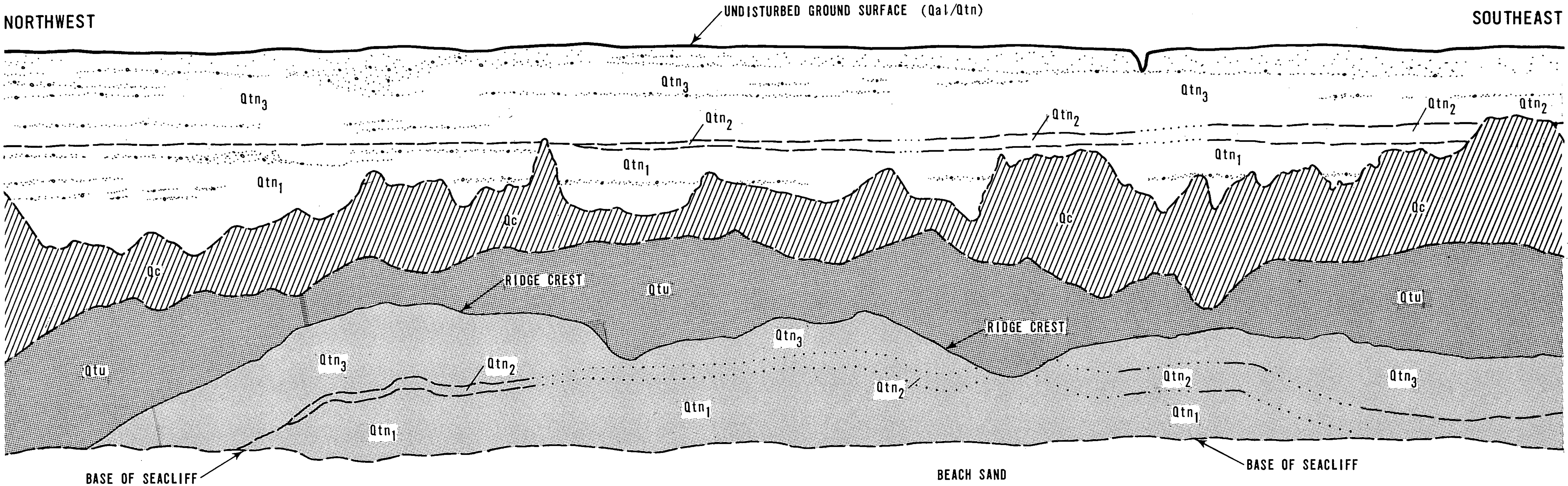
AREA 1

TRENCH LOGS

10-77

FIGURE I-4

TERRACE PROFILE A



EXPLANATION

Qc — COLLUVIUM

Qtu * — UNDIFFERENTIATED TERRACE DEPOSITS IN LANDSLIDE DEBRIS

Qtn3 *, Qtn2 *, Qtn1 * — QUATERNARY NON-MARINE TERRACE DEPOSITS

* NOTE: SHADING REPRESENTS DISTURBED MATERIALS. NON-SHADING REPRESENTS INPLACE DEPOSITS.

SYMBOLS

— — · · · CONTACT: DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE INFERRED

GRAVEL BEDS

0 40 80
FEET
(APPROXIMATE)

NOTE: VIEW TOWARDS NORTHEAST, APPROXIMATELY 3.5 MILES SOUTHEAST FROM SAN ONOFRE POWER PLANT. BASE MODIFIED FROM PHOTOS 431-A-3-77, 431-A-5-77 AND 431-A-6-77, TAKEN BY BRENT BAILEY, MAY 23, 1977.

LOCATION SHOWN ON FIGURE I-1

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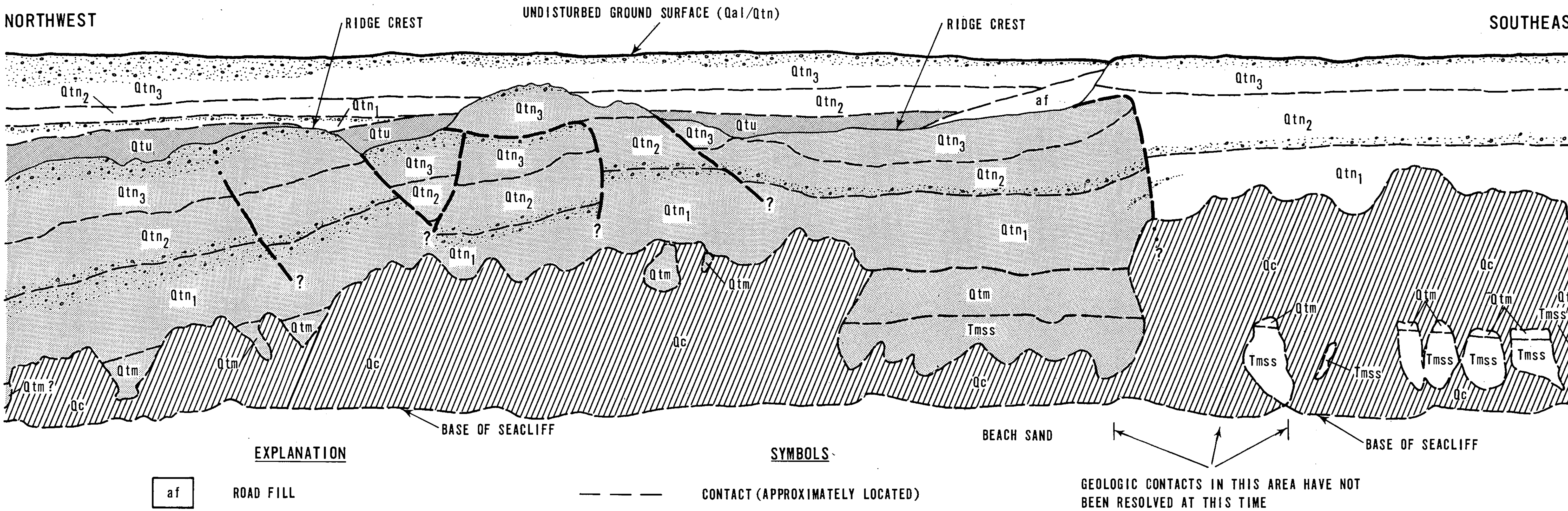
S.O. UNITS 2 & 3
AREA 1

TERRACE PROFILE A

10-77

FIGURE I-5

TERRACE PROFILE B



EXPLANATION

- af — ROAD FILL
- Qc — COLLUVIUM
- Qtu * — UNDIFFERENTIATED TERRACE DEPOSITS IN LANDSLIDE DEBRIS
- Qtn_3 *, Qtn_2 *, Qtn_1 * — QUATERNARY NON-MARINE TERRACE DEPOSITS
- Qtm * — QUATERNARY MARINE TERRACE DEPOSITS
- Tmss * — SANDSTONE MEMBER, MIDDLE MIOCENE MONTEREY FORMATION

NOTE: SHADING REPRESENTS DISTURBED MATERIALS WITH NUMEROUS OFFSETS IN THE Qtm–Tmss CONTACT. NON-SHADING REPRESENTS INPLACE DEPOSITS BEYOND THE LIMIT OF DISTURBED MATERIALS; WHERE Tmss FRACTURES DO NOT OFFSET Qtm.

SYMBOLS

- — — — CONTACT (APPROXIMATELY LOCATED)
- ━ ━ • • FRACTURE IN LANDSLIDE DEBRIS
- GRAVEL BEDS

0 40 80

FEET

(APPROXIMATE)

NOTE: VIEW TOWARDS NORTHEAST, APPROXIMATELY 3.6 MILES SOUTHEAST FROM SAN ONOFRE POWER PLANT. BASE MODIFIED FROM PHOTOS 431-A-10-77, 431-A-11-77, AND 431-A-12-77, TAKEN BY BRENT BAILEY MAY 23, 1977.

LOCATION SHOWN ON FIGURE I-2.

FUGRO

PROJECT NO.: 77-206-01

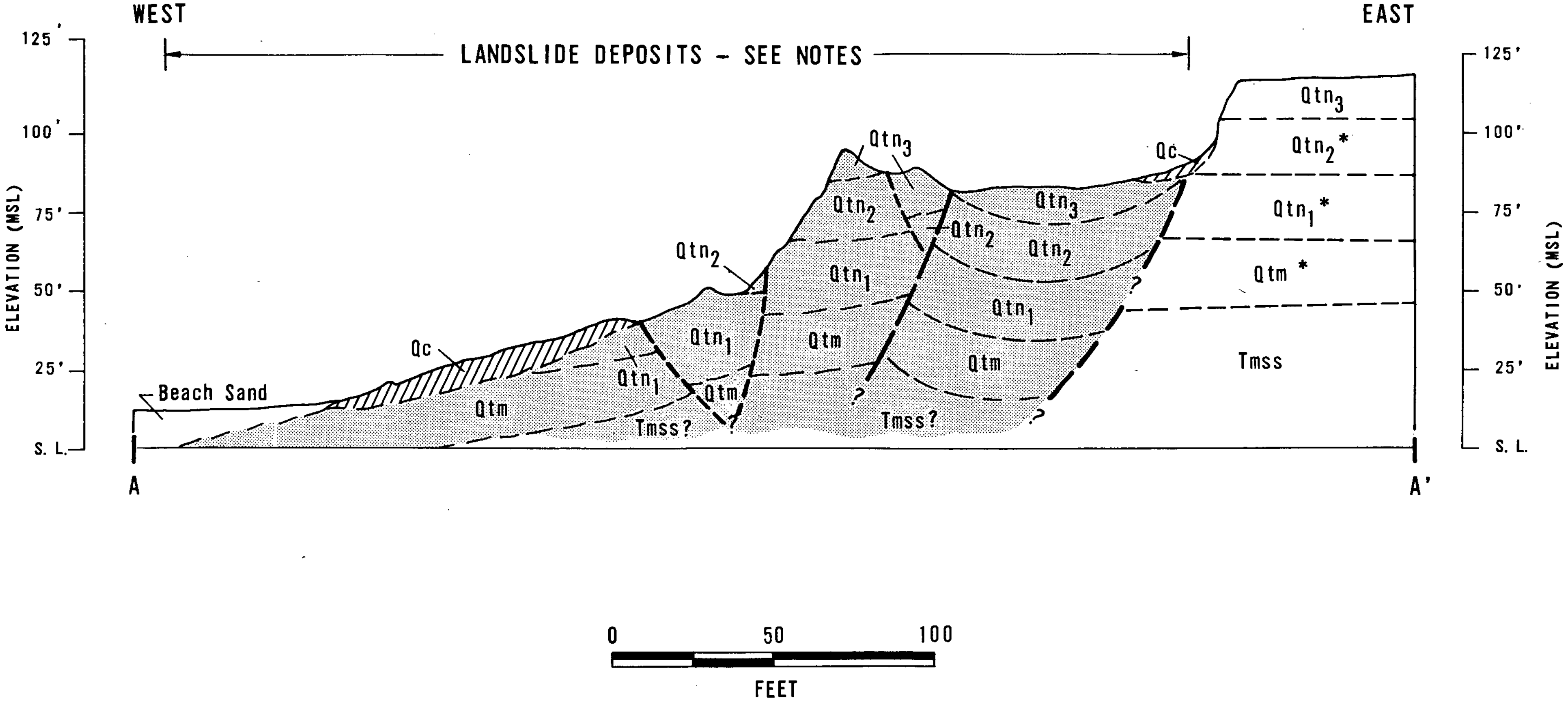
S.O. UNITS 2 & 3
AREA 1

TERRACE PROFILE B

10-77

FIGURE I-6

GEOLOGIC CROSS-SECTION



SEE GEOLOGIC MAP (FIGURE I-2)
FOR LOCATION OF CROSS-SECTION

EXPLANATION

Qc	COLLUVIUM AND SLOPE WASH
Qtn_3, Qtn_2, Qtn_1	QUATERNARY NON-MARINE TERRACE DEPOSITS
Qtm	QUATERNARY MARINE TERRACE DEPOSITS
Tmss	SANDSTONE MEMBER, MONTEREY FORMATION

SYMBOLS

- – – – CONTACT (APPROXIMATELY LOCATED)
- — — FRACTURE IN LANDSLIDE DEBRIS

NOTES

SHADING REPRESENTS DISTURBED MATERIALS.
NON-SHADING REPRESENTS INPLACE DEPOSITS

* THICKNESS BASED ON UNDISTURBED SEACLIFF EXPOSURES

FUGRO | PROJECT NO 77-206-01
S.O. UNITS 2 & 3
AREA 1

GEOLOGIC CROSS-SECTION

10-77 FIGURE I-7

SECTION II

REPORT OF GEOLOGIC INVESTIGATIONS, HORNO CANYON LANDSLIDE (AREA 2)

REPORT OF GEOLOGIC INVESTIGATIONS, HORNO CANYON LANDSLIDE (AREA 2)

INTRODUCTION

This report is the result of geologic studies performed in the vicinity of Horno Canyon on the Camp Pendleton Marine Corps Base approximately 5 miles southeast of San Onofre Nuclear Generating Station (Figure 1). Previous studies (Los Angeles Department of Water and Power, 1971) indicate that the bedrock/marine terrace deposit contact, which is approximately 120,000 years old, is disrupted along the boundaries of a graben about 200 feet southeast of the mouth of Horno Canyon (Figures II-1, II-2, and II-3). The objectives of this study were to:

1. Identify and document the nature and extent of the disrupted bedrock/marine terrace deposit contact.

2. Determine the origin of the disruption.

3. Determine the significance of the disruption relative to the seismic design for San Onofre.

Scope of Study

To satisfy the study objectives, the scope of work included the following:

1. Geologic mapping at scales of 1"=100' and 1"=20' on specially prepared topographic maps (5 feet and 2 feet contour interval).

2. Detailed logging of natural exposures of marine and non-marine terrace deposits.

3. Analysis of vertical aerial photographs.

Summary of Results

1. Landsliding within and near Horno Canyon has occurred in multiple episodes since deposition of the bedrock (Tmsh).

2. No fractures displaying offset were observed on the backscarp of the "old" landslide.

3. Fractures at the graben displace bedrock, marine, and non-marine terrace deposits.

4. The fractures which display offset at the graben have an orientation dissimilar from the prevailing structural trend.

5. The graben feature identified in the LADWP (1971) report is due to landsliding and has no significance to the seismic design of San Onofre Units 2 and 3.

GEOLOGIC SETTING

The southern California coastal region, within the general study area, is typified by a gently sloping coastal plain which terminates abruptly at the beach in a precipitous sea-cliff. At the seacliff the terrace surface is at about elevation 100 feet and slopes gently upward toward the northeast to approximately elevation 200 feet, where it merges with the rolling foothills of the San Onofre Mountains. Numerous less well preserved terraces are evident on the seaward flank of the San Onofre Mountains and have been mapped to an elevation in excess of 1200 feet (Ehlig, 1977). Drainage across the broad coastal plain is predominantly by sheetflow and through small gullies, although a few, deeply incised, southwest-trending streams (e.g., Horno Canyon and "Dead Dog Canyon," Figure 1) are present.

Bedrock exposures are present in the incised canyons and along the seacliff, although several landslides along the beach have locally obscured the underlying undisturbed rock for thousands of feet. A detailed discussion of landsliding at Horno Canyon is presented in subsequent sections of this report.

The oldest mapped bedrock unit in the general area is the Miocene, San Onofre Formation, a breccia. This formation is not exposed in the specific area of Horno Canyon. A shaly member of the Miocene Monterey Formation (Tmsh), which unconformably overlies the San Onofre Formation, is the predominant bedrock type in Horno Canyon.

Within Horno Canyon, 200 to 300 feet inland from the present beach, a section of Monterey shale (Tmsh) about 10 to 15 feet in thickness is exposed along the southeast canyon wall (Figures II-1 and II-2). The upper limit of the bedrock (Tmsh) represents a nearly planar, wave-cut platform upon which marine terrace (Qtm) and localized river terrace (Qtr) materials have been deposited. A sequence of non-marine deposits (Qtn) extends from the top of the marine terrace (Qtm) to the present surface of the broad coastal plain about 100 feet above sea level.

Lithology

Monterey Formation (Tmsh). A shaly member of the middle Miocene Monterey Formation (Ehlig, 1977) is the predominant rock type exposed in and adjacent to Horno Canyon at the beach. At this location it consists of green-gray, laminated to thinly-bedded, soft to moderately hard, shale and massive siltstone with some massive sandstone.

Marine Terrace Deposits (Qtm). The Quaternary marine terrace deposits consist of a basal gravel about 6 to 12 inches thick, typically overlain by clean, light brown, thinly laminated, locally cross-bedded, fine to coarse-grained, dense to very dense sand. Thickness of this unit ranges from a few inches (due to scour in the ancestral Horno Canyon channel) to approximately 20 feet. Age dates on similar deposits along the California coast (including the San Onofre region), range from about 70,000 to 130,000 years B.P. (Fugro, 1975).

Non-Marine Terrace Deposits (Qtn). Quaternary non-marine terrace deposits in the Horno Canyon area consist primarily of clay and silt with small amounts of sand and some gravel. The contact of the marine terrace deposits with these overlying non-marine terrace deposits (Qtn) is gradational, and consists of 5 to 10 feet of reworked marine sand, cemented by clay and small amounts of carbonate. The non-marine materials are brown to light-brown, massive to crudely-stratified, and very stiff to hard, with some stringers of carbonate. Interbedded with these deposits (Figure II-4) are scattered beds or lenses of gravel and cobbles (1/2 to 4 inches in diameter) predominantly composed of metamorphic clasts which are blue-gray to gray, and subangular to subrounded. Thickness of the entire unit is about 50 feet. A weakly developed soil approximately 5 feet thick has formed at the present day surface of the non-marine terrace deposit.

River Terrace Deposits (Qtr). Deposits of well-sorted to well-graded gravel, sand, silt and clay occur in Horno Canyon (Figures II-1 and II-2). These fluvial terrace materials, of probable late Quaternary to Holocene age, are up to 10 feet thick and lie about 10 to 20 feet above the existing stream bed. These deposits display a very weakly developed surface soil approximately 6 to 12 inches thick.

Landslide Deposits (Qls). Historic to active landslides are numerous in the Horno Canyon area (Figures II-1 and II-2) and occur as either small slumps or as large blocks of material which have moved from a few inches to many feet. The deposits are composed of chaotic blocks of shale and siltstone (Tmsh) and overlying marine (Qtm) and non-marine (Qtn) terrace deposits. Older inactive episodes of landsliding have occurred in the Horno Canyon area and are discussed in later sections of this report.

To determine the origin and nature of the graben at the sea-cliff, geologic units have been mapped within the old landslides and are also discussed in detail in a following section of this report.

Colluvium (Qc). Deposits of colluvium mantle considerable portions of the Horno Canyon area (Figures II-1 and II-2). These deposits are thin (1 to approximately 5 feet), massive to indistinctly stratified, poorly sorted, and composed of non-marine terrace material derived from nearby slopes.

Alluvium and Beach Sand (Qal, Qb). Recent alluvium, occurring as thin deposits of gravel, sand, and silt, is found in the ephemeral stream channel of Horno Canyon (Figures II-1 and II-2). Beach deposits (Qb) are present between the seacliff and the ocean and are composed of wave deposited sand and gravel.

STRUCTURE

Bedding

Quaternary deposits in the study area are underlain by a series of bedrock units (sandstones and shales), which generally dip seaward at less than 25 degrees (Figure II-2; and LADWP, 1971). Massive landslides along the coastline have obscured much of the bedrock structure, leaving only a few in-place bedrock outcrops at the bottom of deeply incised canyons, the seacliffs, and in the tidal zone. An ancient bedrock landslide has involved much of the exposed bedrock in Horno Canyon.

Faulting

The dominant observed and inferred faults and zones of deformation near the San Onofre site strike north to northwest (SCE, 1976). No features related to tectonic faulting were observed at Horno Canyon. Fractures which offset the Tmsh/Qtm contact and form a graben, were observed in a slide mass about 200 feet southeast of the mouth of Horno Canyon (Figures II-1, II-2, and II-3). A detailed discussion of the graben is presented in a subsequent section of this report.

HISTORY OF LANDSLIDING AND GRABEN ORIGIN

The subject area has been the site of considerable landsliding of varying magnitude. At least three episodes of landsliding can be identified; the two oldest events being of the greatest extent. The three episodes are herein defined as follows (from the oldest to youngest):

- o Ancient bedrock sliding prior to development of the wave-cut platform.
- o Old landsliding that occurred after deposition of the marine and non-marine deposits.
- o Historic to active sliding and slumping along the seacliff.

Ancient Bedrock Landslide

The sole of the ancient bedrock slide is exposed in Horno Canyon about 400 feet inland of the strand line (Figure II-1 and II-2). The total areal extent of the ancient bedrock slide is unknown. All exposed bedrock seaward of a line striking about N50^{O}W at the sole of the ancient bedrock slide (Plate II-1) has been disturbed for a distance of at least 300 feet northwest and 1200 feet southeast of Horno Canyon. Most of this ancient slide appears to have been removed during formation of the wave-cut platform, which extends across the backscarp of the ancient bedrock slide. Both the platform and the overlying marine terrace (Qtm) deposits are uninterrupted at the backscarp. Thus, the ancient bedrock slide is older than about 120,000 years B.P. (the approximate age for marine terrace deposits.)

The following factors probably contributed to the ancient bedrock landsliding.

1. Lithology (highly fractured shale overlying massive siltstone and sandstone).

2. Structural orientation (strike of bedding parallel to seacoast with shallow seaward dips).

3. Undercutting of the seacliff due to wave action during lower seal level.

4. High pore water pressures.

Bedrock within the ancient slide mass is composed predominantly of thinly bedded, very fractured shale. The underlying undisturbed bedrock consists predominantly of massive siltstone and sandstone.

Bedrock bedding plane attitudes indicate a gentle seaward dip.

PLATE II-1 SOLE OF ANCIENT LANOSLIDE

With undercutting of the shaly bedrock unit (Tmsh) by wave erosion, these beds were probably exposed near the toe of the cliff, thereby reducing the stability of the overlying deposits and ultimately resulting in failure along bedding planes.

In the sole of the ancient bedrock slide, the presence of unfractured pods (boudins?) of siltstone (Plate II-1), which have apparently been plucked from the underlying in-place bedrock and thinned in a direction generally parallel to the base of the slide (5 to 10 degrees from horizontal), suggests that soft sediment deformation occurred in a highly plastic condition. In addition, bedrock materials, exposed seaward (down dip in landslide debris) of the head of the slide, display numerous open fractures as well as colluvium-filled fractures, while in-place rock (behind the head of the landslide) is massive and relatively unfractured.

Subsequent to the ancient bedrock landslide, a wave-cut platform developed across the surface of the landslide as well as inland on in-place bedrock. Marine sediments consisting of well-stratified sands and gravels with scattered cobbles were deposited on the wave-cut bedrock bench. A sequence of non-marine materials was subsequently deposited to the present elevation of about 100 feet.

Old Landsliding

Another episode of landsliding (shaded area on Figures II-1 and II-2) occurred after deposition of the non-marine continental deposits. This landslide involves an area of about 6 acres with an estimated volume of over 1 million cubic yards, and is largely responsible for the topography as it is today. The boundaries of the landslide are well defined (Figure II-1) with the exception of the northwest flank at Horno Canyon where river terrace deposits (Qtr) overlie the contact. The geomorphic features produced by this slide are still well preserved. A large pull-away zone (Plate II-2) exists at the head of the landslide; the block itself has been rotated toward the backscarp and downdropped about 9 to 12 feet. The original terrace surface of the disturbed block is hummocky and irregular (Figure II-5).

This episode of landsliding was probably initiated in response to the three factors previously mentioned (i.e., lithology, structure and wave erosion) as well as the surcharge generated by the overlying 70 to 80 feet of terrace material. The back scarp of this old landslide is seaward of the head of the ancient bedrock slide (Figures II-1, and II-2) which suggests possible reactivation within the ancient bedrock slide mass.

Following this episode of landsliding, the stream in Horno Canyon deposited materials now preserved as river terraces flanking the canyon and overlying the bedrock bench and marine terrace deposits.

<u>Historic to Active Sliding</u>

The present seacliff has about 90 to 100 feet of near-vertical relief. Consequently, mass wasting through landsliding and slumping, is currently in progress and has been throughout

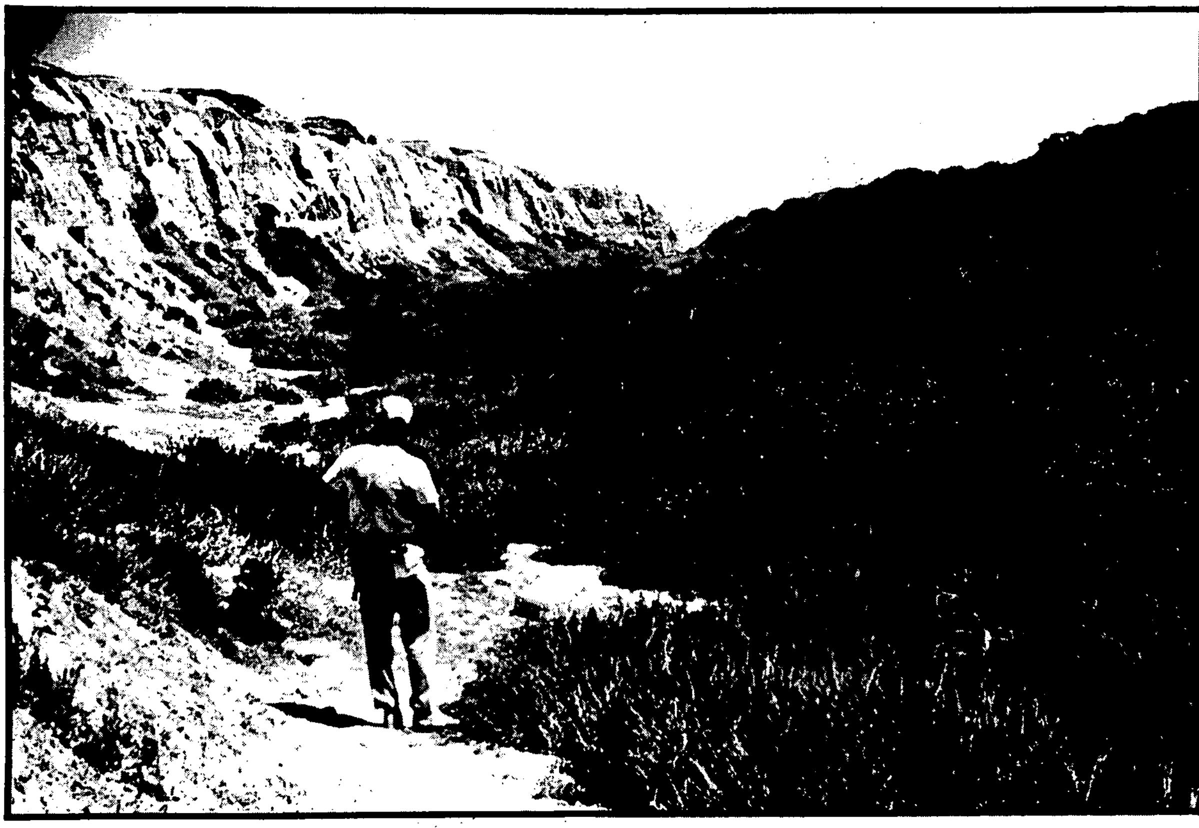


PLATE II-2 LOOKING SOUTH ALONG PULL-AWAY ZONE AND BACKSCARP OF OLD LANDSLIDE historic time. The size of the most recent slumps and landslides in the study area is on the order of tens to hundreds of cubic yards, as compared to the ancient and old landslides which are in excess of one million cubic yards.

Graben Description

The graben (as shown on Figure II-3) is exposed with the old landslide mass and is downdropped on the order of 3 feet. The graben offsets the bedrock/marine terrace deposit (Tmsh/Qtm) contact, and strata within the non-marine terrace deposits (Qtn). Both sides of the graben are bounded by fractures; one offsets non-marine (Qtn) materials (Figure II-3), the other was exposed to within about 3 feet of the base of the non-marine (Qtn) terrace deposits, where it was concealed by slump block. Attitudes on the fracture surfaces ranged from N80E, 86N to N72W, 86N.

The amount of offset and orientation varied along the fractures. Maximum displacement (about 30 inches) was observed on the northwest margin of the graben at the Qtm/Tmsh contact. Minimal displacement was noted on the southeast margin of the graben where the fracture penetrated Qtn deposits (Figure II-3).

The backscarp of the old landslide exposes interbedded lenses of clays, sands, and gravels of non-marine terrace deposits. These strata were continuous across the area where a projection of the graben fractures would be expected (Figure II-4). No disruption of the non-marine terrace deposits was observed.

Relationship of Graben to Area Structure

As shown in Figure II-2, the Qtm/Tmsh contact is at about elevation 23 feet immediately south of Horno Canyon. About 200 feet further to the southeast the contact elevation drops to elevation 20½ feet. At the graben, the contact drops to 17½ feet then rises to 19½ at the southeast edge of the graben. The contact elevation continues to drop slightly to elevation 16½ feet, approximately 1200 feet southeast of the graben where the contact is obscured by colluvium and slide debris. These irregular changes in elevation of the contact occur beyond the limits of the graben and are indicative of the type of adjustments that would be anticipated as a result of block adjustments within a large slide mass (Figure II-5). Attitudes on the graben fractures are nearly normal to the predominant structural trend of regional faulting and are internally inconsistent along the same fracture. This suggests they are not related to a through-going, consistent, linear feature, but rather are confined solely to the slide mass.

CONCLUSIONS

Based on the results of this study, the following conclusions are made:

1. The subject area has undergone multiple episodes of sliding.

2. The fractures which make up the boundaries of the graben at the seacliff are restricted to the slide mass.

3. The graben was created by mechanisms of landsliding and is not tectonic in origin. Thus, the graben has no significance to seismic design at San Onofre Units 2 and 3.

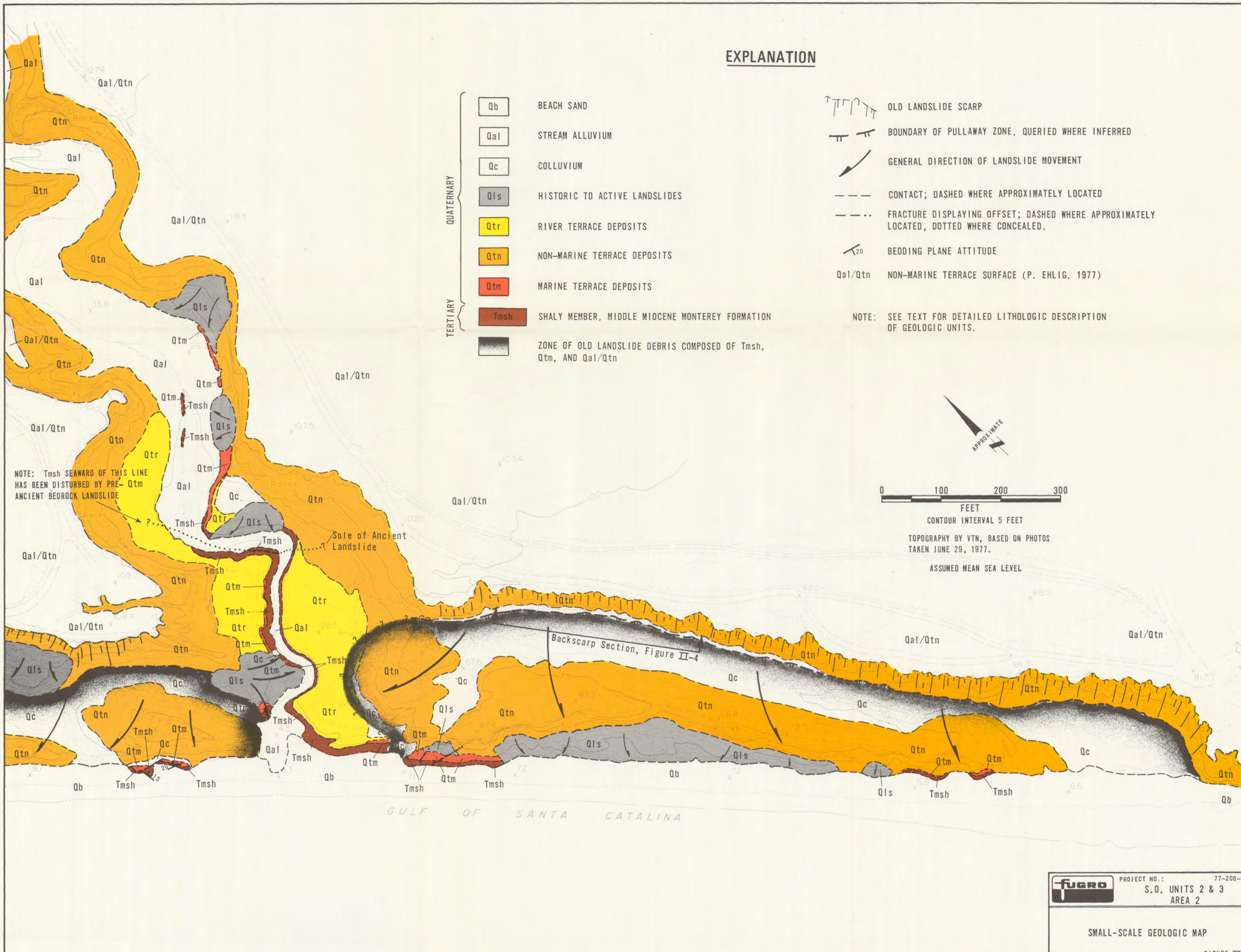
REFERENCES

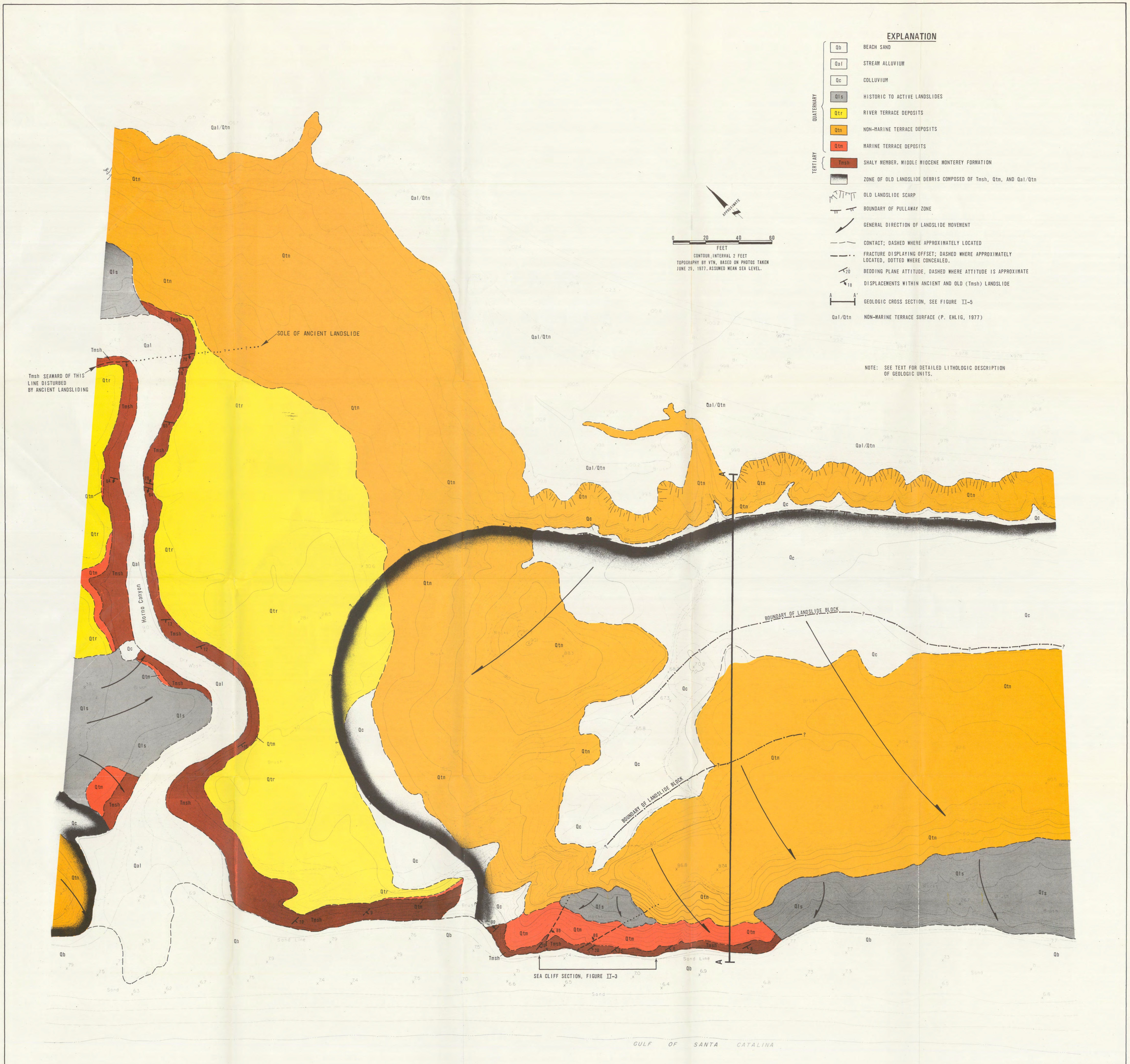
1. Ehlig, Perry, L., 1977, Geologic Report on the Area Adjacent to the San Onofre Nuclear Generating Station, Northwestern San Diego County, California.

2. Fugro, Inc., 1975, Summary of Geomorphic and Age Data for the First Emergent Terrace (Qt_1) at the San Onofre Nuclear Generating Station; Recent Geotechnical Studies of Southern Orange County, California, February, 1976.

3. Los Angeles Department of Water and Power (LADWP, 1971, Preliminary Geologic Report of the Coastal Central Portion of Camp Pendleton Marine Base, San Diego County, California.

4. Southern California Edison Company, 1976, Final Safety Analysis Report, San Onofre Nuclear Generating Station Units 2 and 3.


EXPLANATION
QUATERNARY
Qb BEACH SAND
Qal STREAM ALLUVIUM
Qc COLLUVIUM
Qls HISTORIC TO ACTIVE LANDSLIDES
Qtr RIVER TERRACE DEPOSITS
Qtn NON-MARINE TERRACE DEPOSITS
Qtm MARINE TERRACE DEPOSITS
TERTIARY
Tmsh SHALY MEMBER, MIDDLE MIOCENE MONTEREY FORMATION
ZONE OF OLD LANDSLIDE DEBRIS COMPOSED OF Tmsh, Qtm, AND Qal/Qtn
OLD LANDSLIDE SCARP
BOUNDARY OF PULLAWAY ZONE, QUERIED WHERE INFERRED
GENERAL DIRECTION OF LANDSLIDE MOVEMENT
CONTACT; DASHED WHERE APPROXIMATELY LOCATED
FRACTURE DISPLAYING OFFSET; DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED.
20 BEDDING PLANE ATTITUDE
Qal/Qtn NON-MARINE TERRACE SURFACE (P. EHLIG, 1977)
NOTE: SEE TEXT FOR DETAILED LITHOLOGIC DESCRIPTION OF GEOLOGIC UNITS.
APPROXIMATE
0 100 200 300
FEET
CONTOUR INTERVAL 5 FEET
TOPOGRAPHY BY VTN, BASED ON PHOTOS TAKEN JUNE 29, 1977.
ASSUMED MEAN SEA LEVEL
NOTE: Tmsh SEAWARD OF THIS LINE HAS BEEN DISTURBED BY PRE-ANCIENT BEDROCK LANDSLIDE
Sole of Ancient Landslide
Backscarp Section, Figure II-4
GULF OF SANTA CATALINA
FUGRO
PROJECT NO.: 77-206-02
S.O. UNITS 2 & 3
AREA 2
SMALL-SCALE GEOLOGIC MAP
10-77
FIGURE II-1



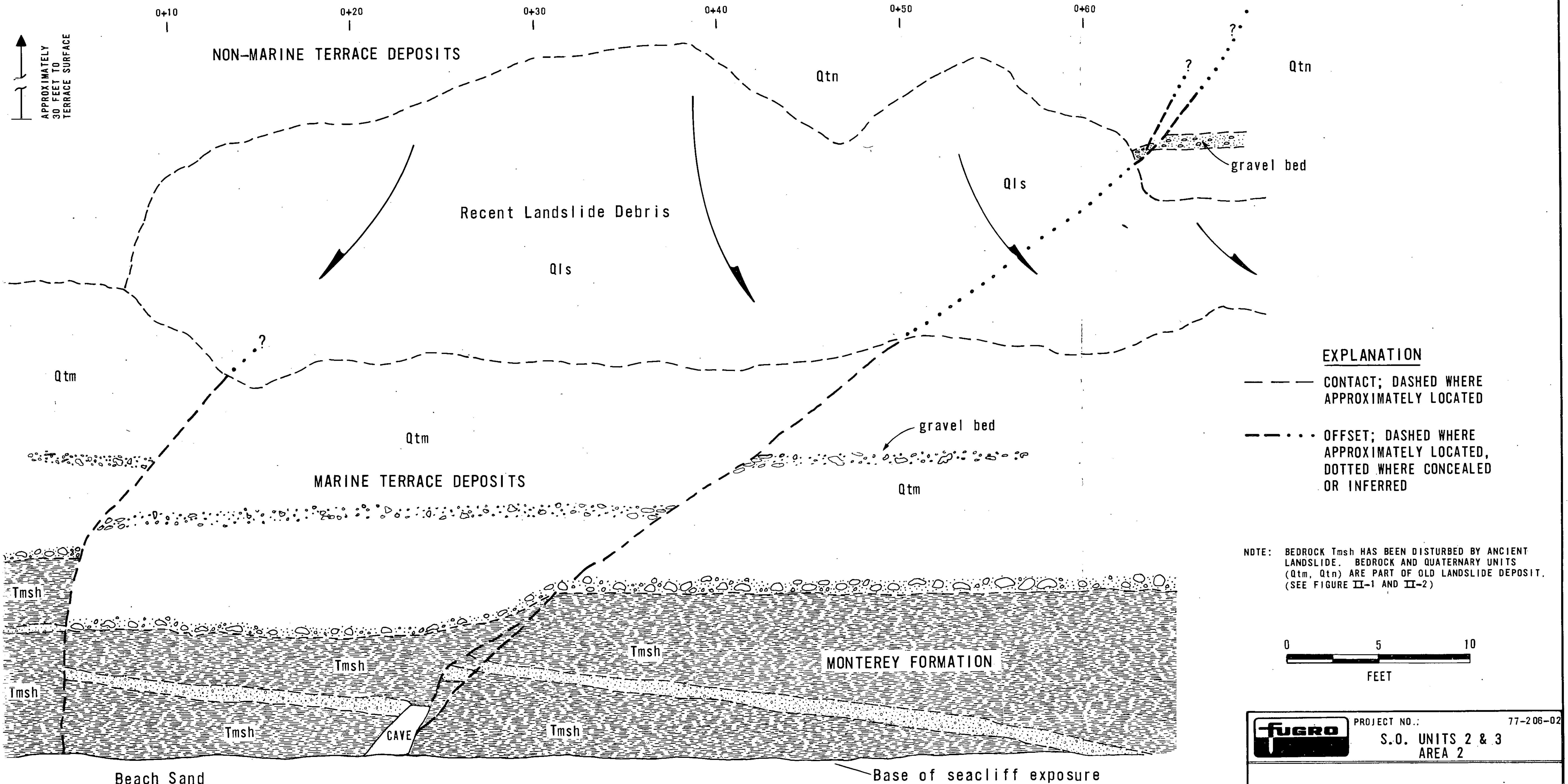
FUGRO
PROJECT NO.: 77-206-02
S.O. UNITS 2 & 3
AREA 2

LARGE-SCALE GEOLOGIC MAP

10-77

FIGURE II-2

SEACLIFF SECTION, AREA 2

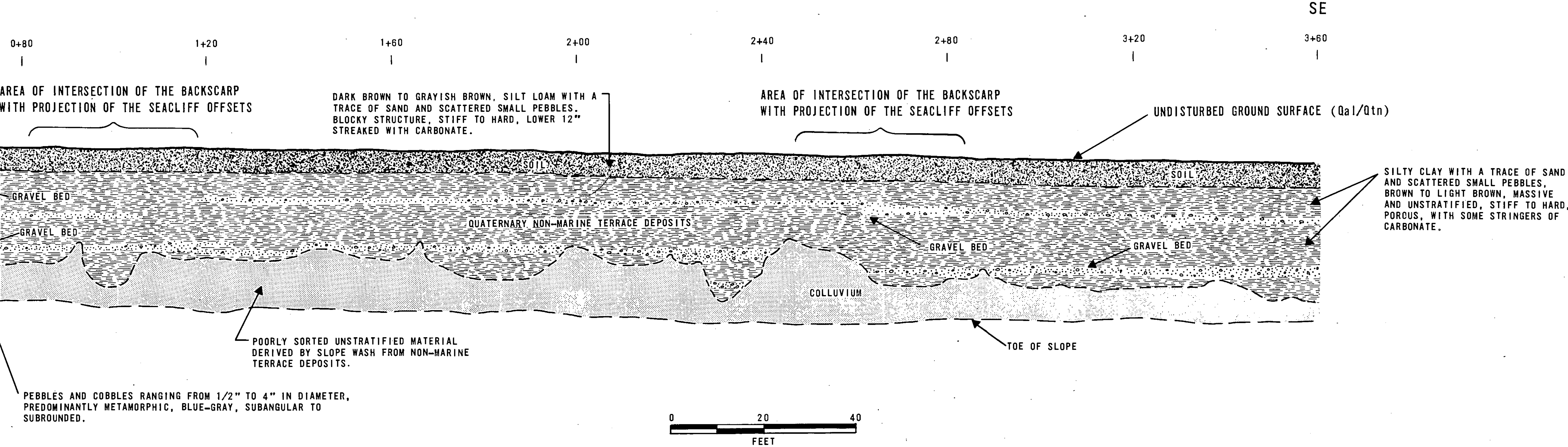


OF SECTION SHOWN ON FIGURE II-2

Beach Sand

FUGRO	PROJECT NO.: 77-206-02
	S.O. UNITS 2 & 3 AREA 2
SEACLIFF SECTION	
10-77	FIGURE II-3

LANDSLIDE BACKSCARP SECTION, AREA 2
VIEW TO NORTHEAST



LOCATION OF SECTION SHOWN ON FIGURE II-1

FUGRO

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S.O. UNITS 2 & 3
AREA 2

LANDSLIDE BACKSCARP SECTION

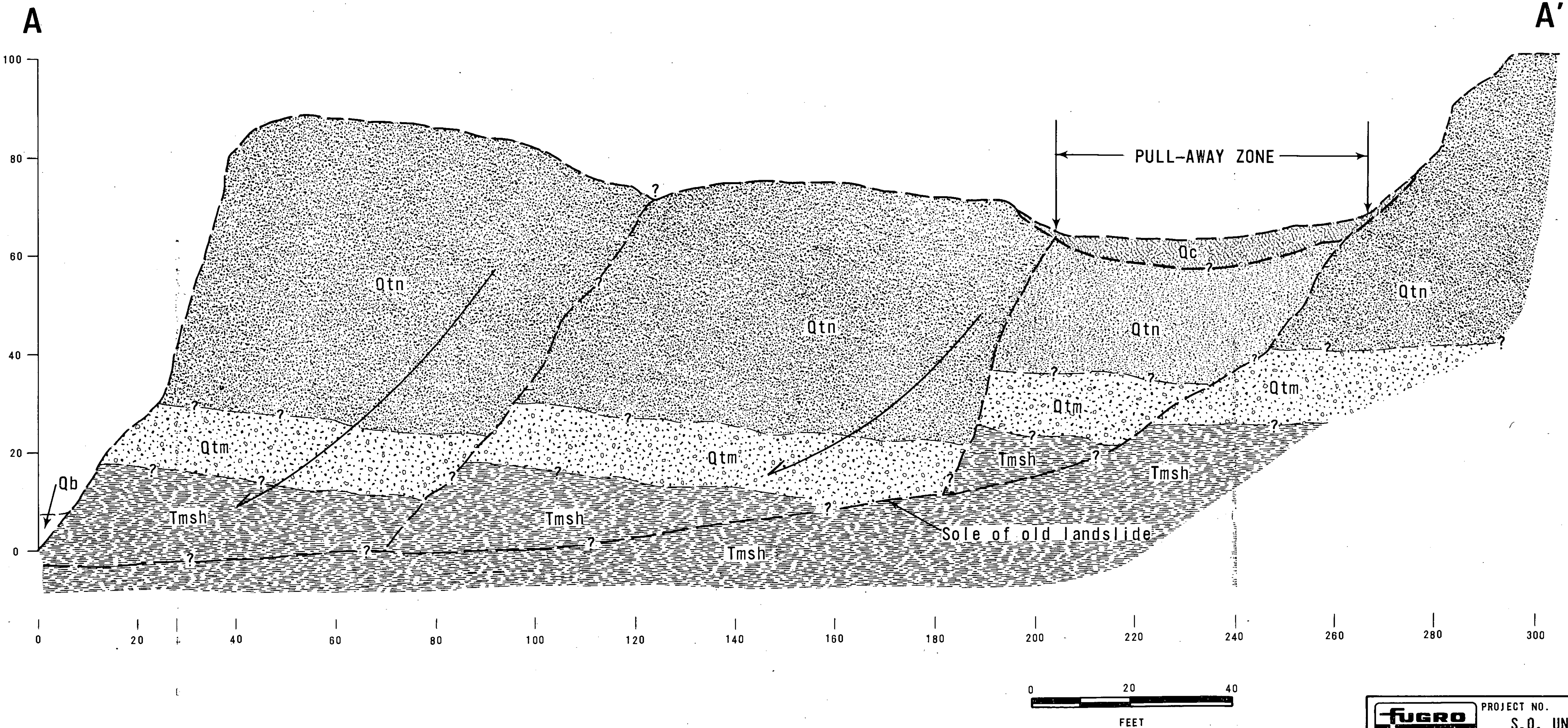
10-77

FIGURE II-4

WEST

GENERALIZED GEOLOGIC CROSS SECTION, AREA 2

EAST



LOCATION OF CROSS SECTION SHOWN ON FIGURE II-2

FUGRO

PROJECT NO. 77-206-02

S.O. UNITS 2 & 3
AREA 2

GENERALIZED GEOLOGIC CROSS SECTION

10-77

FIGURE II-5

ENCLOSURE 2

GEOLOGIC INVESTIGATION OF OFFSETS IN TARGET CANYON CAMP PENDLETON, CALIFORNIA

FOR:

SOUTHERN CALIFORNIA EDISON COMPANY
Rosemead, California 91770

BY:

FUGRO, INC.
CONSULTING ENGINEERS AND GEOLOGISTS
Long Beach California

Project No. 77-206-03

October 15, 1977

GEOLOGIC INVESTIGATION OF OFFSETS IN TARGET CANYON CAMP PENDLETON, CALIFORNIA

For:

SOUTHERN CALIFORNIA EDISON COMPANY
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Rosemead, California 91770

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I. INTRODUCTION

This report presents results of geologic studies of coastal exposures at Target Canyon, Camp Pendleton, California, approximately 6½ miles southeast of San Onofre Units 2 and 3 (Figure 1). At Target Canyon, the bedrock/marine terrace deposit contact (approximately 120,000 years old and undisturbed in the in the vicinity of San Onofre Units 2 and 3) was reported to be displaced in previous studies (Los Angeles Department of Water & Power, 1971; and San Diego Gas & Electric Company, 1977). The objectives of this latest geologic study were to (1) document the characteristics and extent of any displacements of the bedrock/marine terrace deposit contact, (2) determine the origin of the observed displacements, and (3) determine the significance, if any, to the San Onofre Units 2 and 3 seismic design.

Scope of Work

The following scope of work has been completed in order to satisfy the above objectives:

1. Detailed geologic mapping at a scale of 1" = 50', with particular emphasis on documenting and evaluating any displacements of the exposed bedrock/marine terrace deposit contact.

2. Trenching in order to trace and expose fractures in the bedrock and marine/non-marine terrace deposits.

3. Detailed logging of three excavated exposures.

4. Analysis of vertical stereo photographs specifically obtained for this investigation at a scale of 1" = 250'.

Summary of Results

A comprehensive discussion of results is presented under "Results of Investigation," Section III. A summary is presented below.

1. The approximately 120,000 year old bedrock/marine terrace deposit contact at Target Canyon is disrupted by Offsets (informal name for fractures that display stratigraphic separation; discussed in detail under "Results of Investigation"). These Offsets were observed at seven localities within a zone about 1000 feet wide and 2,000 feet long (Figure 2). A zone of aligned Offsets can be traced for about 2,000 feet.

2. Separation on most Offsets is less than one foot with maximum displacement of about 14 inches. The amount of observed displacement gradually diminishes to an inch or less in the non-marine deposits. The youngest, or uppermost, stratum displaced by an Offset is roughly near the middle section of the non-marine terrace deposits, about 17 feet below the ground surface.

3. Displacement is primarily dip-slip with some apparent horizontal movement. Most Offsets have apparent normal movement, and two have apparent reverse movement.

4. The strike of Offsets varies between north and north 15 degrees east, and the dip varies between 26 degrees and near vertical. Where exposed, the Offsets are about 6½ miles from San Onofre Units 2 and 3. If the Offsets were conservatively projected northward, the projection would lie tangent to a five-mile radius from San Onofre Units 2 and 3 at a point 3 miles north of Target Canyon.

5. Fractures, confined solely to bedrock, occur near Offsets. These fractures trend approximately north-south and dip in a conjugate manner about 45 degrees east and 45 degrees west. East- and west-dipping fractures displace bedrock up to 4 inches with apparent normal movement, but do not displace the bedrock/terrace deposit contact.

6. The cause of the Offsets could not be determined but may be due to either a tectonic or non-tectonic origin. However, if the Offsets were assumed to be capable faults, the Offsets would not affect the design level of San Onofre Units 2 and 3.

II. GEOLOGIC SETTING

General

The southern California coastal region within the general study area consists of a relatively broad (1 mile wide), nearly flat-lying coastal terrace which terminates abruptly at the beach in a precipitous seacliff. At the seacliff the terrace surface is at about elevation 100 feet and slopes gently toward the northeast to approximately elevation 200 feet, where it merges with the rolling foothills of the San Onofre Mountains. Numerous less well-preserved terraces are evident on the seaward flank of the San Onofre Mountains and have been mapped to an elevation in excess of 1200 feet (P. Ehlig, 1977). Drainage across the broad coastal plain is predominantly by sheetflow, although numerous small gullies channel water into a few deeply incised, southwest-trending stream canyons such as Target Canyon.

Excellent bedrock exposures are present in the incised canyons and along the seacliff, although several localized landslides and colluvial deposits have obscured bedrock exposures for short distances. The oldest mapped unit exposed in Target Canyon is the Miocene San Onofre Formation (Tso), a breccia. A sandy member of the Miocene Monterey Formation (Tmss) unconformably overlies the San Onofre Formation (Tso), and is the predominant bedrock type exposed in the study area.

Within Target Canyon, a section of Monterey sandstone (Tmss) about 10 to 15 feet thick is exposed at the coast and for about 1400 feet inland from the present beach. The upper surface of the bedrock (Tmss) is a nearly planar, wave-cut platform upon which marine terrace materials (Qtm) have been deposited. A sequence of non-marine terrace deposits (Qtn), including the transition zone from marine to terrestrial deposits, extends from the top of the marine terrace deposits (Qtm) to the present surface of the broad coastal plain.

Lithology

San Onofre Formation (Tso). This middle Miocene formation is predominantly a breccia, containing abundant fragments of blue-green glaucophane schist which has been well cemented with calcite. The San Onofre breccia is exposed extensively along the flank of the San Onofre Mountains. Two small outcrops of the San Onofre breccia occur in Target Canyon (Figure 3), but have recently been partially buried by artificial fill from road construction.

Monterey Formation (Tmss). A sandstone member of the middle Miocene Monterey Formation is the main bedrock unit exposed within and adjacent to Target Canyon. The unit consists of massive light brown, fine to coarse grained sandstone with scattered lenses and clasts of green-gray shale. This sandstone member of the Monterey Formation was previously identified (LADWP, 1971) as an undifferentiated sandstone unit underlying the Monterey Formation and as the Pliocene San Mateo Formation (SCE, 1976). Recent analysis indicates that this unit is part of the mid-Miocene Monterey Formation (P. Ehlig, 1977). Therefore, the designation (Tmss) used in this report is based on the most recent data.

Marine Terrace Deposits (Qtm). Quaternary marine terrace deposits typically consist of a basal gravel 6 to 12 inches thick overlain by clean, light-brown, thinly laminated, locally crossbedded, fine to coarse-grained sand. Many individual laminations or beds are well-defined and can be traced in exposures for tens of feet. As a result, any disruption in the continuity of stratification is readily observable. Thickness of the marine terrace deposits range from a few inches (due to subsequent scour by stream beds) to approximately 12 to 15 feet. The basal contact is a very distinct, nearly planar, wave-cut platform scoured in bedrock (Tmss). In contrast, the contact of the marine terrace deposits with the overlying non-marine terrace deposits (Qtn) is gradational. Similar marine terrace deposits along the California coast have been correlated with these near San Onofre. Age dates obtained from shells in the basal portion of these deposits range from about 70,000 to 130,000 B.P., but cluster at about 120,000 B.P. (Fugro, 1975).

Non-Marine Terrace Deposits (Qtn). These Quaternary alluvial deposits consist primarily of clay and silt, with some sand. They are brown to light-brown, massive to crudely-stratified, very stiff to hard, and contain some stringers of carbonate and interbeds of pebbles and cobbles (1/2 to 4 inches in diameter) composed predominantly of blue-gray to gray, subangular to subrounded glaucophane schist. Thickness of the entire unit ranges from about 30 to 50 feet.

The non-marine terrace deposits include a basal transition zone 5 to 10 feet thick of poorly stratified, reworked marine sand. The transistion zone is overlain by terrestrial clay layers that are distinctly continental in origin (Figures 4, 5, and 6, BHT-2, 4, and 6). The top of the non-marine terrace deposits contains a weakly-developed soil, approximately 5 feet thick.

River Terrace Deposits (Qtr). Fluvial deposits of well sorted to well graded gravel, sand, silt and clay occur on the flanks of Target Canyon (Figure 3). These fluvial terrace materials are about 2 to 10 feet thick and lie at levels about 4 and 30 feet above the existing stream bed.

Landslide Deposits and Colluvium (Qls, Qc). Colluvium and landslide deposits mantle portions of Target Canyon (Figure 3). These deposits are thin (1 to 5 feet), massive to indistinctly stratified, and generally consist of debris derived from nearby slopes.

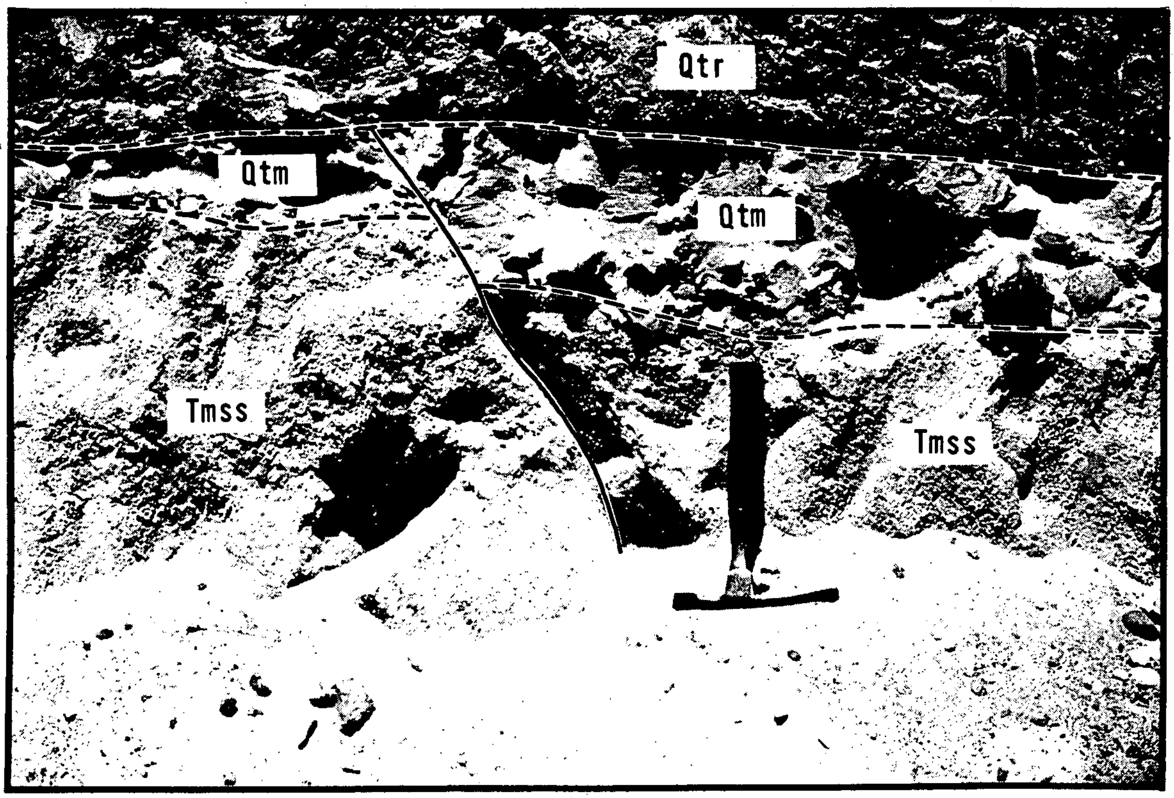
Alluvium (Qal), Beach Sand (Qb) and Artificial Fill (af). Recent alluvium (Qal) is found in the ephemeral stream channel of Target Canyon (Figure 3). It occurs as thin deposits of gravel, sand, and silt. Beach deposits (Qb) are composed of wave deposited sand and gravel. Artificial fill (af) is material used to construct a haul road located in Target Canyon (Figure 3).

III. RESULTS OF THE INVESTIGATION

In this report, the term "Offset" is used to represent the fracture(s) along which the bedrock/marine terrace deposit contact is displaced. It should be understood that these Offsets are by strict definition, "faults" (American Geological Institute, 1972) since they are fractures with observed displacement. The term fault implies to many geologists a substantial amount of displacement due to tectonic stress along a well-defined structure. However, the amount of displacement along these Offsets is commonly one foot or less and their origin could be due to either tectonic or nontectonic causes. Therefore, in order to avoid any premature generic implications, the term Offset as used in this report refers to fractures which displace the bedrock/marine terrace deposit contact and overlying materials.

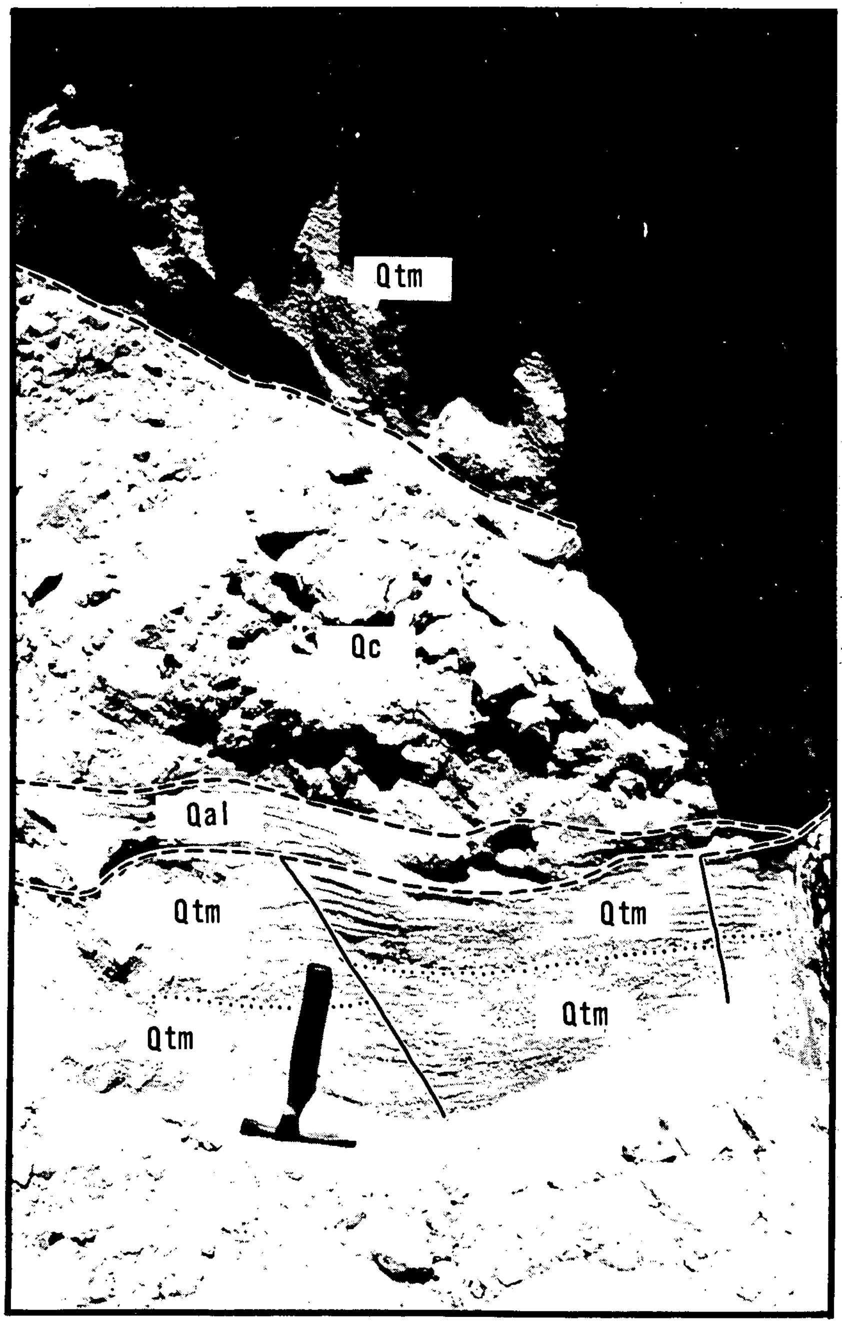
Within the study area, the observed displacements of the bedrock/marine terrace deposit contact are consistent with those previously reported (LADWP, 1971; and SDG&E, 1977). Two additional Offsets (Plates 1 and 2) were identified that had not been previously observed or reported and several Offsets were traced beyond their natural exposures.

A more detailed investigation of Offsets at two locations in Target Canyon was conducted. These two areas encompass the locations where trenching and detailed logging were performed (Figures 2, 4, 5, and 6).



VIEW LOOKING NORTH OF MOST EASTERLY OFFSET IN TARGET CANYON
(FOR LOCATION SEE FIGURE 2)

PLATE 1



VIEW LOOKING NORTH OF OFFSETS IN SOUTHERN TRIBUTARY OF TARGET CANYON
(FOR LOCATION SEE FIGURE 2)

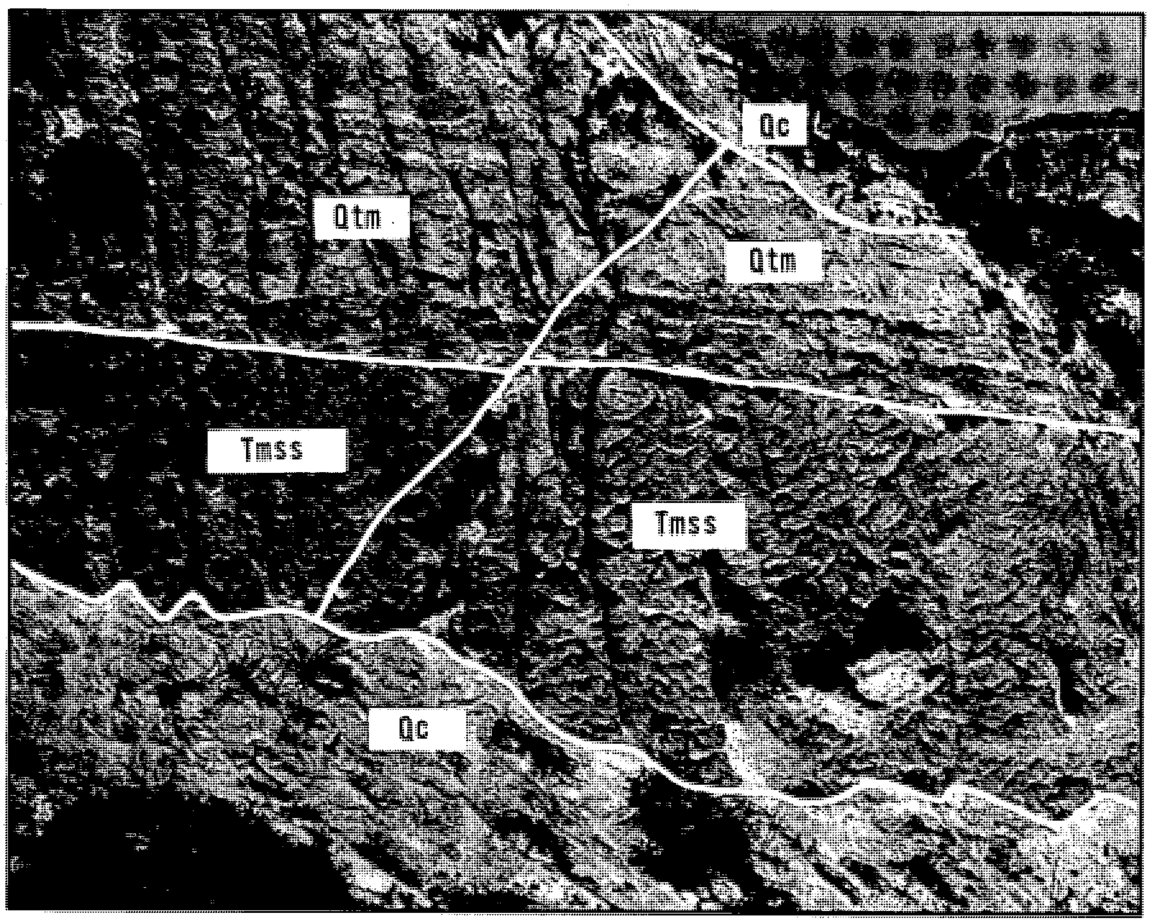
PLATE 2

Characteristics of Offsets

The Offsets are planar and have no associated gouge or brecciated material. They displace the bedrock/marine terrace deposit contact and extend into and displace the marine (Qtm) and some non-marine (Qtn) terrace deposits. They strike between due north to north 15 degrees east, and dip northeast between 26 degrees and near vertical. The dip commonly varies from 45 degrees to 60 degrees to the northeast. Where Offsets are exposed in non-marine terrace deposits the amount of dip increases with elevation to near vertical (Figures 4, 5 and 6). One Offset, located about 300 feet east of the mouth of the Target Canyon on its north side, dips 65 degrees southwest (Plate 3).

Displacements observed and documented on most Offsets are usually on the order of less than one foot. The maximum amount of displacement observed (Figure 4; trench log BHT-1) is 14 inches. Most Offsets exhibit a normal sense of movement, and two have apparent reverse movement (Plate 2). Displacement is primarily dip-slip with a lesser amount of apparent horizontal movement.

Offsets were traced into non-marine terrace deposits at three excavated exposures (Figures 4, 5, and 6). On these Offsets, displacement on the order of 4 to 14 inches in bedrock gradually decreased to an inch or less within the middle portion of the overlying non-marine terrace deposit. As an



VIEW LOOKING NORTH OF OFFSET LOCATED ABOUT 300 FEET EAST OF THE MOUTH OF TARGET CANYON -Tmss/Qtm CONTACT DISPLACED 6 INCHES.

(FOR LOCATION SEE FIGURE 2)

PLATE 3

example, at "Detail Area 1" (Figure 4), an Offset displaces the bedrock/marine terrace deposit contact about 14 inches and diminishes to one inch (where last observed) near the top of the excavation (middle portion of non-marine terrace deposit). In homogenous non-bedded silts and clays which commonly occur in the non-marine terrace deposits, displacement and even a fracture itself may not be discernable. However, where a fracture continues upward into a thinly bedded unit, displacement is readily recognized. This is the case in trench BHT-2 (Figure 4) between vertical datum 17 and 19½ feet.

Even though the amount of displacement generally decreases upward through the section, the amount of apparent vertical displacement varies along a particular Offset. For example, in trench BHT-4 (Figure 5), apparent vertical displacements vary on the center Offset from 3 inches at the 2 foot vertical datum line, to 1 inch at the 3 foot vertical datum line, to 2 inches at the 4 and 5 foot vertical datum lines. This inconsistent amount of apparent displacement suggests a possible horizontal component of movement which has juxtaposed beds of varying thickness and extent. A tabular clast of clay was exposed in marine terrace deposits and was severed by the easternmost Offset observed on the south flank of the Target Canyon (Figure 2). The displaced clay fragment appears to have undergone about 3 inches of left lateral separation in addition to normal separation. The apparent reverse separation on the Offset in the south tributary of Target Canyon (Figure 2 and Plate 2) may have been caused by horizontal displacement or reverse movement.

Bedrock Fractures Other Than Offsets

Fractures which do not break the bedrock/marine terrace deposit contact were observed in the Miocene sandstone (Tmss); however, the appearance of these fractures is distinctively different from that of the Offsets. The fractures are expressed as light gray to white, slightly resistant ridges 1/4 inch to one inch wide. This is in contrast to the thin planar characteristics of the Offsets. The fractures, as shown on the geologic map (Figure 3), exist in scattered localities, but are more numerous near the observed Offsets. This is particularly true in Detail Area 2 (Figures 2 and 3).

The fractures trend about due north and dip in a conjugate manner, both west and east about 45 degrees. The east- and west-dipping fractures displace the bedrock (where observed in Detail Area 2) about four inches with apparent normal movement, but do not displace the bedrock/marine terrace-deposit contact. Hence, the bedrock fractures formed prior to the formation of the wave-cut bench. The bedrock fractures and Offsets are similar with regard to trend, dip, and amount of displacement. This suggests similar stress orientation persisted both prior to and after beveling of the bedrock.

Areal Extent of Offsets

Offsets were directly observed or exposed by trenching along the flanks of deeply incised stream canyons in the study area. As shown in Figure 2 and 3, three Offsets were traced to both sides of Target Canyon. The maximum observed length of these Offsets is about 100 feet (Detail Area 1; Figure 2). Along projection of the Offsets and beyond the limits of the incised stream canyons, Offsets and the bedrock/marine terrace deposit contact are not exposed.

An estimated length of about 2,000 feet is suggested by the alignment of Offsets in the eastern end of Target Canyon, in the southern tributary to Target Canyon, and in stream gullies along the seacliffs about 1,500 feet southeast of Target Canyon (Figure 2). Due to the thick (30 to 40 feet) overburden above the bedrock/marine terrace deposit contact, no evidence is available to confirm that these individual Offsets are interconnected.

The continuity of Offsets beyond the area of deeply incised stream canyons in the study area cannot be determined. Thus, the northern and southern extent of the Offsets is unknown. Recent geologic mapping by Dr. P. Ehlig in the San Onofre Mountains, north and east of Target Canyon, has not identified any faults along the northern projection of Offsets observed at Target Canyon (P. Ehlig, 1977). If the zone of Offsets were projected three miles north of Target Canyon, the northern projection would lie tangent to a 5-mile radius from San Onofre Units 2 and 3. The relatively small amount of displacement observed on the Offsets suggests they are a local phenomenon that do not extend very far beyond the study area.

<u>Vertical Extent and Relative Age Offsets</u>

The Offsets disrupt the marine and non-marine terrace deposits. The age of the marine terrace deposits (approximately 120,000 years) has been evaluated by numerous workers, and summarized in a previous report (Fugro, 1975). This age corresponds well with one of the high stands of sea level during the Sangamon interglacial. The range ages of the overlying non-marine terrace deposits (and transition zone) is currently under study (Shlemon, 1977).

Three localities were excavated by trenching to determine the youngest, or uppermost, strata displaced by the Offsets (Figures 4, 5, and 6; BHT-2, 4, and 6). At these exposures, Offsets displace the transition zone of the non-marine terrace deposits. Two of the Offsets (Figures 4 and 5; BHT-2 and 4) displace the terrestrial section of the non-marine deposits as well. The highest displacement observed occurs roughly in the middle section of the non-marine deposits, about 17 feet below the ground surface.

At trench BHT-2 (Figure 4), the transition zone of the non-marine terrace deposit is displaced 6 inches (Photograph A; Figure 4). The Offset continues upward and displaces a distinctive clay layer about 2 inches. Above this clay layer the Offset displaces laminar bedded sand about 1¼ inches (Photograph B; Figure 4). Above this disrupted sand (about 17 feet below the ground surface), no obvious displacement was observed. Although a fracture in the soil does align with the Offset, it is not clear that the fracture and the Offset are related.

At trench BHT-4 (Figure 5) three Offsets are observed, two of which (the left and center Offsets) converge upward at the base of the non-marine terrace deposits. These two Offsets displace the transition zone of the non-marine terrace deposits about 3 inches and an overlying distinctive terrestrial silty clay layer about 1½ to 2½ inches. This silty clay layer (Figure 5; vertical datum 12 feet) is the uppermost unit seen to be displaced (about 24 feet from the ground surface). Above the clay layer no displacement was observed but a fracture continues upward for a distance of 7 feet to a point where it can no longer be traced. The easternmost Offset disrupts a gravel bed in the transition zone but does not appear to displace the overlying clayey layer. It continues upward as a crack which dies out about 4 feet above that clayey layer.

Three Offsets are identified in trench BHT-6 (Figure 6). A gravel lens in the transition zone of the non-marine terrace deposit is displaced about one inch. Above this point no displacement is observed, but the fracture continues upward as a crack for about 3 feet where it can no longer be traced.

In summary, the Offsets displace the bedrock/marine terrace deposit contact and are less than 120,000 years old. The youngest, or uppermost strata displaced by an Offset is near the middle section of the non-marine terrace deposits, about 17 to 24 feet below the ground surface. No minimum age of last movement has been established because the age of the non-marine terrace deposits is unknown. The range of ages of the overlying non-marine terrace deposits (and transition zone) is currently under study (Shlemon, 1977).

Origin

The characteristics and length of the Offsets are suggestive of three possible origins. A tectonic cause and two non-tectonic causes, settlement and landsliding, are considered plausible and were evaluated for supportive and/or non-supportive evidence. A summary of the evidence is presented below and is followed by a discussion of the data.

Tectonic Origin.

Evidence supportive of a tectonic origin is as follows:

1. An isolated exposure of the San Onofre Formation, a breccia, is located in Target Canyon (Figure 3). This exposure is anomalous because it is the only outcrop of the San Onofre Formation along the coast southwest of the San Onofre Mountains. If the exposure of San Onofre Breccia is related to

faulting, the Offsets could be interpreted as being structurally controlled. However, no large-scale faults have been identified in the San Onofre Mountains that could be associated with the anomalous exposure of San Onofre Formation.

2. Fractures within bedrock (other than Offsets) exist at scattered localities in the vicinity of Target Canyon, but are numerous near the observed Offsets (Figure 3). These bedrock fractures are different from the Offsets in appearance and age, but are similar with regard to trend, dip, and amount of displacement. This suggests a similar stress orientation persisted both prior to and after beveling of the bedrock about 120,000 years ago.

3. The trend of the Offsets is parallel with onshore structures (shears, joints, faults) mapped in bedrock units in vicinity of Target Canyon (Ehlig, 1977; SCE, 1976).

4. The strike of the Offsets appears to be consistent for a distance of 2,000 feet with no apparent splaying or arcuate characteristics.

5. Apparent horizontal separation is associated with vertical separation.

If the Offsets are due to tectonic stress, their small amount of displacement and other characteristics suggests they reflect minor crustal adjustments.

The evidence non-supportive of a tectonic origin is related to the regional structure of Southern California. The north-south orientation of Offsets is at variance with the general northwest trend of most late Quaternary offshore structures between Los Angeles and San Diego.

Settlement. Settlement is another viable origin for the Offsets. The anomalous exposure of San Onofre Formation in Target Canyon indicates high topographic relief of basement rock terrain. Thus, deep basins in the basement terrain probably occur adjacent to the anomalous basement high and may be conducive to diagenetic compaction (settlement) of overlying sediments.

Evidence supportive of settlement is as follows:

1. The anomalous outcrop of San Onofre Formation may be due to erosional processes and have no structural control. The numerous changes of sea level during the Pleistocene epoch provide several periods when dewatering of bedrock units could induce settlement.

2. The one west dipping Offset (Plate 2; Figures 2 and 3) is separated from the other east-dipping Offsets by the outcrop of San Onofre Formation. This suggests the sediments have settled around a basement high.

3. Displacement along the Offsets progressively decreases upwards in section and becomes unmeasurable in non-marine terrace deposits.

Evidence non-supportive of settlement is as follows:

1. The strike of Offsets is uniform with no apparent splaying or arcuate characteristics.

2. The Offsets appear as shears with no filled fractures or other evidence of tensional cracking. The Offsets cannot be traced to the ground surface.

Landsliding. Large scale landsliding could be expected since landslides are ubiquitous in this coastal region. However, the non-supportive evidence for landsliding as an origin is substantial, and tends to indicate landsliding as the least plausible of the origins considered.

Supportive evidence is that landsliding is common in the Monterey Formation and a major stream canyon (Las Pulgas Canyon) exists immediately south of Target Canyon which could have oversteepened slopes susceptible to sliding.

Non-supportive evidence for landsliding is as follows:

1. No topographic expression indicative of large scale landsliding exists in or adjacent to Target Canyon. Exposures of Miocene bedrock

in Target Canyon are competent sandstone showing no evidence of extensive fracturing typical of landslides.

2. The strike and dip of Offsets is not widely variable as would be expected if associated with landsliding.

3. The amount of displacement increases with depth.

4. Offsets do not parallel the coastline, as nearly all recent or ancient slides do throughout the area.

Discussion. Of the three origins postulated above, only two (tectonic and settlement), have sufficient supportive evidence to seriously be considered as viable origins. Evidence for each of these postulated origins was collected and analyzed from 1) the detailed studies of Target Canyon during this investigation, and 2) the detailed information presented in the San Onofre PSAR and other studies of the Camp Pendleton area. None of the evidence available from these sources conclusively demonstrates which of the two origins is most likely. However, some significant deductions can be made from the available data to place the Offsets observed in Target Canyon in perspective relative the seismic design of San Onofre Units 2 and 3.

One of the more important considerations between a tectonic or settlement explanation of the Offsets is the consistency of trend and overall length of the displacements. Surface features resulting from settlement can be quite long and linear, but usually are a local phenomenon and often have diffuse boundaries and sinuous or arcuate traces. In contrast, surface displacements relative to steeply dipping faults tend to be linear, relatively long, and usually associated with a causative fault having greater length and displacement. The zone of displacements observed at the surface can be narrow or wide depending on the nature of the fault.

In reviewing the mapped geology of the San Onofre Mountains (Ehlig, 1977), about 2 miles north of Target Canyon, and the extensive offshore geophysical data to the south, three significant observations can be made.

1. Diagnostic marker beds (tuffs) within the San Onofre Formation can be traced continuously, in the San Onofre Mountains, for thousands of feet across the north projection of Offsets exposed in Target Canyon. This evidence indicates no major faults exist along the north projection of Offsets and any postulated fault underlying the Offsets should terminate before reaching the San Onofre Mountains.

2. Several remnants of wave-cut terraces exist on the west flank of the San Onofre Mountains north of Target Canyon. The terrace deposits reflect

about eight episodes of terrace development older than 120,000 years. The terrace elevations are uniform and they extend for miles across the north projection of Offsets with no apparent disruption. This indicates no major faulting has occurred along the Offset's projection.

3. The offshore geophysical surveys south of Target Canyon indicate a complex zone of deformation with chiefly northwest trending major faults. The offshore structure, as presented in San Onofre PSAR Figures 2E-2 and -3 (SCE, 1970), indicates no major north trending faults exist which might be interpreted as connecting with the Target Canyon area.

Since there is no evidence of significant bedrock displacements or faults either north or south of Target Canyon, it is reasonable to conclude that the Offsets have no apparent association with any known long, continuous fault. If the Offsets are tectonic in origin, the underlying fault (approximately 6½ miles from San Onofre Units 2 and 3) must be relatively short with a correspondingly small displacement and, therefore, be insignificant in comparison to the geologic model upon which the seismic design of San Onofre Units 2 and 3 is based.

A second important consideration is that the Offsets at three localities appear to align with each other along a zone about

2,000 feet in length. Due to the thick (30 to 40 feet) overburden above the bedrock/marine terrace deposit contact, there is no evidence to confirm that the Offsets are interconnected. If the individual Offsets are not connected to one another, then they are relatively short and form a diffuse broad zone in the Target Canyon area, as might be expected in a settlement origin. This hypothesis might be further supported by the small amount of displacement and diminishing nature of the Offsets. Displacement observed on Offsets is commonly less than one foot and does not exceed 14 inches. In addition, the displacements gradually diminish to zero in marine and non-marine deposits that overlay bedrock. This gradual and progressively decreasing displacement suggests creep or some similar type of movement rather than large episodic displacements.

The third important consideration is the presence of an isolated outcrop of San Onofre Formation within Target Canyon, previously discussed. The presence of this exposure indicates a prominent basement high at Target Canyon. This basement high might be explained by faulting, however, based on the earlier discussions of evidence for an absence of long faults in the vicinity, it seems more consistent to explain it as an erosional remnant. As discussed earlier, Offsets located east of the basement high dip eastward and one Offset situated west of the basement high dips to the west. If the basement high were a long, north trending ridge separating these diverse senses of the dip, then more supportive arguments might be made for settlement.

At the present time, there is convincing evidence for both a settlement or tectonic origin of the Offsets. There is substantial evidence to demonstrate no significant bedrock faulting trends through Target Canyon. This precludes any long faults related to the Offsets. Therefore, the Offsets, even if assumed capable, will not affect the seismic design at San Onofre Units 2 and 3.

IV. CONCLUSIONS

The nature and extent of the Offsets indicates minor adjustments (14 inches and less) within bedrock and overlying terrace deposits. The Offsets disturb the approximately 120,000-year-old-bedrock/marine terrace deposit contact and penetrate and displace at least the middle section of the overlying, non-marine terrace deposits of unknown age. The cause of the Offsets could not be determined, but may be due to either a tectonic or nontectonic origin.

However, if the Offsets were assumed to be capable faults, the Offsets would not affect the design level of San Onofre Units 2 and 3. The Offsets are not significant in comparison to the hypothesized Offshore Zone of Deformation (the basis for San Onofre Units 2 and 3 DBE) based on proximity to the site, length, and amount of displacement.

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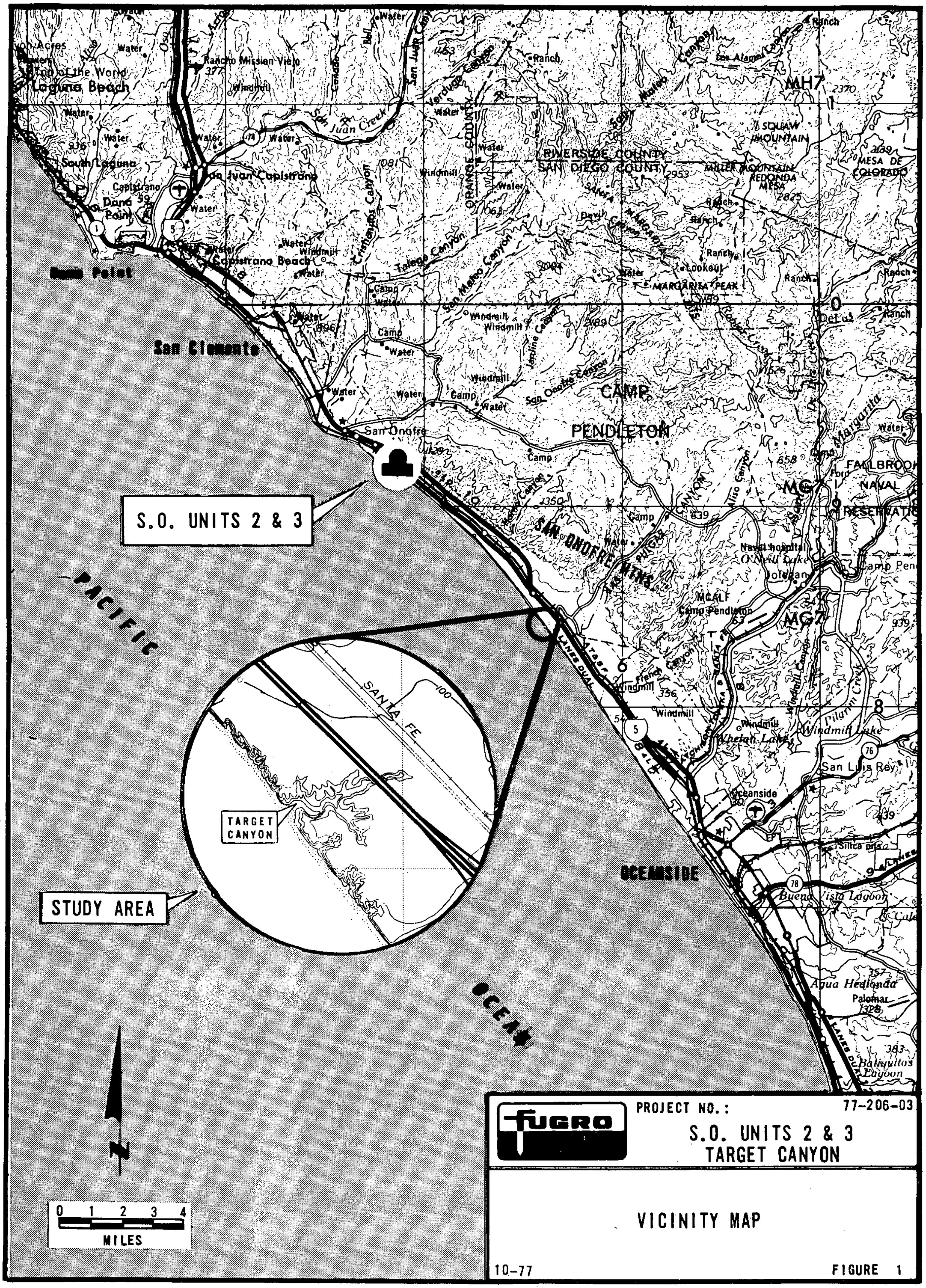
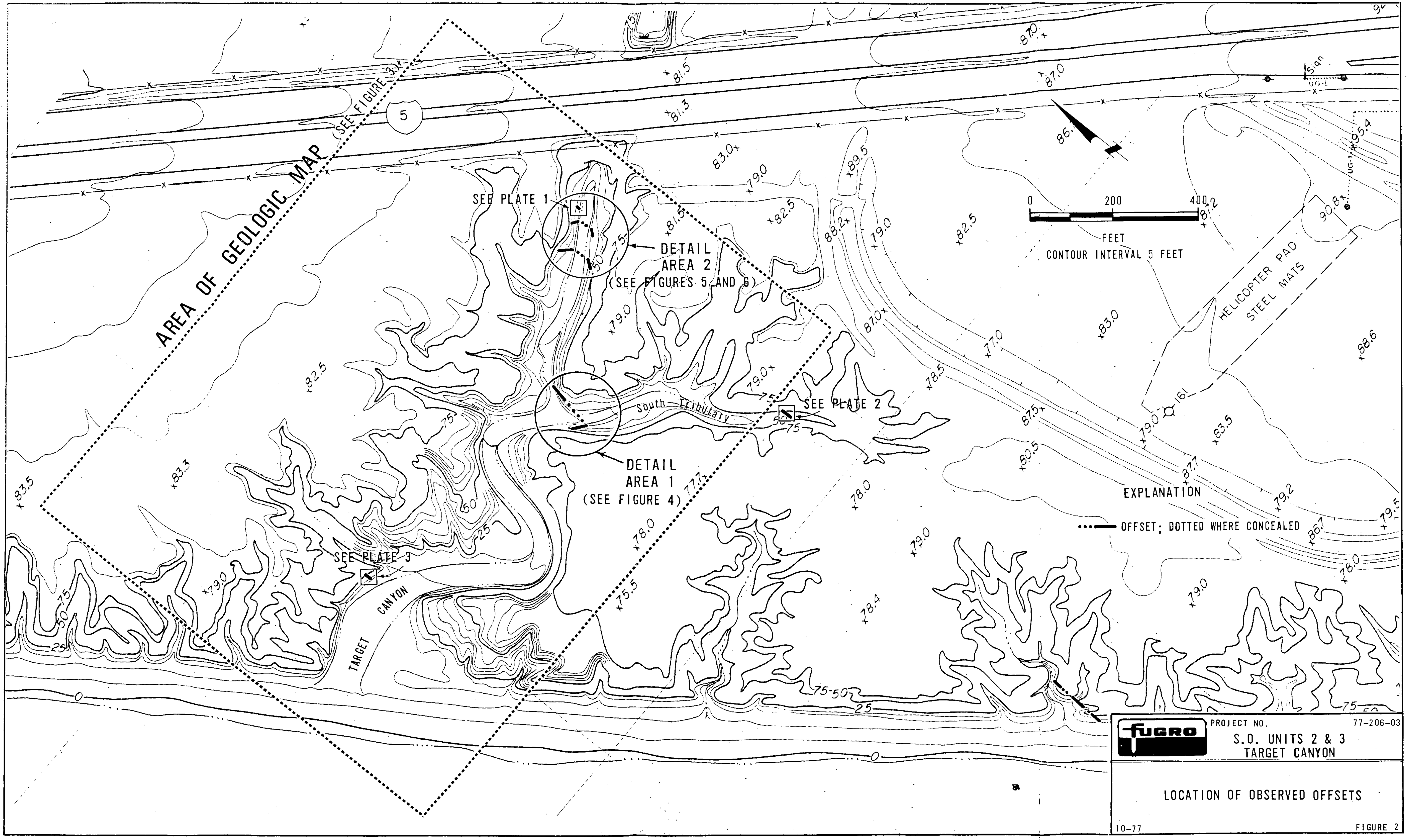


Laguna Beach
South Laguna
San Juan Capistrano
Dana Point
Capistrano Beach
San Clemente
San Onofre
S.O. UNITS 2 & 3
RIVERSIDE COUNTY
SAN DIEGO COUNTY
ORANGE COUNTY
CAMP
PENDLETON
SAN ONOFRE MTNS
PACIFIC
OCEAN
OCEANSIDE
Oceanside
San Luis Rey
Buena Vista Lagoon
Agua Hedionda
FALLBROOK
NAVAL
RESERVATION
SANTA FE
TARGET
CANYON
STUDY AREA
0 1 2 3 4
MILES
FUGRO
PROJECT NO.: 77-206-03
S.O. UNITS 2 & 3
TARGET CANYON
VICINITY MAP
10-77
FIGURE 1



FUGRO

PROJECT NO. 77-206-03

S.O. UNITS 2 & 3
TARGET CANYON

LOCATION OF OBSERVED OFFSETS

10-77

FIGURE 2

EXPLANATION

af	ARTIFICIAL FILL	QUATERNARY
Qb	BEACH SAND	
Qal	STREAM ALLUVIUM	
Qc	COLLUVIUM	
Qls	LANDSLIDE DEPOSITS	
Qtr2 / Qtr1	RIVER TERRACE DEPOSITS	
Qtn	NON-MARINE TERRACE DEPOSITS	
Qtm	MARINE TERRACE DEPOSITS	
Tmss	SANDSTONE MEMBER, MIDDLE MIOCENE, MONTEREY FORMATION	TERTIARY
Tso	BRECCIA, MIOCENE, SAN ONOFRE FORMATION	

CONTACT; DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED OR INFERRED

65 OFFSET; DOTTED WHERE CONCEALED

FRACTURE IN Tmss (SEE TEXT FOR DESCRIPTION)

GENERAL DIRECTION OF LANDSLIDE MOVEMENT.

Qal/Qtn NOTATION FOR NON-MARINE TERRACE SURFACE

NOTE: SEE TEXT FOR DETAILED LITHOLOGIC DESCRIPTION OF GEOLOGIC UNITS.

SEE FIGURE 2 FOR LOCATION OF GEOLOGIC MAP

0 50 100

Scale in feet

CONTOUR INTERVAL 5 FEET

10,000 FOOT GRID BASED ON CALIFORNIA COORDINATE SYSTEM

FUGRO

PROJECT NO : 77-206-03

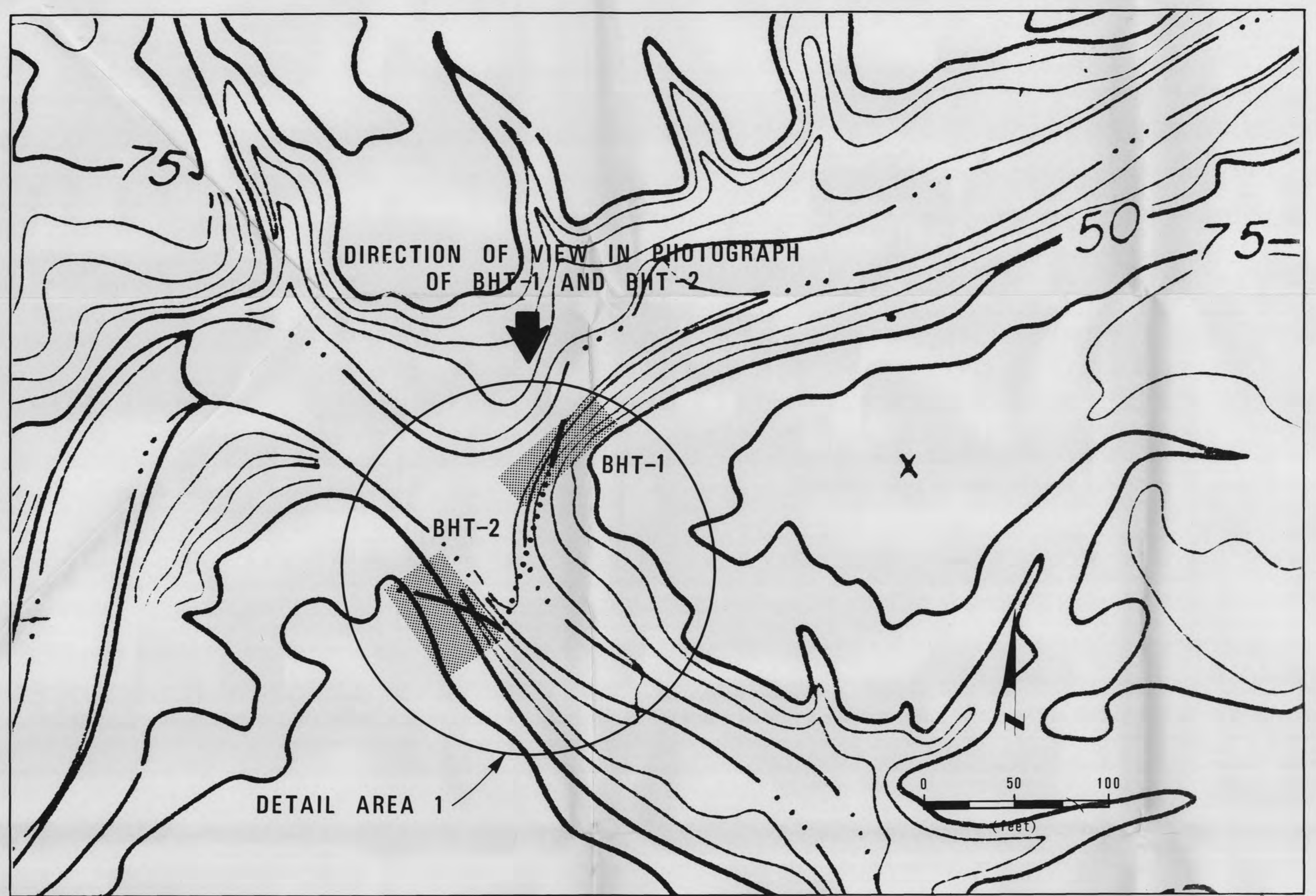
S.O. UNITS 2 & 3
TARGET CANYON

GEOLOGIC MAP

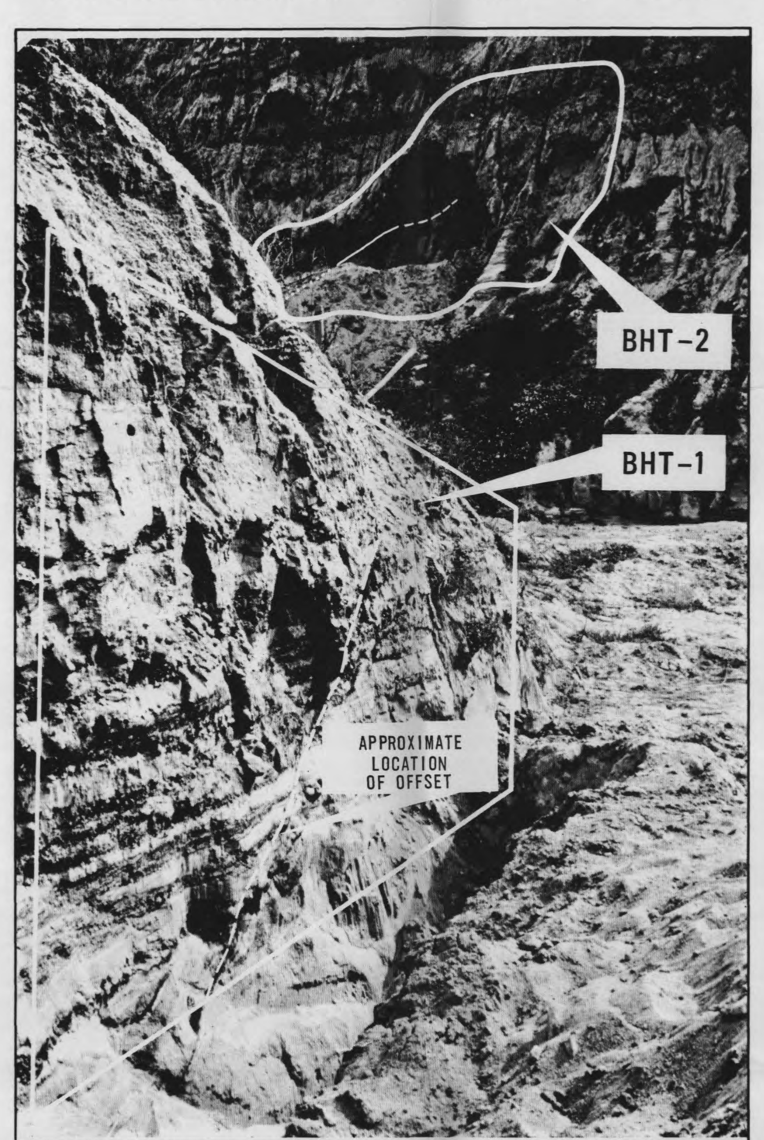
10-77

FIGURE 3

LOCATION MAP BHT-1 &-2



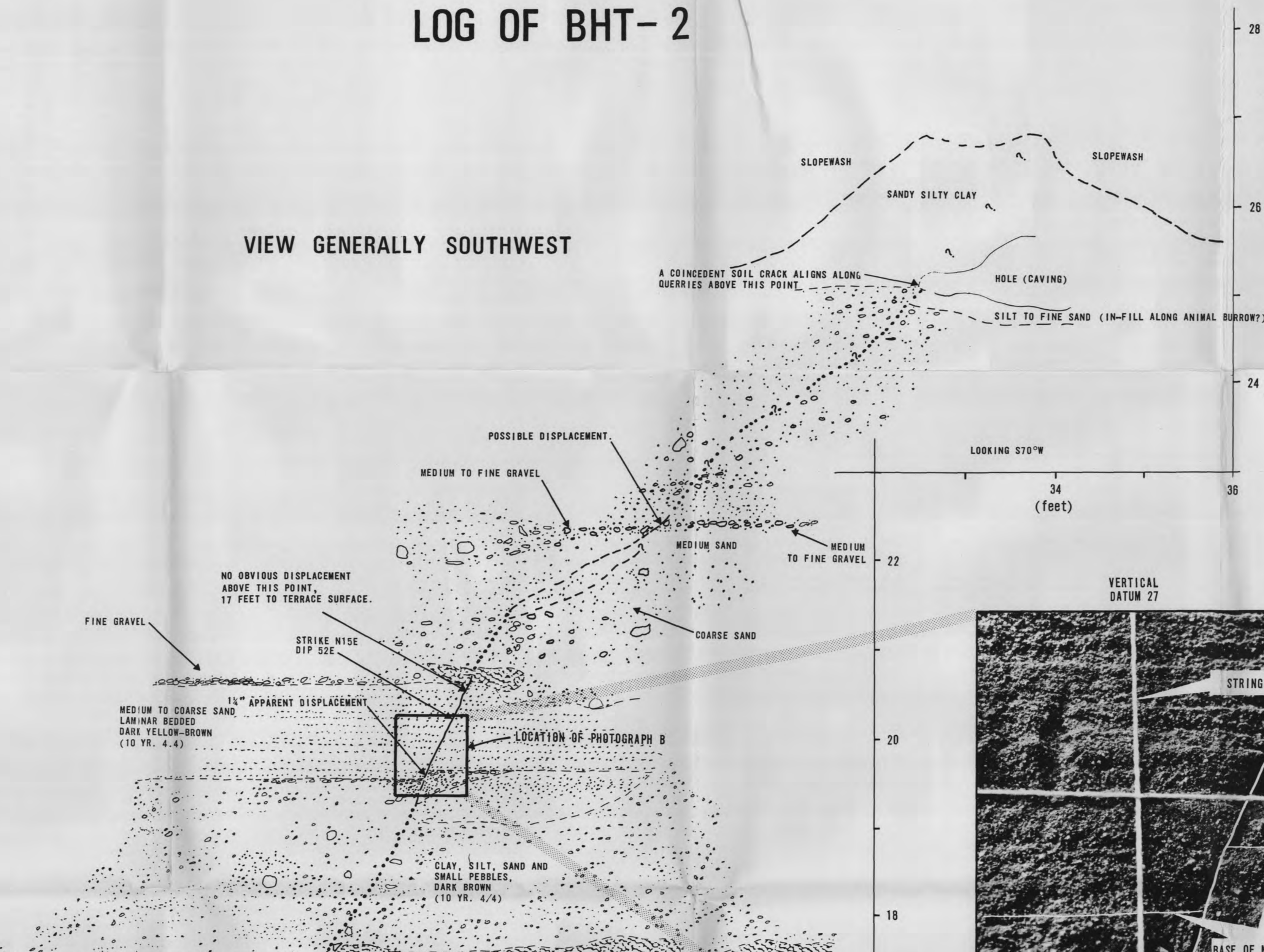
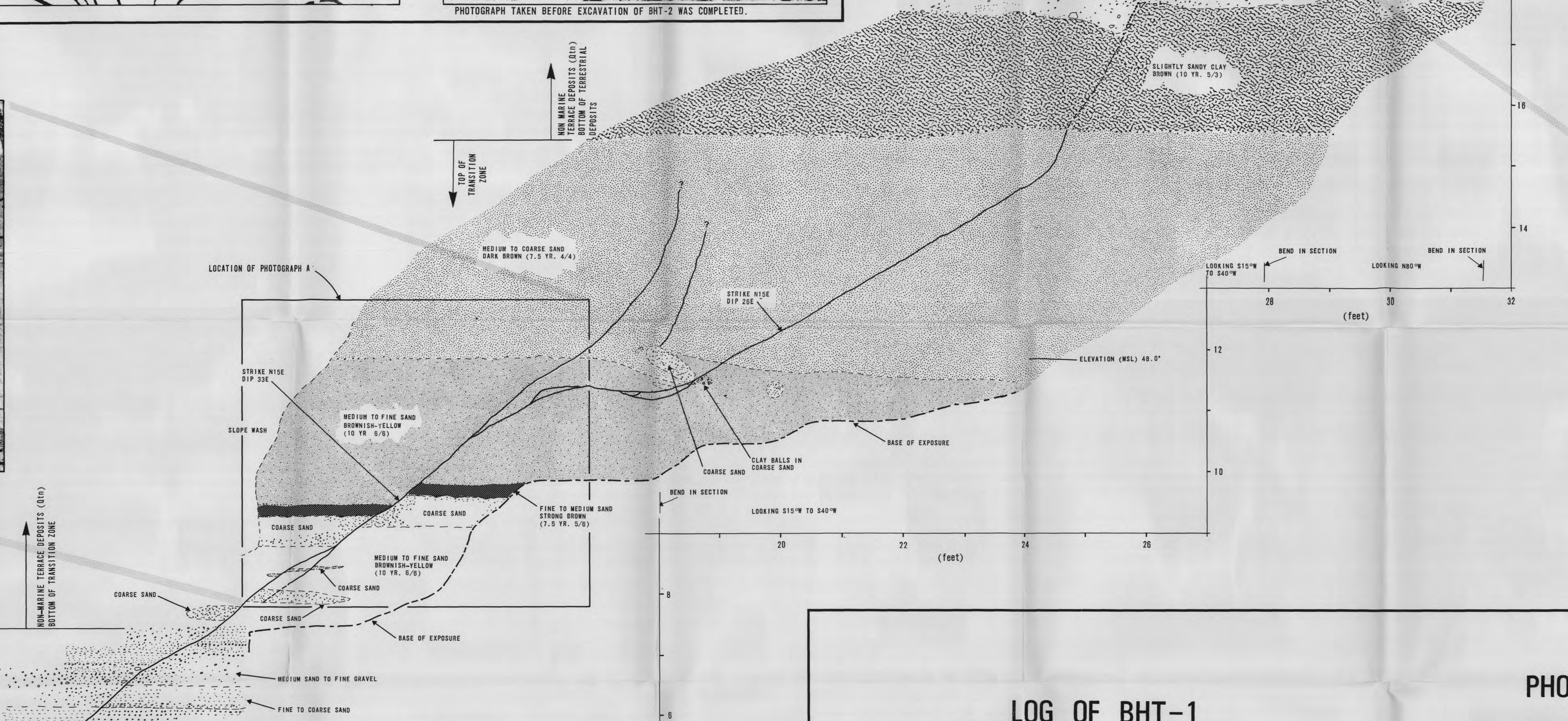
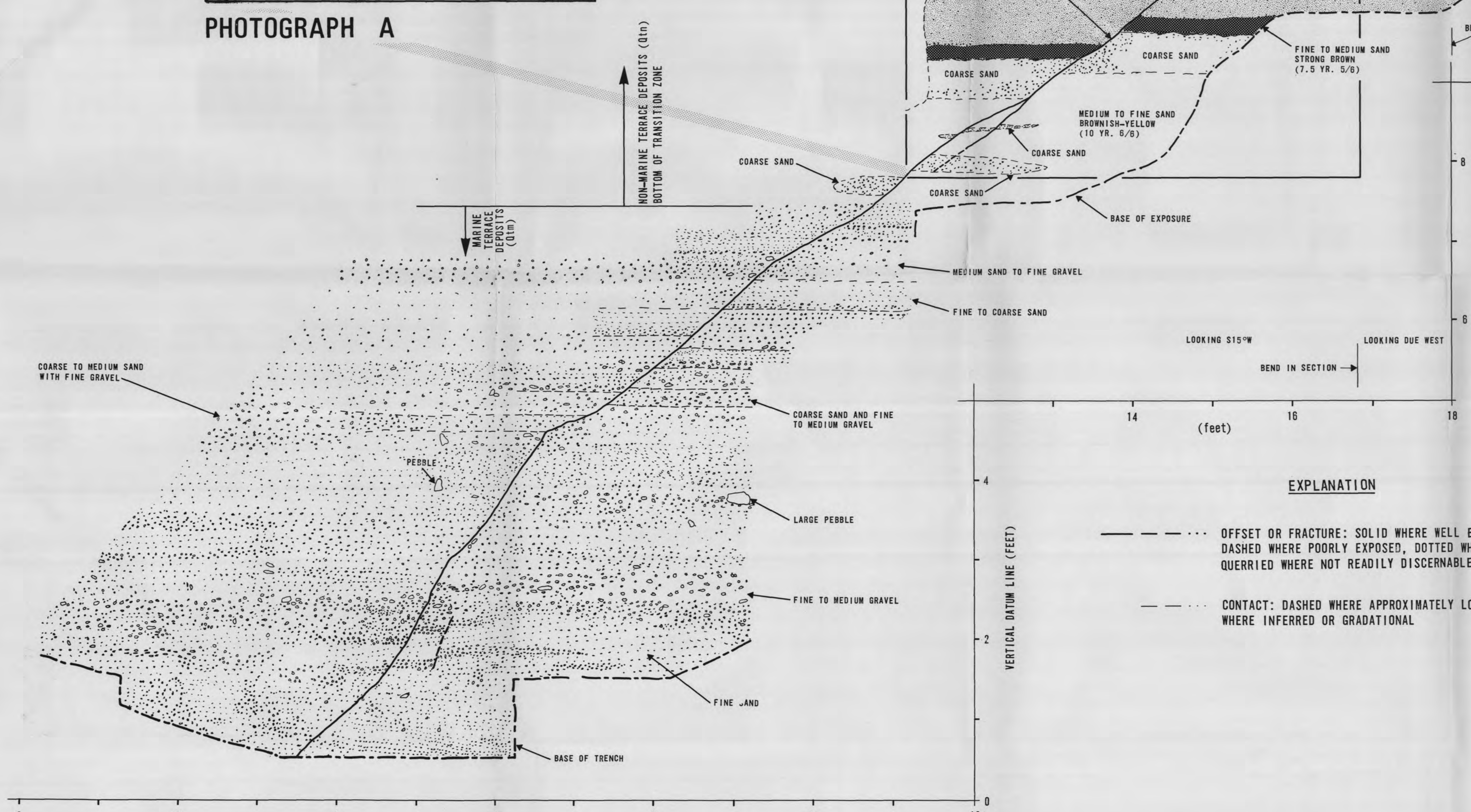
PHOTOGRAPH OF BHT-1 &-2

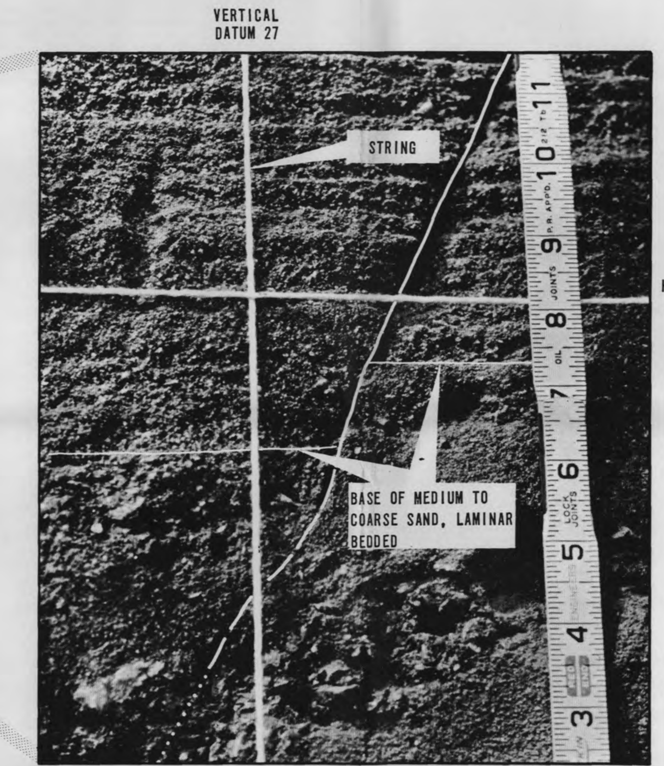


PHOTOGRAPH TAKEN BEFORE EXCAVATION OF BHT-2 WAS COMPLETED.

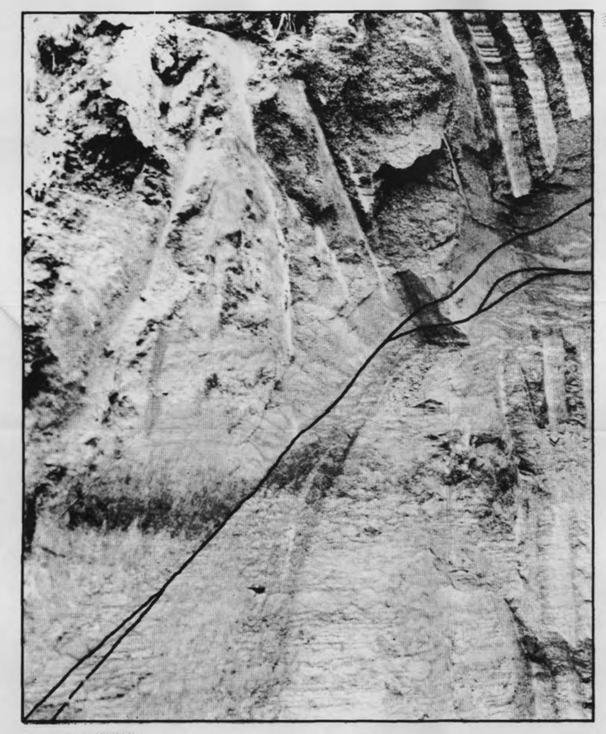
LOG OF BHT-2

VIEW GENERALLY SOUTHWEST



PHOTOGRAPH B



PHOTOGRAPH A

LOG OF BHT-2

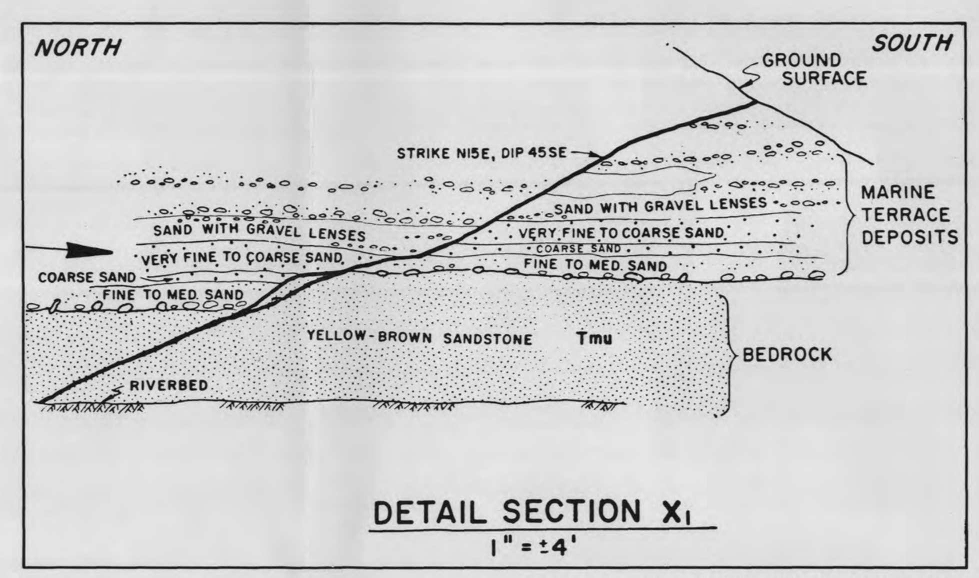
VIEW GENERALLY SOUTHWEST

EXPLANATION

OFFSET OR FRACTURE: SOLID WHERE WELL EXPOSED OR DISTINCT, DASHED WHERE POORLY EXPOSED, DOTTED WHERE INFERRED, QUERRIED WHERE NOT READILY DISCERNABLE.

CONTACT: DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE INFERRED OR GRADATIONAL

LOG OF BHT-1

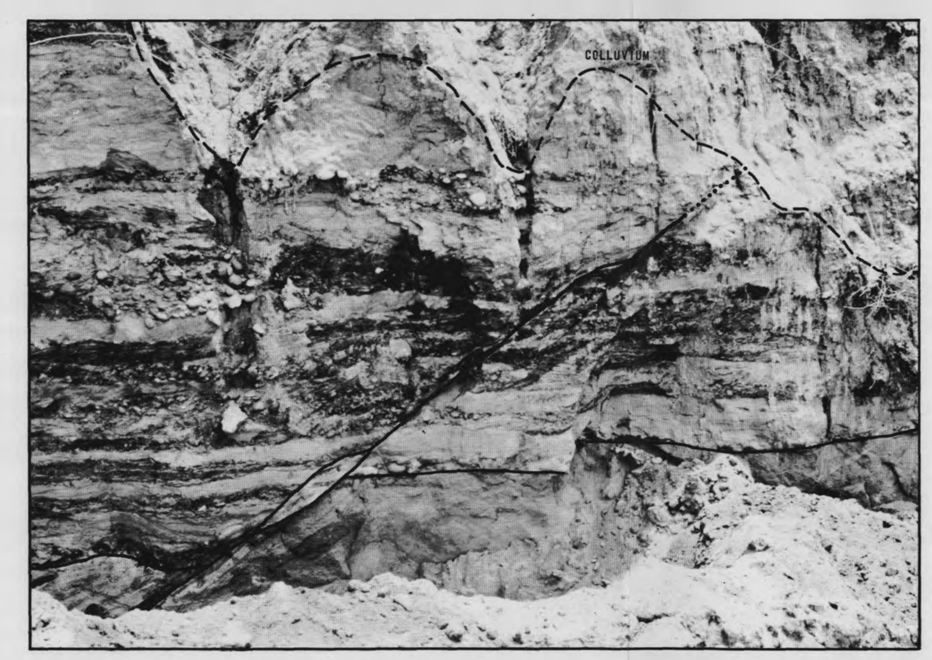


DETAIL SECTION X_1

1" = 4'

REPRODUCED FROM LADWP REPORT DATED 1971

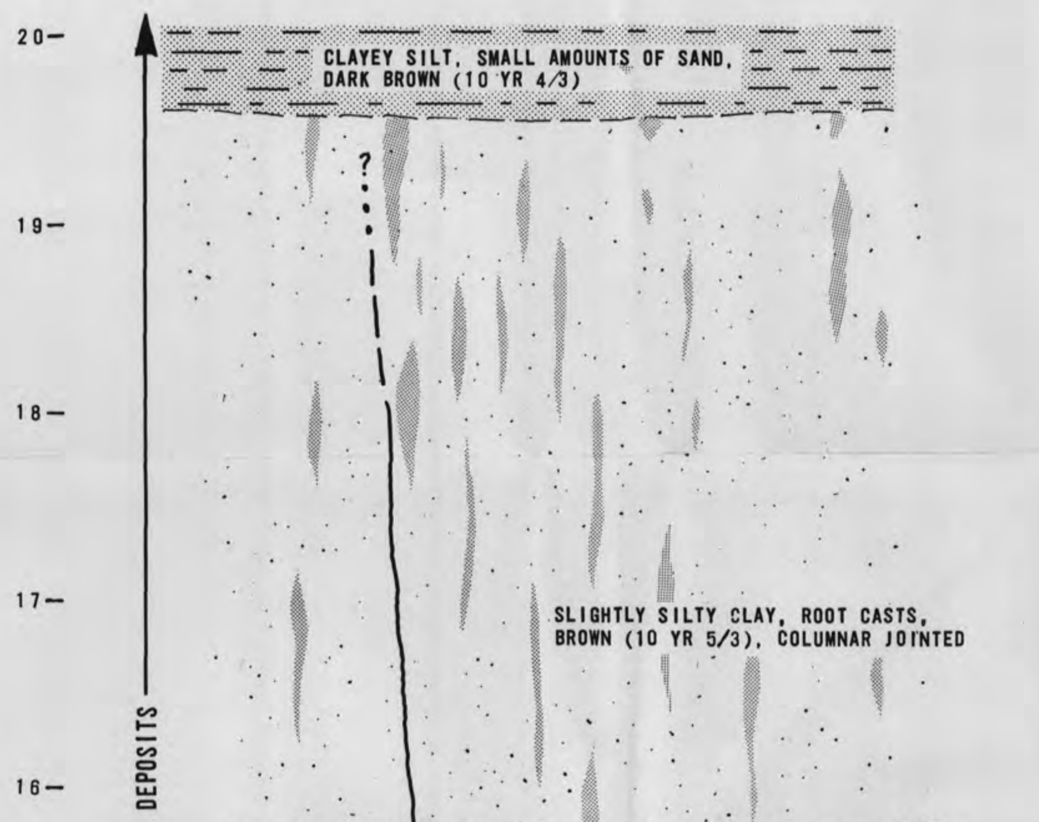
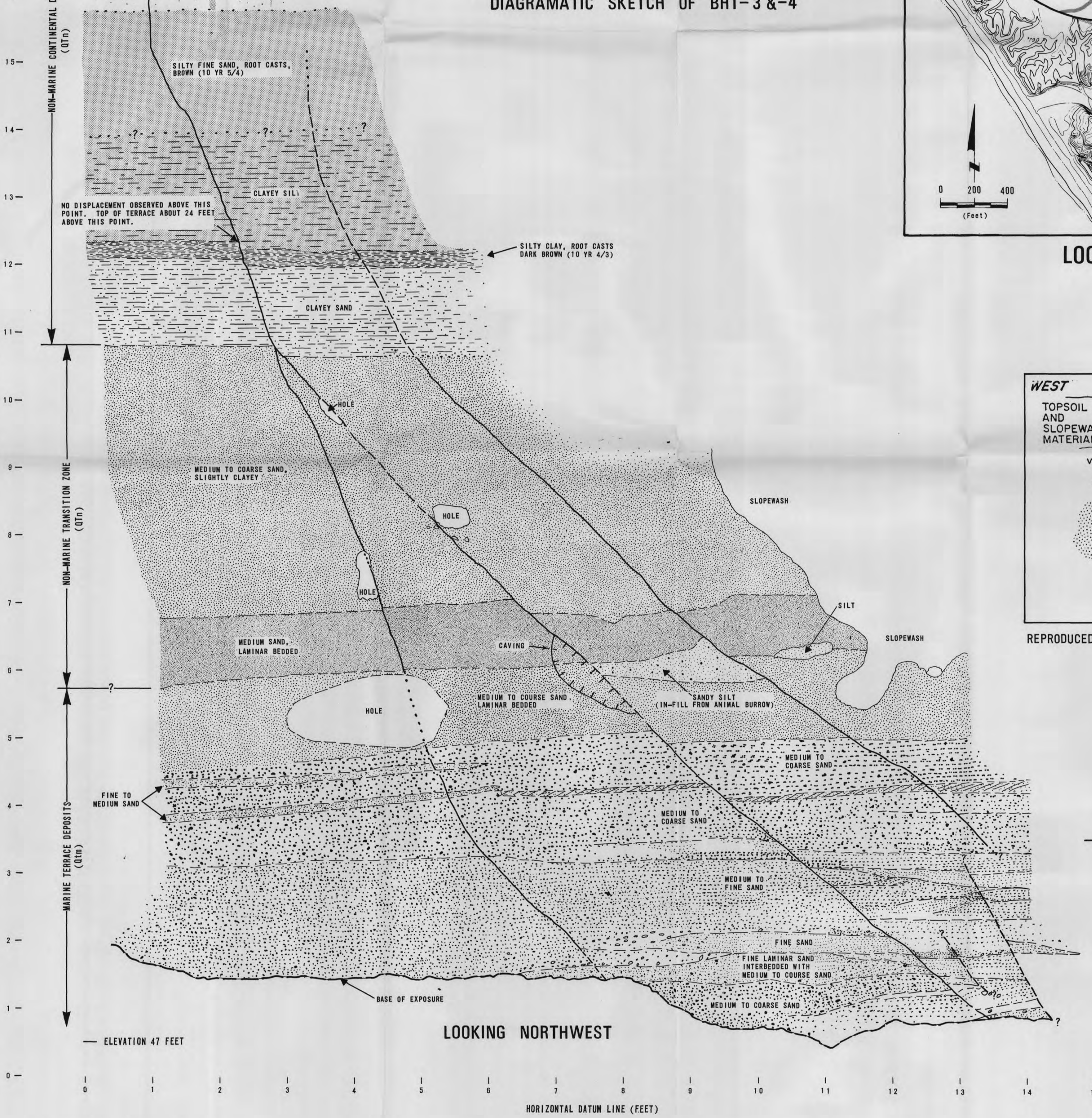
PHOTOGRAPH OF BHT-1

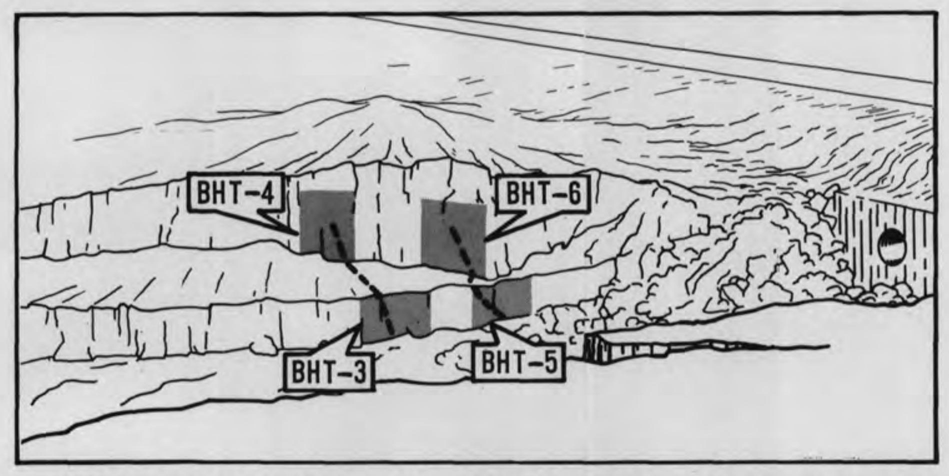


FUGRO	PROJECT NO.: 77-206-03
	S.O. UNITS 2 & 3 TARGET CANYON
	LOG OF BHT-1 AND BHT-2
10-77	FIGURE 4

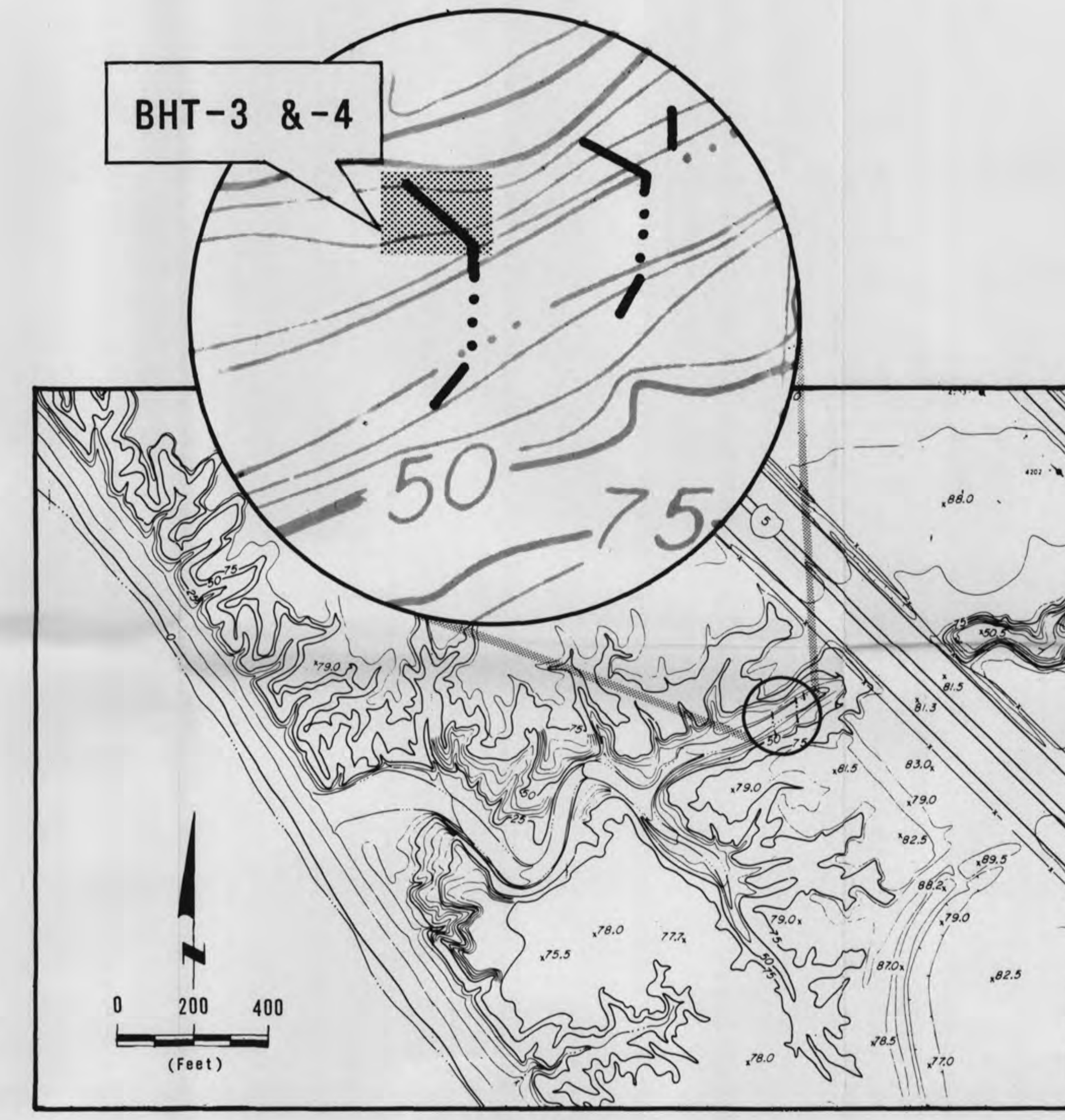
BHT-4

HORIZONTAL AND VERTICAL SCALE 1" = 1'

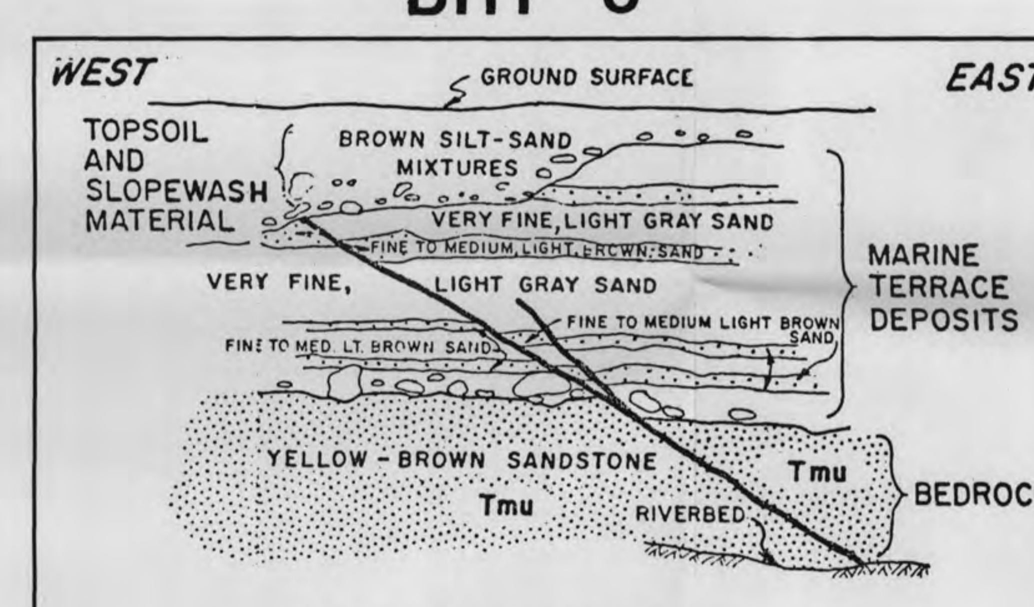


DIAGRAMATIC SKETCH OF BHT-3 &-4



LOCATION MAP

BHT-3



DETAIL SECTION X2

1" = ±2'

REPRODUCED FROM LADWP REPORT DATED 1971

EXPLANATION

OFFSET OR FRACTURE: SOLID WHERE WELL EXPOSED AND DISTINCT, DASHED WHERE POORLY EXPOSED, DOTTED WHERE INFERRED.

CONTACT: DASHED WHERE LOCATION IS DISTINCT, DOTTED WHERE APPROXIMATELY LOCATED OR GRADATIONAL.

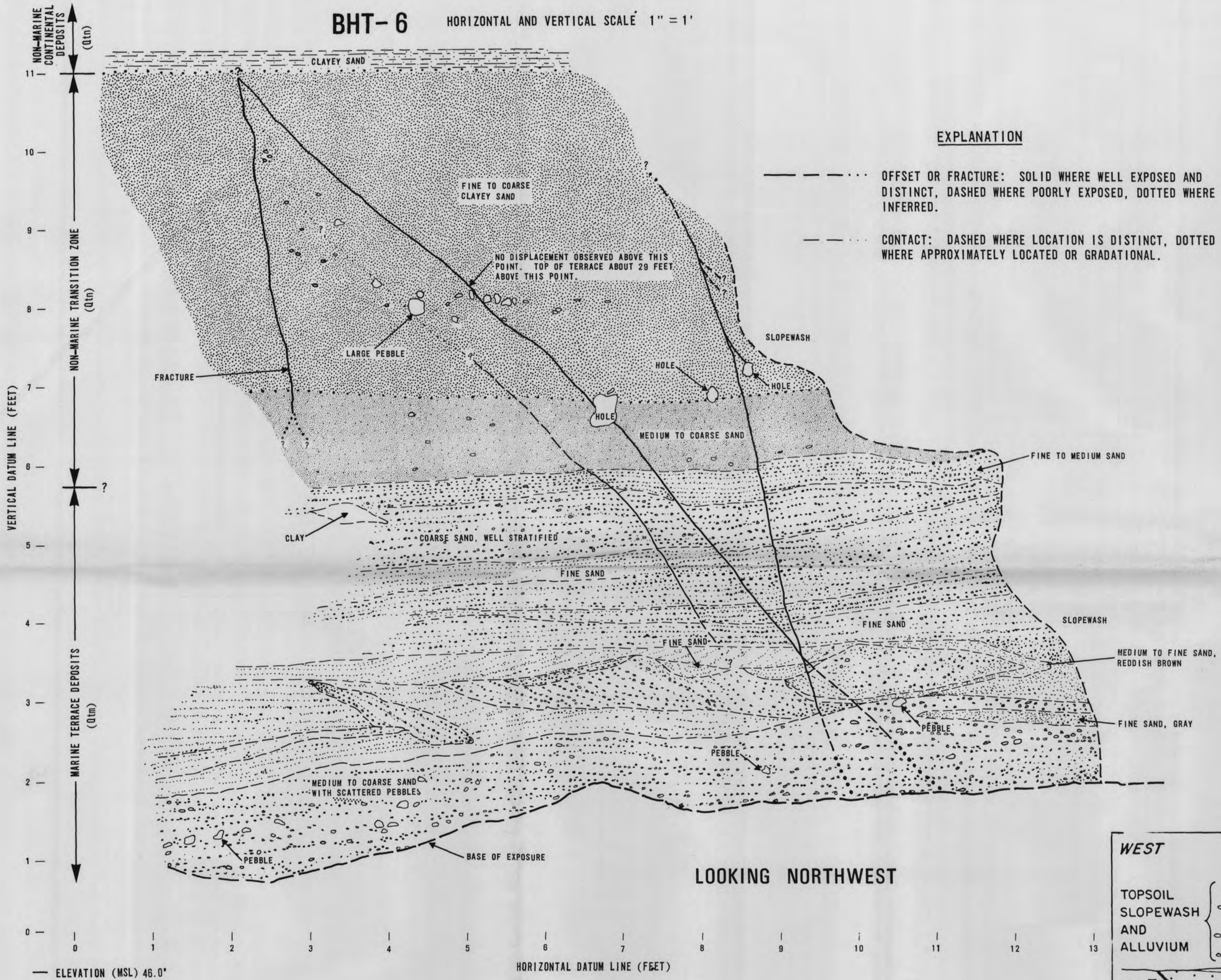
FUGRO | PROJECT NO.: 77-206-03
S.O. UNITS 2 & 3
TARGET CANYON

LOG OF BHT-3 AND 4

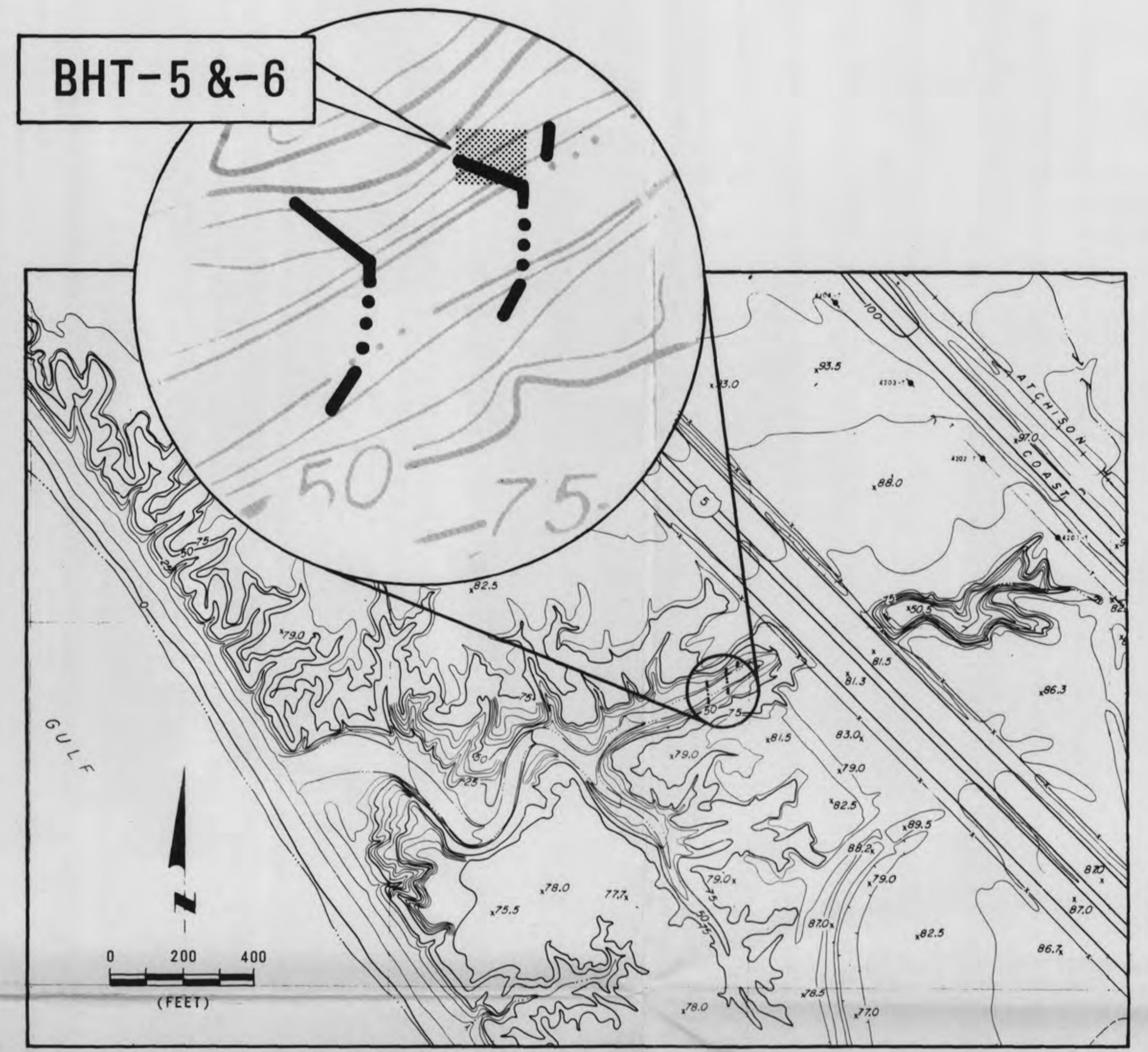
10-77 FIGURE 5

BHT-6

HORIZONTAL AND VERTICAL SCALE 1" = 1'

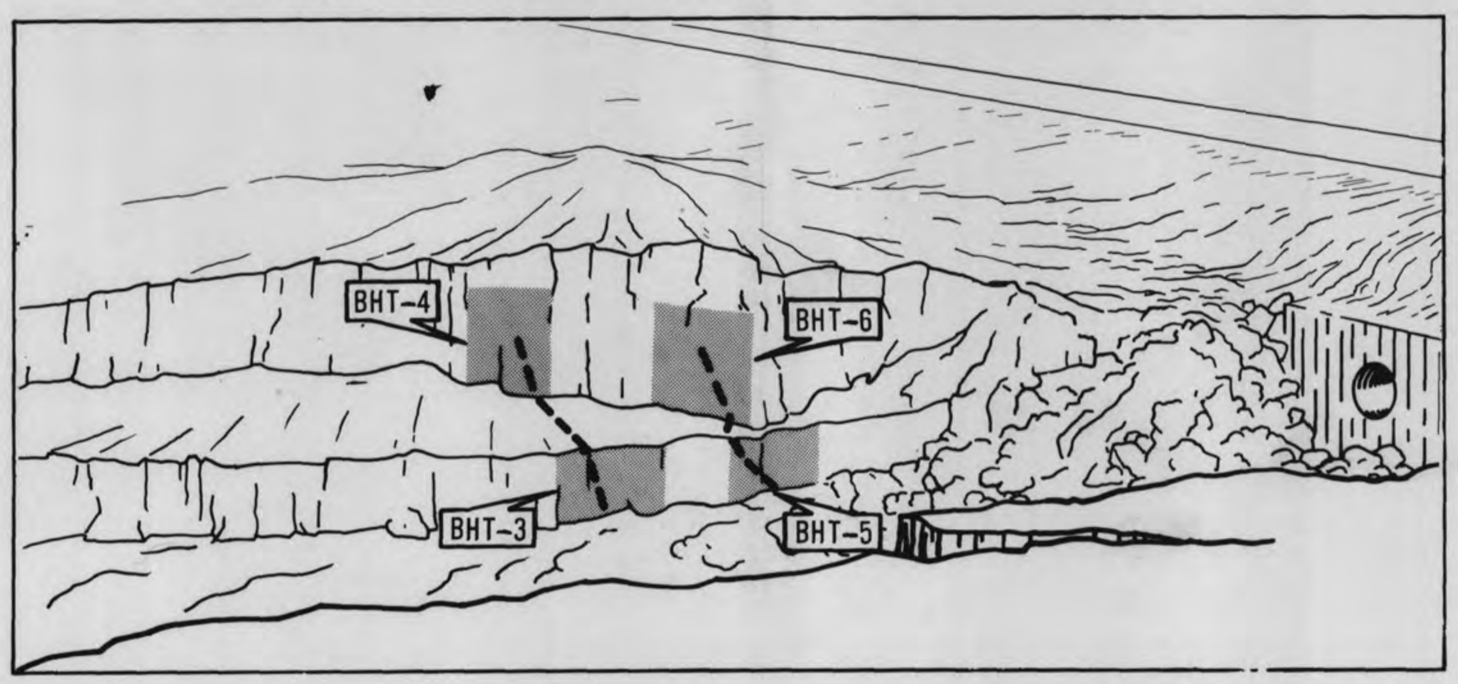


LOOKING NORTHWEST

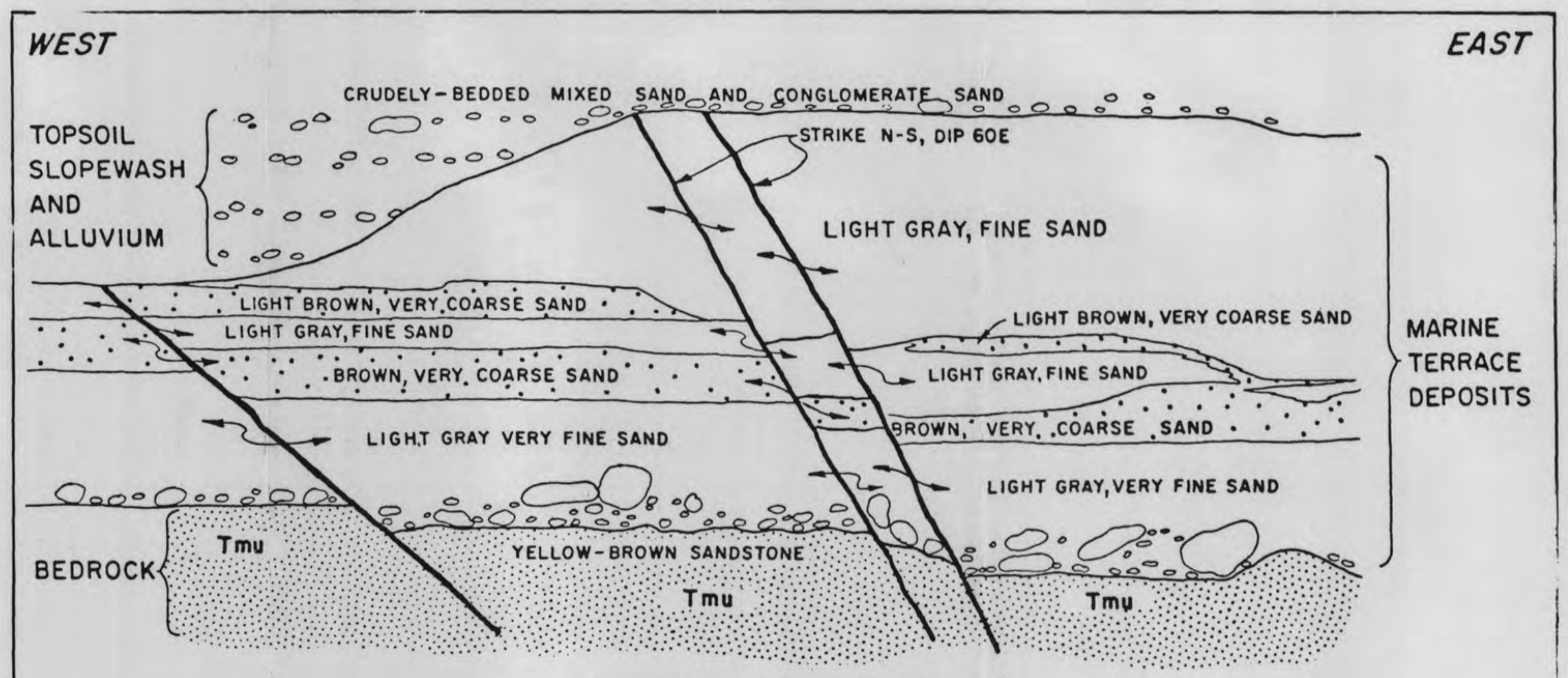


LOCATION MAP BHT-5 &-6

DIAGRAMATIC SKETCH OF BHT-5 &-6



BHT-5



DETAIL SECTION X_3

1" = ±10' (SIC)

REPRODUCED FROM LADWP REPORT DATED 1971

FUGRO	PROJECT NO.: 77-206-03 S.O. UNITS 2 & 3 TARGET CANYON
	LOG OF BHT-5 AND 6
10-77	FIGURE 6

ENCLOSURE 3

GEOLOGIC REPORT ON THE AREA ADJACENT TO THE SAN ONOFRE NUCLEAR GENERATING STATION NORTHWESTERN SAN DIEGO COUNTY, CA.

FOR:

SOUTHERN CALIFORNIA EDISON COMPANY
Rosemead, California 91770

BY:

PERRY L. EHLIG
South Pasadena, California 91030

September 31, 1977

GEOLOGIC REPORT

ON THE AREA ADJACENT TO THE

SAN ONOFRE NUCLEAR GENERATING STATION

NORTHWESTERN SAN DIEGO COUNTY, CALIFORNIA

by

Perry L. Ehlig

1560 Via del Rey

South Pasadena, California 91030

for

Southern California Edison Company

2244 Walnut Grove Avenue

Rosemead, California 91770

September 31, 1977

TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

This report, prepared at the request of Southern California Edison Company, is based on the study of a 60 square kilometer area extending from San Mateo Canyon on the northwest to Las Pulgas Canyon on the southeast and from the coast to the east side of the San Onofre Mountains. The San Onofre Nuclear Generating Station is in the northwestern corner of the subject area.

This report is based on:

1. Twenty two days (44 man days) of geologic mapping and field study by Perry Ehlig and his field assistant, Thomas Farley, during the period between July 17 and September 6, 1977;

2. the study of two sets of aerial photographs provided by Southern California Edison Company;

3. the review of published and unpublished reports on the geology of the area including pertinent parts of an earlier report on Units 2 and 3 of the San Onofre Generating Station and a report prepared for Los Angeles Department of Water and Power (1971).

4. discussions with staff geologists and consultants of Southern California Edison Company who are associated with the geologic investigation for Units 2 and 3 of the San Onofre Nuclear Generating Station; and

5. prior knowledge of the regional geology and a review of literature pertaining to it.

REGIONAL GEOLOGIC AND PHYSIOGRAPHIC SETTING

The area surrounding the San Onofre Nuclear Generating Station is in the southwestern part of the Peninsular Range Province of southern California. The main body of the province consists of ranges with a northwest-trending structural grain. Relief within and between ranges is due largely to differential erosion superimposed on broad regional uplift and warping. Differential uplift by faulting has occurred along branches of the Elsinore and San Jacinto faults and along the eastern margin of the province. (See FSAR Figure 2.5-6)

Basement rocks are exposed over much of the province. They include remnants of a thick sequence of Triassic and Jurassic sedimentary and volcanic rocks interspersed between Cretaceous batholithic rocks of granitic to gabbroic composition. The Mesozoic basement rocks are unconformably overlain by Upper Cretaceous and younger sedimentary strata in coastal areas and in the Los Angeles Basin, a structural depression that occupies the northwestern corner of the Peninsular Range Province.

The basement terrane of the Peninsular Ranges probably terminates at or near the northwest-trending South Coast Offshore Fault Zone which is about 5 miles offshore from San Onofre (see Figure 1). All observed basement rock to the west of the fault zone consists of Catalina Schist and associated rocks. This western basement is considered to be derived from a Franciscan assemblage of sedimentary and volcanic rocks that were deposited on oceanic crust and subsequently metamorphosed at great depth within a late Mesozoic subduction zone (Platt, 1975).

From the perspective of global tectonics, the Peninsular Range Province became a relatively rigid part of the North American continental plate following emplacement of Cretaceous batholithic rocks. Between the Cretaceous and Early Miocene the province appears to have been stable except for gentle westward tilting accompanied by erosion on the east and sedimentation on the west. During this time, interaction between the Farallon and North American plates was taking place to the west.

Reconstructions by Atwater and Molnar (1973) indicate the east Pacific Rise passed beneath the continental margin in the area of the Peninsular Ranges during Early to Mid-Miocene. This corresponds to a period of volcanism and great tectonic activity in the Los Angeles Basin and adjoining California Continental Borderland although little appears to have happened within the interior of the Peninsular Range Province.

Plate reconstructions in combination with data from land based geology suggest large magnitude right slip occurred along northwest-trending transform faults within the Continental Borderland during the Miocene. Commencing about 4.5 million years ago during Early Pliocene and continuing to the present, motion between the Pacific and North American plates has taken place primarily by spreading in the Gulf of California and right slip along the San Andreas fault and its branches (Atwater and Molnar, 1973). As a result of this, Baja California and the Peninsular Ranges have been detached from the North American plate and become part of the Pacific plate.

During the Pleistocene and Holocene the Peninsular Ranges have been uplifted and warped, probably as a result of interaction between the Pacific and North American plates. Much of the Quaternary deformation within the northern part of the Peninsular Ranges appears to be due to interplate compression along the bend in the San Andreas fault which extends from the northern end of the Salton Trough to the southern end of the Coast Ranges.

LOCAL GEOLOGIC AND PHYSIOGRAPHIC SETTING

Within the coastal area adjacent to the San Onofre Nuclear Generating Station there is a pronounced change in the bedrock geology across the north-northwest-trending Cristianitos fault. The area east of the fault belongs to a large, essentially intact structural block which extends from the Elsinore fault to the coast and includes the Santa Ana, Elsinore, Santa Margarita and San Marcos Mountains along with ranges further to the southeast (see Figure 1). The area west of the fault is part of the Capistrano Embayment, a northward-trending structural trough of Late Miocene and Early Pliocene age which interconnects with the Los Angeles Basin.

The structural block east of the Cristianitos fault has basement rock exposed over most of its surface. About 6 miles inland from the coast the basement terrane is unconformably overlain by a thick sequence of sedimentary rocks which dip southwestward toward the coast. The lower part of the sequence is Upper Cretaceous to Eocene in age and consists mainly of quartzofeldspathic sandstone derived from erosion of basement terrane to the northeast. Only the upper part of the Eocene La Jolla Group was observed during this investigation. Two to four miles inland from the coast, Eocene strata are overlapped by the Lower to Early Middle Miocene San Onofre Breccia.

The breccia has an average dip of about 35 degrees toward the southwest and a maximum exposed thickness of nearly 4600 feet. It consists of coarse schist debris which was deposited on alluvial fans emanating from a mountainous area southwest of the present coast. Because of its resistance to weathering and erosion, the breccia forms the San Onofre Mountains, a prominant northwest-trending ridge extending from Oceanside to San Clemente along the landward side of the coastal terrace. The Middle to Early Upper Miocene marine Monterey Formation unconformably overlies the San Onofre breccia and generally dips toward the southwest at low to moderate angles. It was deposited by a sea transgressing from the southwest (the direction from which the San Onofre breccia was derived) and includes a basalt conglomerate and sandstone member derived from erosion of the breccia. The bulk of the Monterey Formation consists of thin bedded siltstone, shale and sandstone in the northern part of the area and massive sandstone in the southern part. The Monterey Formation is the youngest bedrock formation present in the study area to the east of the Cristianitos fault.

To the west of the Cristianitos fault is the Capistrano Embayment, a relatively flat-bottomed structural trough trending about north 10 degrees west. The trough was a marine embayment during the Late Miocene and Pliocene but has subsequently been uplifted relative to sea level and is marked by hilly terrain. It is about 3.5 miles wide near the coast and gradually narrows toward the north. The San Onofre breccia and the Monterey Formation are exposed near its margins. Siltstone and sandstone of the Upper Miocene to Lower Pliocene marine Capistrano Formation constitute exposed bedrock within the interior of the trough. The Capistrano Formation has been gently folded in an irregular pattern. The formation is locally capped by subhorizontal siltstone and sandstone of the Upper Pliocene marine Niguel Formation. Sandstone of the Upper Miocene to Lower Pliocene San Mateo Formation crops out adjacent to the Cristianitos fault near the coast and underlies the San Onofre Nuclear Generating Station.

Pleistocene marine terraces are well developed along this part of the southern California coast. The lowest terrace has an average width of about one half mile and is continuous except where interrupted by major drainage courses. It is mantled by marine and non-marine deposits. Numerous higher terraces are present on the southwest flank of the San Onofre Mountains. The highest terrace mantled by beach gravel is at 1,275 feet above sea level. Higher benches of probable marine origin but lacking marine deposits occur as high as 1,500 feet above sea level. The highest terraces may be Pliocene in age. River terraces are present in inland areas but were not encountered during this study except locally adjacent to Las Pulgas, San Onofre and San Mateo Canyons.

The Cristianitos fault is the only major fault in the area. It has an average strike of north 18 degrees west and dips steeply toward the west. Normal dip-slip displacement occurred along the Cristianitos fault in association with development and deepening of the Capistrano Embayment during the Late Miocene and Early Pliocene. The fault has not moved since formation of the lowest marine terrace and has probably been inactive since the Pliocene.

Minor faults are present in many places within the San Onofre breccia but are not generally traceable beyond individual outcrops. Four faults have been mapped because they displace the unconformity between the Monterey Formation and the San Onofre breccia. All four are subparallel to the Cristianitos fault but three have a reverse sense of displacement opposite to that of the Cristianitos. None appear to have been active during the Late Pleistocene or Holocene.

STRATIGRAPHY

DESCRIPTION AND ORIGIN OF FORMATIONS

La Jolla Group

Medium to thick bedded friable sandstone composed of quartz, feldspar and biotite underlies the San Onofre breccia along the north flank of the San Onofre Mountains. In most places the sandstone is covered by soil or slope debris. During our limited examination of the sandstone we found no fossils. Since it has previously been mapped as part of the Eocene La Jolla Group (Moyle, 1973), we have designated it as such on the geologic map (Figures 5, 6 and 7).

Sandstone similar to that described above underlies the San Onofre breccia on the ridge between San Onofre and San Mateo Creeks. We designate it as Eocene La Jolla Group on the geologic map although part of it was previously mapped as the Monterey Formation (Moyle, 1973). It is clearly not part of the Monterey Formation as used in this report and it may belong to the Lower Miocene Topanga or Vaqueros Formations. These units were not differentiated from the underlying La Jolla Group during this study.

San Onofre Breccia

The San Onofre breccia of this area has previously been described by Woodford (1925) and Stuart (1975). Most of the formation is a repetitious sequence of coarse, poorly sorted and irregularly bedded breccia containing sedimentary structures typical of alluvial fan deposits. Clasts within the breccia are angular to subangular and are exclusively of metamorphic rock types characteristic of the Catalina Schist and other basement rocks associated with it. Common clast types include: blue-gray glaucophane schist varying from very fine grained schist to schist with abundant epidote crystals as much as 1.5 inches long; gray-green schist composed of variable amounts of chlorite, actinolite, epidote and albite; dark gray muscovite-albite schist; quartz schist derived from chert and containing such minerals as riebeckite, muscovite, manganiferous garnet and piedmontite; milky-white vein quartz; dark colored amphibolite and garnet amphibolite; metagabbro and metaserpentinite. Most clasts fall within the size from granules to small boulders but clasts 3 to 6 feet long are present in many places and the largest observed clast is 43 feet long.

The coarseness of the San Onofre breccia increases from south to north along the San Onofre Mountains and from the base upward within the lower part of the formation. Relatively fine grained sediments representing distal fan deposits are common near the base of the formation throughout the area. Between Horno and Las Pulgas Canyons they comprise the lower 330 feet of the formation and consist of interbedded granule to pebble breccia, sandstone and sandy mudstone varying from light brown to reddish brown in color. Bedding planes tend to be parallel to each other and are commonly well developed in sandstone. Sandy mudstone beds representing old soil horizons are internally massive and grade from brown near the base to red-brown at the top.

The middle and upper parts of the formation appear to represent rapid accumulation on a relatively steeply sloping alluvial fan.

The most abundant lithology is breccia with clasts ranging from pebbles to small boulders in size and showing clast to clast support. Tabular schist clasts within the breccia tend to have their broad surfaces in subparallel alignment. Clast imbrication is common and characteristically indicates sediment transport from the southwest to the northeast. The matrix between clasts consists of granule- to silt-sized particles derived from mechanical abrasion of the clasts. The fine grained part of the matrix is rich in chlorite and muscovite. Interspersed between breccia beds are thin discontinuous beds of sandstone. The sandstone has the same composition as the matrix of the breccia. Bedding varies considerably in orientation from place to place within individual sandstone beds as well as from one sandstone bed to the next. When seen in fresh exposures, the material forming the sandstone and the matrix of the breccia is greenish gray in color and appears to have experienced little weathering prior to deposition. The red coloration seen in many places along the south flank of the San Onofre Mountains is a surficial weathering feature caused by prolonged exposure during the Quaternary.

Coarse, internally massive beds of probable mudflow origin are fairly common within the middle and upper parts of the formation. Clasts generally show little preferred orientation and are enclosed within a greenish gray, muddy matrix having essentially the same composition as the clasts.

In several places there are thick massive units interpreted to be avalanche deposits. The individual units are typically monolithologic and consist of tightly packed angular fragments of highly variable size.

Tuff beds and tuffaceous sediments occur in a few places. Most are composed of fine grained ash and alteration products derived from ash. The only tuff bed which was traced more than a hundred feet occurs in the highest exposed part of the formation directly northeast of the landward edge of the lowest marine terrace between map grid locations 20,500 feet southeast and 33,800 feet southeast. The tuff is exposed at 9 locations distributed over a distance of 2.5 miles as shown on the geologic map. The main part of the tuff consists of fairly well sorted, closely packed, cream-colored pumice lapilli. The most southeasterly exposure is estimated to be about 16 feet thick, lacks visible bedding and contains angular fragments as much as 2.5 inches long of a dense black volcanic rock scattered among the pumice lapilli. It is interpreted to be an airfall deposit at this location and is probably quite close to the vent. In the northwestern exposures part of the tuff was transported by water as shown by bedding.

The tuff is important because all 9 exposures are in linear alignment parallel to the strike of bedding in the San Onofre breccia. This indicates a lack of significant cross-cutting faults within the 2.5 miles interval in which the exposures occur.

The San Onofre breccia has a maximum exposed thickness of about 4900 feet as shown by cross sections E-E' (Figure 9 of this report). The thickness shown may vary by several percent because of uncertainty concerning the mean dip of bedding and because of possible repetition of strata by minor faults. The exposed thickness is greatest in the vicinity of San Onofre Mountain and this southward due to original lensing in this direction and thins northward due to unconformable overlapping by the Monterey Formation. The entire thickness is of nonmarine alluvial fan origin. Stuart (1975) refers to the presence of marine fossils within the San Onofre breccia of this area; however, the strata which contain marine fossils are assigned to the Monterey Formation in this study.

The San Onofre breccia is of Late Lower to Early Middle Miocene age as shown by its stratigraphic position. The age of the strata immediately underlying it is not known within this area.

The lower part of the Monterey Formation which unconformably overlies the San Onofre breccia in this area contains abundant fossils of Middle Miocene age.

The San Onofre breccia is a product of tectonic activity within the nearshore part of the Continental Borderland. It was derived from a landmass southwest of the present coast as shown by paleocurrent directions derived from clast imbrication and by the fact that clast types are characteristic of Catalina Schist terrane which is only known to occur to the west of the present coast. (see Stuart, 1975, for greater detail). The coarseness and thickness of the breccia is characteristic of accumulation along a fault scarp adjoining a subsiding basin. The source area must maintain high relief in order to deliver coarse debris while at the same time the crust beneath the alluvial fan must be subsiding in order to allow thick deposits to accumulate. It should be noted that although the San Onofre breccia has been referred to as an alluvial fan deposit, it actually represents a coalescence of fans derived from several drainage systems emanating from a relatively linear range front. This is shown by the fact that the types of clasts present and their relative abundances vary along the trend of the range and by the fact that paleocurrect directions are subparallel along the trend of the range rather than being arranged in a fan shape. Deposits interpreted to be of avalanche origin and some of the very coarse debris, including a block 43 by 27 by 19 feet and another 38 by 27 by 13 feet, may have originated by landsliding from a steep mountain front or escarpment.

Monterey Formation

In the coastal area southeast of the Cristianitos fault the non-marine San Onofre breccia is unconformably overlain by marine strata which vary in their gross lithology both laterally, parallel to the trend of bedding, as well as stratigraphically upward perpendicular to bedding. This has led to uncertainty concerning the assignment of formation names and has resulted in conflicting assignments among prior geologic reports on the area. The problem has been resolved by the dating of microfossil assemblages from 14 widely scattered localities within the area between the Cristianitos fault and Las Pulgas Canyon (Figure 3). All of the microfossil assemblages are of Middle to Early Upper Miocene age (Table 1). Marine strata of this age are traditionally assigned to the Monterey Formation in coastal areas of California and are so assigned in this report. (Anderson, Warren, 1977, Appendix A)

In the area of the Capistrano Embayment to the west of the Cristianitos fault, Woodford (1925, p. 216-217) established the Capistrano Formation to include Upper Miocene and Lower Pliocene marine shale and sandstone which conformably overlie shale of the Monterey Formation but are lithologically different from it. Although the two formations are different in their gross appearance, they contain overlapping lithologies such as diatomaceous shale. This causes uncertainty concerning placement of the contact between the two formations. Our formational assignments are consistent with those of Blanc and Cleveland (1968) who have mapped the contact in the area north of San Clemente. It should be recognized that the Capistrano Formation is a local name. Had it not been established, the Upper Miocene strata included within it would either be referred to as part of the Monterey Formation or the Puente Formation, a local formational name used to the northwest of this area.

The base of the Monterey Formation is exposed in several places near the northwest end of the San Onofre Mountains. The base is concealed beneath deposits mantling the lowest marine terrace in most of the area southeast of the Cristianitos fault and lies at depth beneath the Monterey and younger formations in the area west of the Cristianitos fault.

The basal part of the formation consists of conglomerate and coarse grained sandstone derived from erosion of the San Onofre Breccia. These basal deposits are as much as 160 feet thick in the area upslope from the lowest marine terrace between map grid locations 6,000 and 12,000 feet southeast. A series of small sand and gravel borrow pits have been excavated in the basal member adjacent to the old highway in this area and provide good exposures. The basal member can be distinguished from the underlying San Onofre breccia by (1) better sorting of clasts and an absence of clasts larger than cobbles, (2) the presence of better rounded clasts, (3) the absence of silt and clay from the matrix of the sandstone and conglomerate, (4) the local occurrence of shells, particularly oyster and pectin shells, and (5) the presence of light colored calcareous material filling the spaces between clasts in some beds. The basal member was previously mapped as part of the San Onofre breccia by Woodford (1925) and Stuart (1975). However, the two formations are separated by an angular unconformity and represent very different depositional environments. The San Onofre breccia was deposited by an alluvial fan emanating from the southwest whereas the Monterey Formation was deposited by a sea encroaching from the southwest.

In the area described above there is a buttress unconformity between the Monterey Formation and the San Onofre breccia as illustrated in Figure 2. The relationships are best seen in the vicinity of a flat-topped ridge near map grid location 9000 feet southeast, 4,500 feet northeast. Bedding within the San Onofre breccia has an average dip of about 37 degrees to the southwest in this area. The unconformity dips about 30 degrees to the southwest as shown by its outcrop pattern. A resistant calcareous conglomerate unit, 10 feet thick, underlies and structurally controls the crest of the flat-topped ridge. The conglomerate unit dips 12 degrees toward the southwest and converges with the unconformity at its uphill end. The conglomerate unit is made up of a series of foreset beds which dip about 40 degrees toward the southwest and represent a seaward prograding of beach derived material, perhaps following deep scour by a severe storm. A good view of these relationships can be obtained by taking the powerline road to the crest of the ridge southeast of the site. Similar relationships are present elsewhere in this general area. The buttress unconformity may represent deposition of sediment against a submerged and erosionally flattened wave cut cliff.

To the north-northwest of the above location, the thickness of the basal sandstone and conglomerate member decreases and bedding within it becomes subparallel to the underlying unconformity. Both dip gently toward the southwest at an angle of about 25 degrees less than the dip of the underlying San Onofre breccia. This probably reflects transgression of the Monterey sea across a subhorizontal erosion surface cut across breccia dipping 25 degrees to the southwest.

On the ridge between San Onofre and San Mateo Canyons, the base of the Monterey Formation overlaps the base of the San Onofre breccia and rests upon the underlying Eocene sandstone. In part of this area the basal sandstone and conglomerate member is no more than 3 feet thick. Diatomaceous and calcareous shale are directly above the unconformity.

From the Cristianitos fault southeastward to Las Pulgas Canyon, the Monterey Formation is well exposed in the lower part of the sea cliffs and in the mouths of canyons in areas not affected by landslides. The exposed beds occupy a relatively thin stratigraphic interval which is probably 100 to 150 feet above the base of the

Monterey Formation in most places (see cross sections CC', DD' and EE' Figures 8 & 9). The lithology of the Monterey Formation undergoes lateral facies changes along this segment of the coast. Close to the Cristianitos fault the exposed strata consist of dark brown to greenish gray thin bedded siltstone and clayey siltstone with thin tuff beds scattered through the section, near grid location 13,500 southeast exposed strata consist of interbedded clayey siltstone and fine grained arkosic sandstone rich in biotite. Southeast of grid location 18,000 feet southeast the exposed strata consist mainly of coarse grained arkosic sandstone. From grid location 28,000 feet southeast to Las Pulgas Canyon the exposed strata are almost entirely massive coarse grained arkosic sandstone. This change in lithology is due to lateral changes in the depositional environment. The massive sandstone along the southeastern part was probably deposited by grain flow near the head of a submarine fan. Thin bedding siltstone near the Cristianitos fault probably represents pelagic sediments deposited on a flat-bottomed ocean floor. Strata exposed in between the two areas probably represent the zone of interfingering between fan derived sediment and pelagic sediments.

South of the area shown on the Geologic Map, the arkosic sandstone is exposed along the coast near Las Pulgas Canyon may have been transported down a submarine channel which had approximately the same location as Las Pulgas Canyon. The Monterey Formation exposed on the west side of Las Pulgas Canyon at fossil locality 27B-1 (see Table I) (map grid SE38420 ft., NE 11360 ft.) consists of very thin beds of fine grained biotite-rich arkosic sandstone separated by diatomite partings. One of the beds contains a mat of fish fossils. This sequence of strata which has an exposed thickness of about 16 feet is truncated on the southeast by massive coarse grained arkosic sandstone. The contact between the two is steeply inclined but irregular and clearly of sedimentary origin.

Only massive arkosic sandstone is exposed across the entire hillside to the southeast. Based on the above relationships, the sandstone appears to be backfill within a submarine channel.

The upper part of the Monterey Formation is exposed to the west of the Cristianitos fault between San Onofre and San Mateo Canyons. It consists of thin bedded diatomaceous siltstone and clayey siltstone with thin ash beds present at fossil locality 57B-2.

Fossil localities are shown on Figure 3 and data pertaining to them are summarized in Table 1. Microfossil assemblages were analyzed by Anderson, Warren and Associates, Inc., (1977, Appendix A) from 14 localities within the Monterey Formation to the east of the Cristianitos Fault and from 4 localities in the Monterey Formation and 2 localities within the lower part of the Capistrano Formation to the west of the Cristianitos fault.

The microfossil data indicate most of the Monterey Formation east of the Cristianitos fault belongs to the Luisian Stage of the Middle Miocene. This is equivalent to an absolute age of 14 $\pm$ 1 million years according to correlation charts currently in use. (Anderson, Warren and Assoc., 1977, Appendix A.) Microfossils from 3 localities east of the fault belong to the Lower Mohnian Stage of the Early Upper Miocene. This equates to 13 $\pm$ 1 million years according to Anderson, Warren and Assoc., (1977, Appendix A). An additional locality east of the fault gives a less diagnostic age of probable Upper Miocene.

Of the four microfossil localities in the Monterey Formation to the west of the Cristianitos fault three indicate a Late Miocene age and one indicates a Middle Miocene age. The strata at locality 49A-1, which yields a Middle Miocene age, are strongly deformed and have probably been dragged upward along the Cristianitos fault. Microfossils from locality 49C-1 belong to the Upper Mohnian Stage of the Upper Miocene and are equivalent to an absolute age of between 9 and 12 million years. This locality is several feet below the base of the San Mateo Formation and represents the youngest part of the Monterey Formation in this area.

The Monterey Formation was deposited during a period of relatively rapid subsidence (or rise in sea level). Part of the basal sandstone and conglomerate were deposited within the surf zone and contain shallow water oyster and pectin shells. Yet the diagnostic microfossil assemblages indicate bathyal depths of 600 to 1200 feet. Localities 49C-2 and 58A-1 are within a few feet of the base of the Monterey Formation yet both indicate middle bathyal depths during the Luisian Stage. As a result of the relatively rapid increase in water depth, the near shore topography was probably fairly rugged during deposition of the lower part of the Monterey. This is probably the reason for the relatively abrupt lateral and vertical changes in the lithology of the Monterey Formation in this area.

Capistrano Formation

The Capistrano Formation occurs within the Capistrano Embayment where it overlies the Monterey Formation with apparent conformity. Only a few exposures of this formation were observed along the west side of San Mateo Canyon during the present investigation. The exposed strata consist of interbedded siltstone, mudstone and fine grained biotite-rich arkosic sandstone. Diatomaceous siltstone occurs with the above lithologies at fossil localities 57D-1 and 57D-2, to the north of the Geologic Map area.

The transition between the Capistrano Formation and underlying Monterey Formation is exposed in section 27 (T.8S.R.7W.) directly northwest of the study area. Here, the upper part of the Monterey Formation consists of thinly interbedded diatomaceous siltstone and clayey siltstone. The basal part of the overlying Capistrano Formation consists of interbedded mudstone, clayey siltstone and fine grained biotite-rich sandstone. This grades upward into a more thickly bedded sequence dominated by fine to medium grained sandstone rich in biotite.

The Capistrano Formation is of Late Miocene and Early Pliocene age as determined from foraminifera by White (1956). Localities 57D-1 and 57D-2 on the west side of San Mateo Creek yielded microfossils indicating a probable Late Miocene age. The study by White (1956) indicates much of the Capistrano Formation was deposited at bathyal depths of 600 to 12,000 feet.

San Mateo Formation

The San Mateo Formation forms the bedrock beneath the San Onofre Nuclear Generating Station and is well exposed in the sea cliffs adjacent to the station. Strata specifically designated as belonging to the San Mateo Formation crop out in a relatively small triangular area bounded by the Cristianitos fault on the east, by the coast on the southwest and, on the north, by a line trending south 70 degrees west from where the Cristianitos fault crosses San Mateo Creek.

Within the area covered by the geologic map, the San Mateo Formation is primarily composed of massive, coarse grained, light yellow-brown to light gray arkosic sandstone. Discernible bedding is rare in most exposures. Lenses of pebble-cobble conglomerate occur in a few places. Clasts within the conglomerate are rounded and include volcanic and granitic rocks along with rocks reworked from the San Onofre breccia. The upper part of the formation contains broad open cross beds in exposures north of Basilone Road about 1/2 mile east of the Camp Pendleton entrance.

The San Mateo Formation is only slightly deformed except in areas close to the Cristianitos fault. In areas where bedding is present, it commonly varies in orientation due to initial deposition on sloping surfaces.

The maximum thickness of the San Mateo Formation within its outcrop area is estimated to be less than 1000 feet. The formation extends from the surface to a depth of 900 feet beneath San Onofre Nuclear Generating Station (FSAR Section 2.5.4.2.1.3). Since bedding is gently inclined the vertical thickness should be close to the true stratigraphic thickness in this area.

The San Mateo Formation appears to be entirely of marine origin. The massive coarse grained sandstone comprising the lower part of the formation near the Cristianitos fault was probably transported by grain flow and could have been deposited within a wide range of water depths. Broadly cross bedded sandstone in the upper part of the formation might also have formed in a wide range of depths but by current action. The sand within the formation was probably transported into this area by the ancestral drainage systems to San Onofre and San Mateo Creeks. The formation probably represents the backfilling of a submarine channel which extended from the mouths of the two creeks. Localization of the formation to this area may have been due to the creation of a structural trough along the down thrown side of the Cristianitos fault. Channels might also have been eroded by sediment being transported from the Capistrano Embayment into a deeper open-ocean basin to the southwest.

The San Mateo Formation has not yielded fossils or other material suitable for dating. Stratigraphic relationships bracket its age as between Early Late Miocene and Late Pleistocene. Its age is generally interpreted to be younger than the Capistrano Formation because it overlies the Capistrano Formation in the area west of San Mateo Creek. However, exposures of the San Mateo Formation in the cliffs along San Clemente State Beach have been examined and it is believed they represent turbidite deposition within a submarine channel within the Capistrano Formation. The San Mateo Formation is well bedded in this area, and displays the Bouma (1962) sequences of turbidite structures. Very similar deposits occur as channel backfills within the Capistrano Formation near Dana Point and are described by Bartow (1966) and Piper and Normark (1971). Therefore, the San Mateo Formation is probably a facies of the Capistrano Formation. The lower part of the San Mateo Formation might be Late Miocene in age and could have been deposited synchronous with the lower part of the Capistrano Formation. The upper part of the San Mateo formation is probably Early Pliocene in age where it rests against the Capistrano Formation at San Clemente State Beach.

Marine Terraces and Associated Deposits

The seaward flank of the San Onofre Mountains contains a remarkable number of marine terraces consisting of wave cut benches which are in part mantled by marine and non-marine deposits. The lowest terrace forms the coastal plane and is essentially intact. Terraces above an elevation of about 450 feet are only locally well preserved due to the combined effects of undercutting of higher terraces during formation of lower terraces and subsequent erosion associated with downcutting of canyons. Deposits on terraces above the elevation of 450 feet are limited to beach gravel and fine grained sediments filling in around the gravel. Much of the gravel is concentrated in beach bars which are in linear alignment from one terrace to the next. The highest occurrence of beach gravel is at an elevation of 1275 feet. Remnants of what appear to be wave cut benches extend to an elevation of about 1550 feet. The crest of the mountains is marked by a gently sloping erosion surface which is probably of non-marine origin.

Marine terraces are not shown as such on the geologic map; only the terrace deposits are shown. Deposits designated as marine in origin consist mainly of pebble-cobble gravel on all but the lower terraces. Beach gravel is easy to distinguish from gravel derived directly from the San Onofre breccia because it is well rounded and is dominantly composed of rock types not found in the San Onofre breccia. The most abundant rocks are volcanic in origin. They probably came from outcrops of the Jurassic Santiago Peak Volcanics in the Santa Margarita Mountains and were transported to the coast by San Mateo, San Onofre and Horno Creeks. Granitic rocks make up a small part of the beach gravel. Their principal source appears to have been Horno Canyon since they are considerablely more abundant to the southeast of it than to the northwest. Beach drift was from northwest to southeast (as it is today) as shown by the symmetry of scallops in the old shorelines. A moderate amount of the beach gravel is derived by reworking of clasts from the San Onofre breccia. Unlike the angular to subangular clasts in the breccia, it is well rounded and, in the case of quartz-rich clasts, typically shows percussion marks from having been tossed in the surf. Beach armor is common at the base of beach gravel deposits and the upper surf zone downslope from the beach. The armor consists of boulders derived from the San Onofre breccia which were too large to be transported by the surf. They show rounding and sculpturing from abrasion by sediment being moved by the surf.

Marine terraces are generally assumed to be Pleistocene in age and to relate to glacially induced changes in sea level. In areas such as this where terraces occur at high elevations, the terraces are assumed to have been uplifted by tectonic processes. If the above assumptions are applied to the San Onofre area, questions concerning the tectonic stability of the area must be considered. Data collected during this study, indicate the marine terraces in this area represent a gradual recession of sea level since Lower Pliocene and is a feature which affects the entire region, not just the San Onofre Mountains. Evidence for this conclusion are developed below.

The first question is whether the observed terraces are essentially a regressional sequence with the oldest at the top and the youngest at the bottom. With one minor exception, the terraces appear to be a recessional sequence. Terraces undoubtedly formed during eustatic low stands in sea level but were later reworked when the bench was reoccupied by the long-term lowering of sea level. This conclusion is supported by the following three lines of evidence.

First, there should be an overlapping of terrace deposits if higher terraces are younger than lower ones. Only one example of this has been observed and it only involves an increase of about 30 feet in terrace level. This example is exposed in the canyon opposite grid location 29,500 feet southeast. The base of the lower terrace is at elevation 370 feet and the base of the overlapping terrace is at an elevation between 400 and 405 feet. The head of the higher terrace is no more than a few tens of feet further inland than the head of the lower terrace. In the case of the higher terraces, only gravel deposits are present but they are concentrated in bars with a relatively clean wave cut bench downslope from each bar. Had higher terraces formed after lower ones, debris transported down slope during formation of the higher terraces should have been deposited over the lower terrace. Even if later erosion removed all fine grained material, a layer of lag gravel should blanket the lower terrace. Such deposits have not been observed.

A second reason for believing the terraces were formed by a long term lowering of sea level is that in many places the higher terraces have been removed by undercutting during formation of lower terraces. The position of the higher terraces is occupied by a faceted ridge representing the remants of a wave cut cliff of a lower terrace. Had the higher terraces formed after lower ones, they should be marked by continuous wave cut benches which truncate the top of the wave cut cliff at the head of the lower terrace.

The third reason relates to the occurrence of volcanic clasts in the terrace gravel. The nearest source for the gravel is the Santa Margarita Mountains, a minimum of 4 miles to the northeast. The area northeast of the San Onofre Mountains is presently occupied by the broad deep valleys of San Mateo, San Onofre and Horno Creeks. These valleys could not have been eroded below the level of the marine terraces at the time the terraces formed. Had they been deeper they would have been unable to deliver the gravel which occurs on the terraces. The above valleys do contain river terraces indicating oscillations in base level but the oscillations are small compared to the total relief within the valley.

The higher terraces on San Onofre Mountain are probably Pliocene in age and probably correspond to a decline in sea level near the close of deposition of the Capistrano Formation. As explained in the discussion of the Cristianitos fault, the Capistrano

Formation was deposited in 2000 to 4000 feet of water. During its deposition the marine strand line was along the base of an upland erosion surface which extends across the Peninsular Ranges to the north and northeast of this area. A decline in sea level occurred in late Pliocene time. The Upper Pliocene Niguel Formation1 which caps the Capistrano Formation at elevations between about 400 and 700 feet above sea level in the Capistrano Embayment, is of shallow marine origin. It reflects a recession in sea level. There is no evidence of younger marine terrace deposits overlying the Niguel Formation in inland areas. Had sea level risen during the Pleistocene to create the terraces on the San Onofre Mountains, there should be a record of this rise in the form of Pleistocene marine deposits in low lying inland areas, such as around El Toro. Pleistocene marine deposits are not known to occur in these areas.

High level marine terraces are known in other areas of southern California. Marine terrace deposits cap the crest of the San Joaquin Hills to the northwest of this area at an elevation of 1000 feet. They occur up to about 1300 feet in the Palos Verdes Hills. The terraces are referred to as Pleistocene but none of the high level terraces have been dated. All of the area surrounding the Los Angeles basin was occupied by deep water during Early Pliocene. The high level terraces may reflect the recession of the Early Pliocene sea.

The marine terraces within the study area show no evidence of major deformation since their formation. Data are inadequate to determine if there has been small scale deformation. In the case of the lowest marine terrace, the elevation of its base varies regionally in exposures along the coast. However, this probably reflects the extent to which the wave cut bench has been removed by erosion.

The elevation along the head of the lower 100 to 200 foot present day terrace varies from place to place also but this reflects variation in the thickness of deposits overlying the marine platform.

Elevations are high in areas where minor drainage systems have deposited alluvial fans across the terrace surface. Elevations are low adjacent to major drainage systems, such as Las Pulgas Canyon where channels are adjusted to modern sea level.

GEOLOGIC STRUCTURE

Cristianitos Fault

The Cristianitos fault crosses the coast .9 miles southeast of San Onofre Nuclear Generating Station. Here, it is well exposed in the sea cliff. The fault plane has an average strike of about north 32 degrees east and an average dip of 58 degrees to the southwest. Well developed slickensides trend subparallel to the dip. Sandstone of the San Mateo Formation forms the west wall of the fault and thin bedded siltstone of the Monterey Formation forms the east wall. These relationships indicate the Cristianitos fault is a normal dip-slip fault with the west side down.

At the outcrop of the Cristianitos fault in the bluffs at San Onofre State Beach, terrace deposits overlie bedrock at an elevation of about 55 feet above sea level. About 3 feet of marine gravel occurs at the base of these deposits and is overlain by 39 feet of nonmarine material. The terrace deposits extend directly across the fault without being offset; thus, dating the most recent displacement as older than the terrace deposits. There is no evidence indicating Quaternary offset along the Cristianitos fault within the area studied.

In the sea cliff exposures to the northwest of the Cristianitos fault, beds within the San Mateo Formation are arched into a broad anticline and cut by numerous small faults as illustrated in Figure 4. These features are typical of "reverse drag" along normal fault as described by Hamblin (1965). They probably result from a flattening of the dip of the Cristianitos fault at depth beneath this area.

The Cristianitos fault is concealed beneath the coastal continental terrace for about one half mile. North of the terrace, the fault trends directly north for .9 miles and then bends westward where it disappears beneath nonmarine terrace deposits. Along this segment of the fault the unconformity between the Monterey Formation and San Onofre Breccia is essentially at ground elevation on the east side of the fault and the San Mateo Formation is on the west side. The San Mateo Formation shows normal drag with bedding dipping more steeply toward the west in beds close to the fault than in those a short distance away. Secondary faults occur subparallel to the main fault within the San Mateo Formation; however, we did not find two separate throughgoing fault traces.

From the east side of San Onofre Canyon to San Mateo Canyon, the Cristianitos fault has an average trend of about north 25 degrees west. The change in trend from that present further south appears to have no special significance. It is common for normal faults to have bends in them as original features, for example, see Hamblin (1965) Figure 1. The dip of the fault in this area is probably steep but exposures suitable for measuring the dip are lacking. The unconformity at the base of the Monterey Formation is within 165 feet of the ground surface on the north side of the fault within most of this area and the contact between the San Mateo Formation and the Monterey Formation is within 165 feet of the ground surface in most areas along the south side of the fault. Thus, the stratigraphic separation along the fault is approximately equal to the stratigraphic thickness of the Monterey Formation, or about 855 feet based on the thickness of the Monterey Formation penetrated in an oil well drilled 2.5 miles to the northwest (Humble Oil and Refining Co., Visbeek No. 1.). This offset is somewhat less than would be obtained by projecting stratigraphic horizons into the fault from a short distance away because strata are dragged upward along the west side of the fault.

The gentle east dips in the San Onofre breccia on the north side of San Onofre Canyon are an anomalous feature. They may be due to backward rotation along an arcuate slip surface within soft sandstone beneath the breccia. The mode of failure would be like that of an arcuate landslide except that the toe of the failure plane would terminate at depth against the Cristianitos fault and movement of the block would be associated with fault movement.

Activity along the Cristianitos fault probably occurred primarily during late Miocene and Early Pliocene in association with subsidence in the Capistrano Embayment. The embayment appears to have formed by crustal extension in an east-west direction and its subsidence was accompanied by deposition of the Capistrano Formation. Paleontologic data from surface samples collected a few hundred feet above present sea level indicate water depths increased during accumulation of the Capistrano Formation. Water depths were between 2,000 and 3,000 feet during the Late Miocene and 2,000 to 4,000 feet furing the Early Pliocene (White, 1956). Such water depths would not have been possible without down-dropping the Capistrano Embayment relative to the Peninsular Ranges to the east. Otherwise, the sea would have extended across the top of an old, somewhat deformed, erosion surface that presently lies at an elevation between 2,000 and 3,500 feet above sea level within the interior of the mountains. Within the headwaters of San Mateo Creek remnants of a once extensive lava field cap the erosion surface. The lava flows have been dated at 8.3 $\pm$ 0.5 million years (Hawkins, 1970). This age is within the Late Miocene. Since the lava flows were deposited on a land surface, the sea could not have extended to the elevation of the flows.

Fault "E" and Related Faults

Minor faults are fairly common within the San Onofre Breccia. In most places they cannot be traced because of inadequate exposures and repetitious lithology. An exception occurs in the northwestern part of the San Onofre Mountains where remnants of the Monterey Formation overlie the San Onofre Breccia. The contrast between the lithologies of the two formations makes it possible to trace faults which offset the contact between them. Four such faults have been recognized.

The largest of the four, referred to as the fault E on the geologic map, offsets the base of the Monterey Formation about 330 feet vertically with the north side down. The fault is not exposed but can be located within a few feet in areas where it brings the two formations in contact. The fault has been projected across areas where only breccia is present. Along the northwestern part of the fault, as shown on the map, the projection was done to link up known fault segments where the Monterey Formation has been downfaulted against breccia.

Two faults with displacements similar to the fault E occur to the northeast of the fault E. Neither of the faults is exposed. In both cases a fault has been shown on the map because the basal part of the Monterey Formation has been juxtaposed against breccia.

The fourth fault, referred to as the fault F on the map, (Area 4), has a dip slip separation of about 26 feet with the west side down. The fault surface is well exposed in a small quarry adjacent to the old highway. It strikes about north 15 degrees west and dips about 78 degrees southwest where exposed in the quarry. Striations occur in more than one direction on the fault surface but steeply inclined striations predominate.

None of the above faults shows evidence of Quaternary activity. The only places where there is physiographic expression along these faults is where erosion has worn down the softer Monterey Formation more than the breccia. It should be noted that the fault E and the other two faults which down drop Monterey Formation on their northeast sides must have been active before erosion stripped the Monterey Formation from the main part of the mountainside in this area, otherwise there would have been no Monterey Formation to down drop. The only reason the Monterey Formation is still present is because it was down faulted while the Monterey Formation still covered the breccia and has subsequently been protected by breccia from erosion. Remnants of a marine terrace mantle the San Onofre breccia between elevation 800 and 900 feet along the ridge crest from the center of the fault E. Since this terrace rests on breccia, it postdates removal of the Monterey Formation from the southside of the fault and therefore postdates down faulting of the

Monterey. On the south end of fault E the remnants of a marine terrace appear to extend across the fault at an elevation of 350 feet. Bulldozing has disturbed the ground surface in this area and leaves doubt concerning whether the terrace is intact.

Faulting within the San Onofre breccia and overlying Monterey Formation might be due to several causes. Much of the minor faulting within the breccia is probably related to folding of the breccia into its present orientation. The breccia lacks well developed bedding planes that can act as flexural slip surfaces during folding. As a result, it acts as a brittle substance and accommodates bending by adjustments along small faults.

The northerly trend of the four faults described above suggests they may be related to the Cristianitos fault or to a system of faults in the San Joaquin Hills to the west of the Capistrano Embayment. The San Joaquin Hills contain numerous north to northwest trending faults which cut Lower and Middle Miocene formations. Many of the faults have Miocene volcanic dikes intruded along them. Thus, at least part of the faults, if not all of them, are Miocene in age.

SUMMARY OF THE GEOLOGIC HISTORY

The coastal area adjacent to the San Onofre Nuclear Generating Station was tectonically very active during the Miocene and Lower Pliocene. Near the beginning of the Middle Miocene, the San Onofre Breccia was deposited on coalescing alluvial fans emanating from an uplifted Catalina Schist terrace located southwest of the present coast. The breccia appears to have accumulated very rapidly within a subsiding basin. During the early part of Middle Miocene, the breccia was tilted southwestward and partially eroded. About the same time the sea transgressed from the southwest depositing the Middle Miocene Monterey Formation on the breccia. Submergence appears to have occurred rapidly. The basal part of the Monterey Formation contains beach deposits yet less than 330 feet above the base faunal assemblages indicate middle bathyal depths.

The Capistrano Embayment developed during the Late Miocene and Early Pliocene. Dip slip displacement along the Cristianitos fault allowed the embayment to become a deep marine trough while the Peninsular Ranges to the east remained above sea level.

Since late Pliocene, the area has been uplifted gradually above sea level, but otherwise appears to have been tectonically stable. Topographic features in the area are products of differential erosion rather than tectonic activity. The San Onofre Mountains stand high, because they are composed of breccia, which is highly resistant to weathering and erosion. Formations on either side of the breccia have been eroded away from flank of the mountains since Late Pliocene.

The marine terraces on the southwest face of the San Onofre Mountains appear to record a gradual decline of sea level since Late Pliocene. So far as can be determined, the terraces are undeformed. The lowest terrace is continuous along the coast except where interrupted by major drainage systems. The lowest terrace extends across the Cristianitos fault with no sign of displacement.

CONCLUSIONS

1. The coastal area adjacent to the San Onofre Nuclear Generating Station appears to have been tectonically stable since Late Pliocene except for regional uplift relative to sea level.

2. The north-northwest-trending Cristianitos fault is the only major fault within the area. It is a normal dip slip fault with the west side down about 900 feet in the area between San Onofre and San Mateo Canyons. The fault has not moved since formation of the lowest marine terrace (about 120,000 years ago) and may have been inactive since Late Pliocene. The youngest formation known to be cut by the Cristianitos fault is the San Mateo Formation. Although the San Mateo Formation was previously considered to be younger than the Capistrano Formation, our study indicates it is a submarine channel backfill within the Capistrano Formation and is of Late Miocene to Early Pliocene age.

3. Four minor faults, including those referred to as the "E" and "F" faults have been mapped on the northwest flank of the San Onofre Mountains to the east of the Cristianitos fault. Each of these faults down drops Monterey Formation against San Onofre breccia. None of these faults shows evidence of Quaternary displacement. Three of the faults have Monterey Formation down dropped on their uphill (northeast) sides. The Monterey Formation has subsequently been stripped from the downhill side of the faults. The stripping occurred prior to the formation of a marine terrace at an elevation between

800 and 900 feet above sea level. The terrace is probably of Late Pliocene age. Therefore, the faulting is probably of Late Pliocene or earlier age.

4. No significant faults, other than those noted above, have been recognized within the area between the coast and the San Onofre Mountains from the Cristianitos southeastward to Las Pulgas Canyon. There is continuity in the geologic structure between the San Onofre Mountains and the coast as shown by geologic cross sections CC', DD' and EE'. Variations in the lithology of the Monterey Formation in exposures along the coast is due to lateral facies changes rather than structural complications.

5. A distinctive tuff bed within the San Onofre breccia crops out in nine places over 2.5 miles extending on either side of Horno Canyon directly upslope from the lower marine terrace. All of the outcrops are in linear alignment, thus indicating an absence of significant cross faults in this area.

6. Marine terraces are well developed along the southwest flank of the San Onofre Mountains below an elevation of about 1500 feet above sea level. These terraces appear to reflect emergence of the coastal area following deep submergence during the Late Miocene and Early Pliocene. Terraces above an elevation of about 1500 feet are likely to be of Late Pliocene age. The terraces do not appear to be deformed or tilted.

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TABLE 1
SUMMARY OF PALEONTOLOGIC
DATA

SAMPLE	FORMATION	AGE	STAGE	NORTH PACIFIC DIATOM ZONE	ENVIRONMENT	FORAMS	CALCAREOUS NANNO.	SILICEOUS MICROFOSSIL	Radiolaria	Diatoms	Silicoflag.	Ebridians	MEGAFOSSILS	COORDINATES (in feet)*	MAP GRID LOCATION (in ft.)	
20D-1	Tm	Prob. Early Late Mioc.	Early Mohnian	17-20	----			X	X	X	X			N420,670 E1,633,230	SE 37,100'	NE 8,800'
26B-1	Tm	Prob. Late Miocene	Mohnian	14-20	Outer Neritic-Bathyal	X		X	X	X	X			N421,540 E1,621,100	SE 27,800'	NE 850'
26B-2	Qm	Quaternary	---	---	----								X	N424,265 E1,618,835	SE 24,260'	NE 1,170'
26C-1	Tm	Middle Miocene	Relizian-Luisian	---	Outer Neritic-Bathyal	X								N428,580 E1,615,030	SE 18,505'	NE 1,560'
26C-2	Qm	Quaternary	---	---	----								X	N425,640 E1,617,710	SE 22,480'	NE 1,360'
26C-3	Qm	Quaternary	---	---	----								X	N425,500 E1,617,850	SE 22,665'	NE 1,360'
27B-1	Tm	Prob. Early Late Mioc.	Early Mohnian	17-20	Outer Neritic-Bathyal	X		X	X	X	X			N421,550 E1,636,000	SE 38,420'	NE11,360'
33B-1	Tm	Early Middle Mioc.	Probable Luisian		Middle to Lower Bathyal	X	X▲							N431,980 E1,611,650	SE 13,675'	NE 1,605'
33D-1	Tm	Early Middle Mioc.	Luisian	20-23	Middle to Lower Bathyal	X	X▲	X*	X	X	X	X		N435,620 E1,607,110	SE 7,870'	NE 1,000'
33D-2	Tm	Middle Miocene	Luisian	20-23	Middle Bathyal	X		X	X	X	X			N435,360 E1,607,400	SE 8,250'	NE 1,025'
33D-3	Tm												X	N435,840 E1,610,200	SE 9,880'	NE 3,340'
33D-4	Tm	Barren	---	---	----								X	N436,370 E1,608,820	SE 8,560'	NE 2,750'
41A-1	Tm	Barren	---	---	----									N437,730 E1,604,820	SE 4,750'	NE 900'
41A-2	Tm	Barren	---	---	----								X	N440,370 E1,605,540	SE 3,370'	NE 3,270'
41A-3	Tm	Middle Miocene	Probabl Luisian	20-23	----			X*	X	X	X	X		N440,385 E1,605,190	SE 3,100'	NE 3,075'
41A-4	Tm	Prob. Early Late Mioc.	Early Mohnian	17-20	Outer Neritic-Bathyal	X		X	X	X	X			N437,190 E1,605,660	SE 5,720'	NE 1,075'
41B-1	Tm	Middle Miocene	Probable Luisian	20-23	----			X*	X	X	X	X	X	N438,710 E1,606,080	SE 4,950'	NE 2,480'
41B-2	Tm	Middle Miocene	Luisian	20-23	----			X	X	X	X			N438,940 E1,609,180	SE 6,990'	NE 4,805'
41C-1	Tm	Middle Miocene	Probable Luisian	20-23	----			X*	X	X	X	X		N441,930 E1,605,120	SE 1,950'	NE 4,080'
41C-2	Tm				----								X	N444,910 E1,605,460	SE 140'	NE 6,480'
49A-1	Tm	Early Middle Mioc.	Luisian	20-23	Probable Middle Bathyal	X	X	X	X	X	X			N447,240 E1,602,965	NW 3,325'	NE 6,330'
49C-1	Tm	Late Miocene	Late Mohnian	13-16	----			X	X	X	X			N451,500 E1,602,140	NW 6,870'	NE 8,710'
49C-2	Tm	Prob. Early Mid. Mioc.	Luisian	20-23	Middle Bathyal	X	X	X	X	X	X			N452,020 E1,602,940	NW 6,690'	NE 9,720'
57B-1	Tm	Late Miocene	Mohnian	15-18	----			X	X	X	X			N454,685 E1,599,180	NW 11,270'	NE 8,900'
57B-2	Tm	Late Miocene	Mohnian	15-20	----			X	X	X	X			N454,935 E1,599,190	NW 11,470'	NE 9,100'
57D-1	Tc	Prob. Late Miocene	---	---	----			X	X	X	X			N458,250 E1,595,195	NW 16,660'	NE 8,650'
57D-2	Tc	Prob. Late Miocene	---	---	----			X	X	X	X			N458,565 E1,596,020	NW 16,330'	NE 9,510'
58A-1	Tm	Early Middle Mioc.	Luisian	20-23	Middle Bathyal	X	X▲	X	X	X	X			N454,790 E1,601,840	NW 9,530'	NE10,890'
SO2/3 1,2	Tsm	Barren	---	---	----				X					N439,800 E1,602,450		
SO2/3 3,4	Tsm	Barren	---	---	----									N437,560 E1,604,700		

Note - Prob.= Probable
Mioc.=Miocene
All the above ages are "Provincial"

*California Grid Zone 6

*These samples have nearly identical siliceous microfossil assemblages
▲These samples have nearly idential nannofossil (calcar.) assemblages

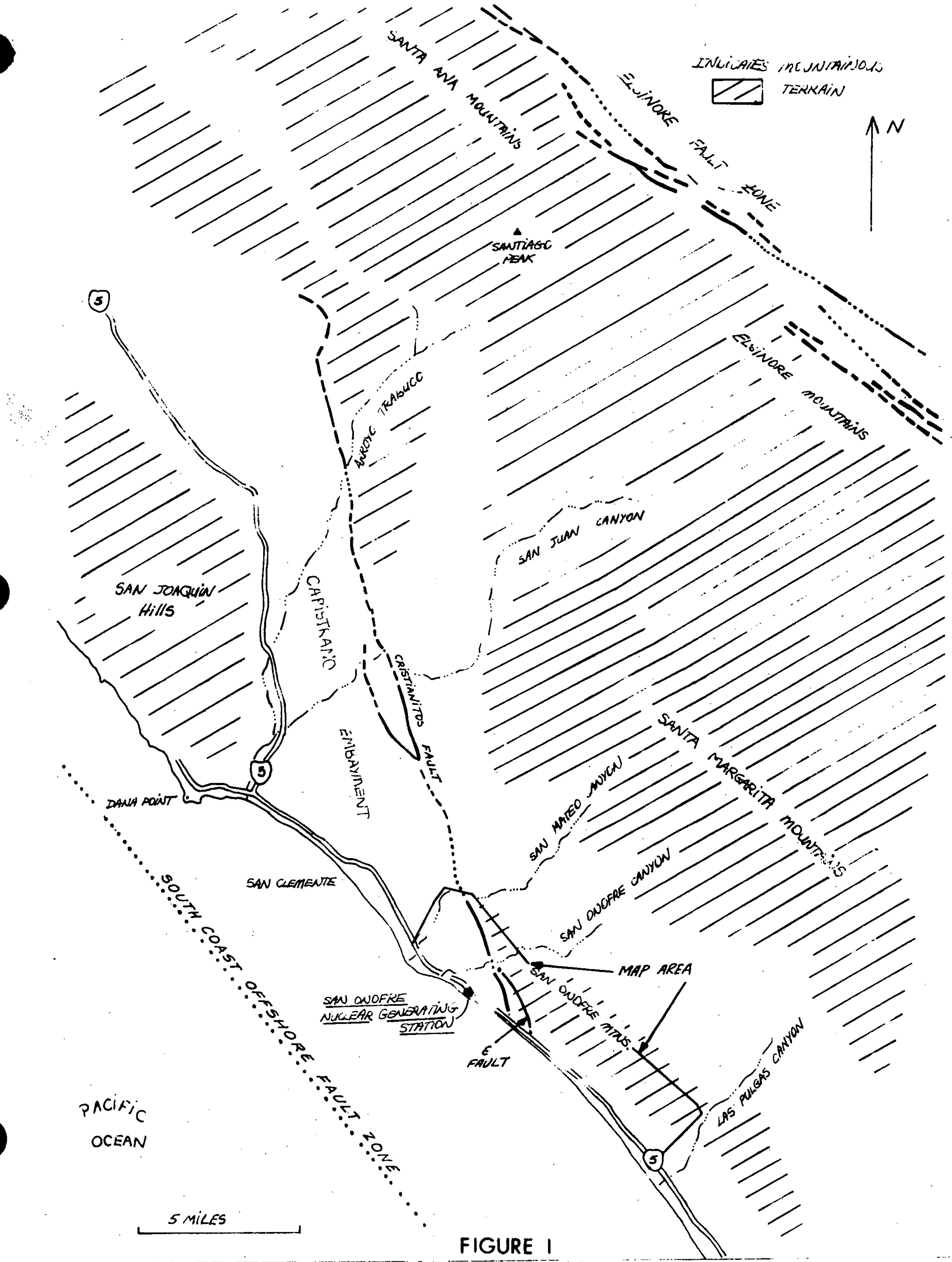
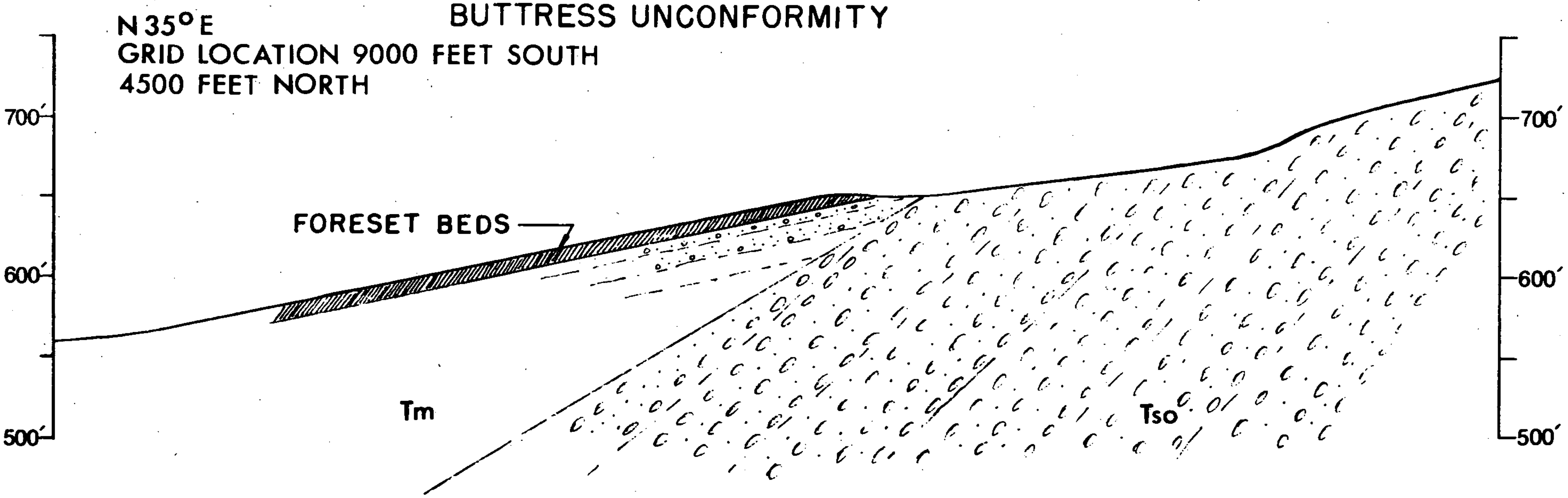


FIGURE I
LOCATION MAP

FIGURE 2

FORESET BEDS NEAR MONTEREY
BUTTRESS UNCONFORMITY



SCALE: 1" = 100'

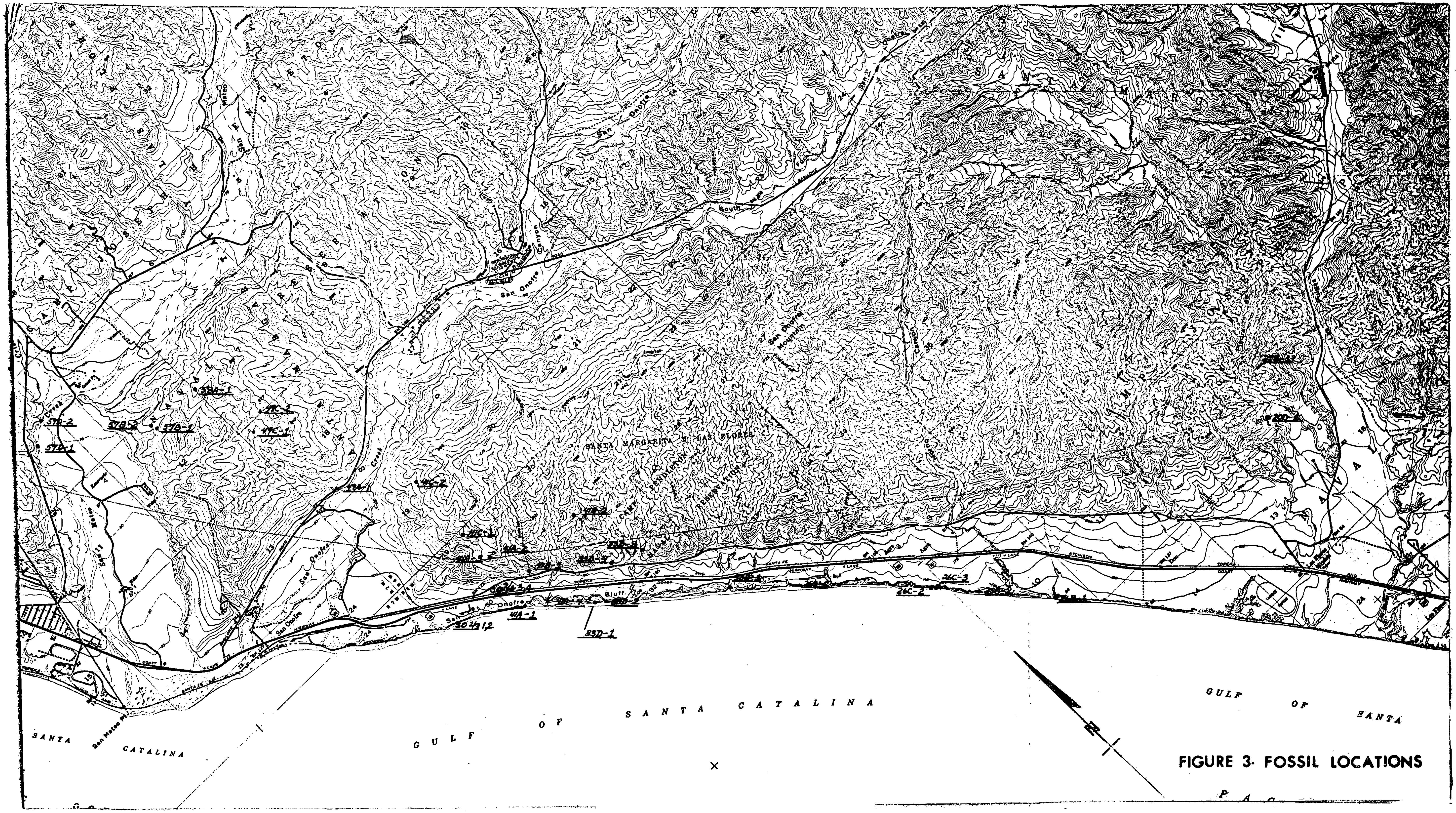
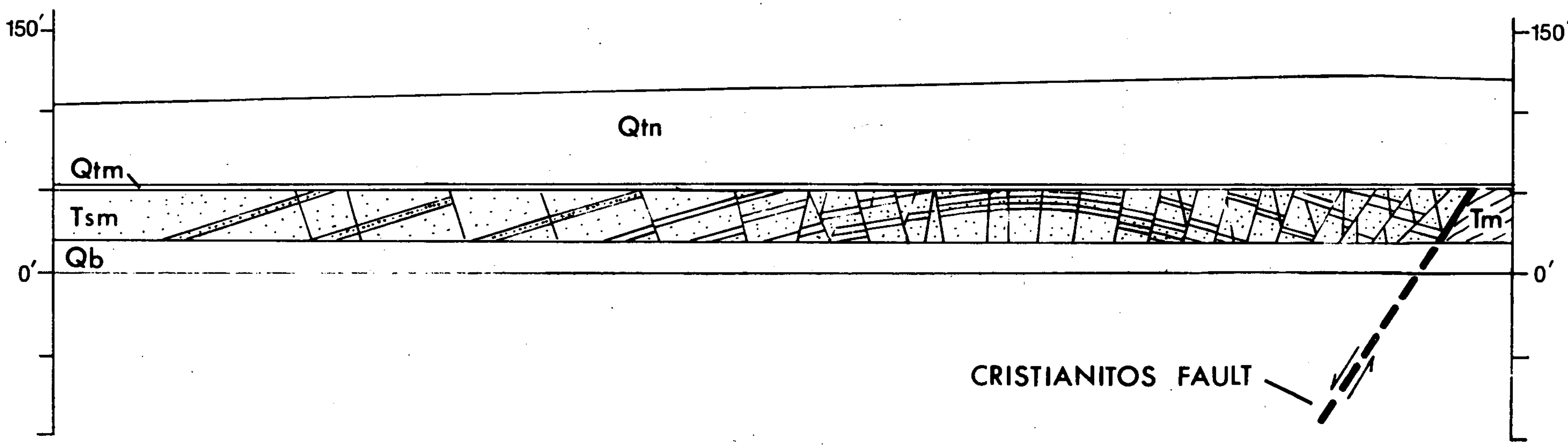


FIGURE 3. FOSSIL LOCATIONS

FIGURE 4

REVERSE DRAG FEATURES AT THE CRISTIANITOS FAULT
LOOKING NORTH



SCALE: 1" = 100'

EXPLANATION

QUATERNARY

Holocene

Qb	Beach sand and gravel
Qal	Alluvium - silt, sand, gravel, cobbles and boulders
Qal/Qtn/Qtm	Alluvium overlying marine and nonmarine deposits
Qls	Landslide
Qtr	Terrace - recent river deposits
Qtn	Terrace deposits - nonmarine
Qtm	Terrace deposits - marine
Qtn/Qtm	Terrace deposits - nonmarine overlying marine

Pleistocene

TERTIARY

Lower Pliocene

Unconformity

Tsm	San Mateo Formation - light gray arkosic sandstone, massive to thickly bedded well consolidated. Deposited contemporaneously with Capistrano Formation.

Unconformity

Middle to upper Miocene

Tm	Monterey Formation - basal coarse grained sandstone and conglomerate with pectin and oyster beds, diatomaceous siltstone and thin bedded sandstone

Unconformity

Tso	San Onofre Formation - dark gray to brown gray breccia and conglomerate characterized by clasts of blue green glaucophane schist, local outcrops of gray brown medium to coarse grained sandstone.

Unconformity

Eocene

Tlj	La Jolla Group - consists of Santiago Formation, gray massive arkosic sandstone, uncemented, and Silverado Formation, marine and nonmarine micaceous sandstone, siltstone, conglomerate and minor thin claystone and coal

SYMBOLS

Contact between rock units, dashed where approximately located, dotted where inferred

Fault, dashed where approximately located, dotted where inferred D - downthrown side, U - upthrown side

49C-2 Fossil locality

25 Strike and dip of joint plane

19 Strike and dip of bedding

Horizontal beds

10 21 Strike and dip of fault plane with plunge of slicken sides

Landslide, arrow marks direction of slide

xxxx Ancient beach bar in a terrace deposit

Tuff

Syncline

A A' Location of cross section

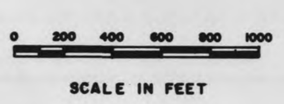


Figure 5

P. L. EHLIG & T. FARLEY
GEOLOGY MAP ADJACENT TO
SAN ONOFRE
NUCLEAR GENERATING STATION

Figure 6

P. L. EHLIG & T. FARLEY
GEOLOGY MAP ADJACENT TO

SAN ONOFRE

NUCLEAR GENERATING STATION

Figure 7

P. L. EHLIG & T. FARLEY
GEOLOGY MAP ADJACENT TO
SAN ONOFRE
NUCLEAR GENERATING STATION

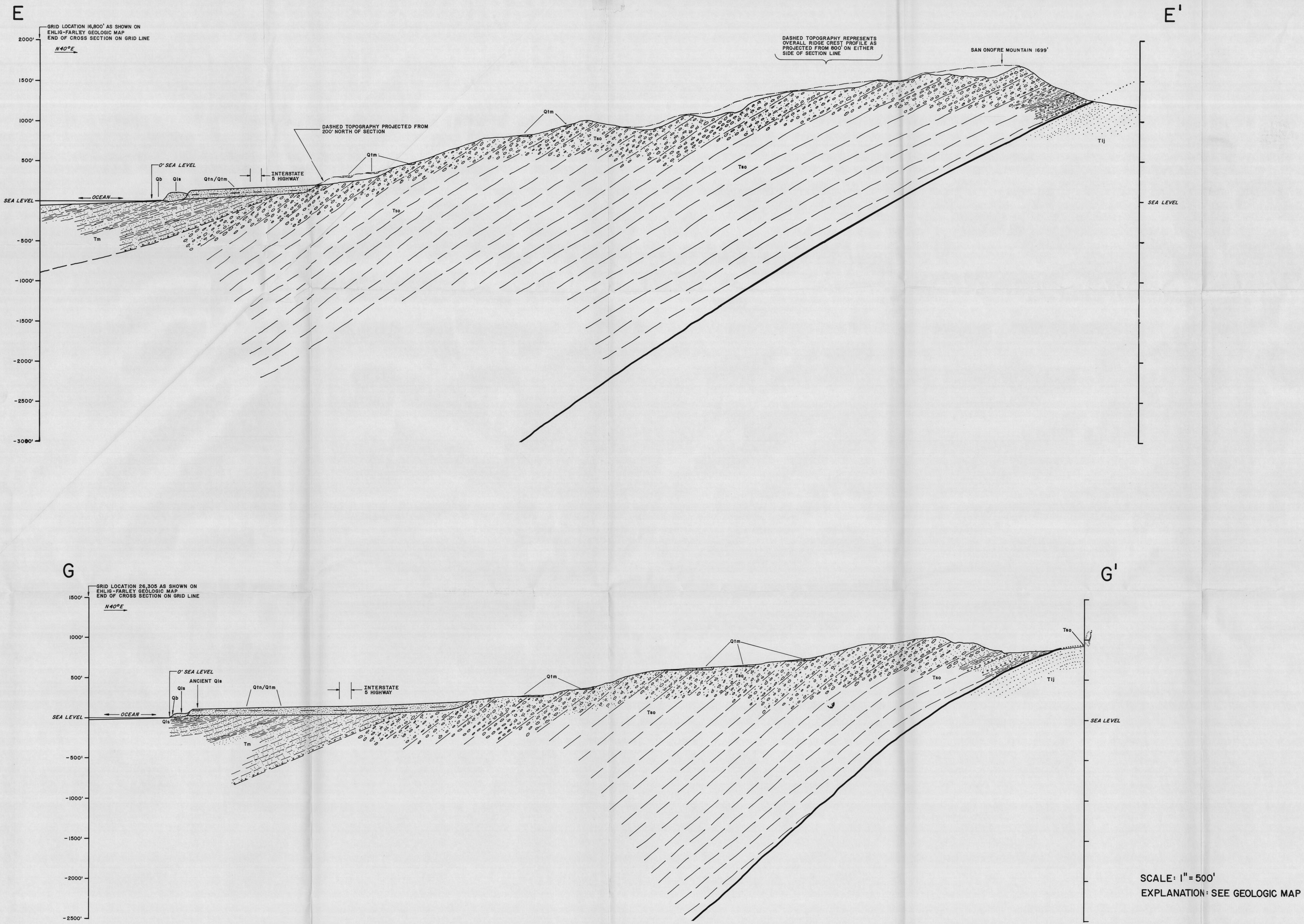
SCALE: 1" = 500'

EXPLANATION: SEE GEOLOGIC MAP

Figure 8

P. L. EHLIG & T. FARLEY
GEOLOGIC SECTIONS ADJACENT TO
SAN ONOFRE
NUCLEAR GENERATING STATION

GEOLOGIC CROSS-SECTIONS
A-A'; B-B'; C-C'; D-D';
F-F'



SCALE: 1" = 500'

EXPLANATION: SEE GEOLOGIC MAP

Figure 9

P. L. EHLIG & T. FARLEY
GEOLOGIC SECTIONS ADJACENT TO
SAN ONOFRE
NUCLEAR GENERATING STATION

GEOLOGIC CROSS-SECTIONS
E-E' AND G-G'

ENCLOSURE 3, APPENDIX A

ANDERSON-WARREN AND ASSOCIATES, INC.

RESULTS OF MICROFOSSIL IDENTIFICATION AND GEOLOGIC AGE CORRELATION, VINCINITY OF SAN ONOFRE GENERATING STATION, CALIFORNIA

FOR:

SOUTHERN CALIFORNIA EDISON COMPANY
Rosemead, California 91770

BY:

ANDERSON, WARREN AND ASSOCIATES
San Diego, California 92121

August 22, 31, and September 20, 1977

ANDERSON, WARREN AND ASSOCIATES

SUBMITTED

AUGUST 24, 1977

ANDERSON, WARREN & ASSOCIATES, INC.
CONSULTING MICROPALEONTOLOGY
11526 Sorrento Valley Road Suite G
San Diego, California 92121
(714) 755-1524
Cable: Micropaleo San Diego

August 22, 1977

TO: Southern California Edison

RE: Outcrop Samples; 8-77
San Onofre Area
California

FORAMINIFERAL REPORT

The following 12 outcrop samples were examined for occurrences of Foraminifera for the purpose of age and paleobathymetric determinations.

33D1*	F6B
41A1 (listed on transmittal as 44A1)	
26C1*	33D4
41C1	41A2
33B1*	SO 2/3; site 1
41B1	SO 2/3; site 2
F6A	

Samples listed above followed by an asterisk (*) contained Foraminifera which are detailed below.

Sample Analysis

33D1

Baggina californica (R), Bolivina advena striatella (VA), Buliminella subfusiformis (C), Nonion costiferum (R), Pullenia miocenica (R), Siphogenerina sp. (R),

RE: S.C.E. - Outcrop Samples 8-77; San Onofre Area

33D1 (con't.)

Uvigerinella cf. parva (C), Valvulineria californica obesa (C), Valvulineria cf. ornata (C).

AGE:	Provincial Middle Miocene, Upper Relizian to Luisian Stages
ENVIRONMENT:	Middle to Lower Bathyal

26C1

Baggina robusta cf. globosa (R), Bolivina sp. (R), Globobulimina sp. (R), Valvulineria californica var. (R), Valvulineria sp. (R).

AGE:	Provincial Middle Miocene, Relizian to Luisian Stages
ENVIRONMENT:	Outer Neritic to Bathyal

33B1

Bolivina advena striatella (VA), B. imbricata (C), Buliminella subfusiformis (A), Nonion costiferum (R), Pullenia miocenica (R), Uvigerinella californica ornata (R), Valvulineria californica (C), V. californica obesa (VA).

AGE:	Provincial Middle Miocene, probably Luisian Stage
ENVIRONMENT:	Middle to Lower Bathyal

Interpreted by: ANDERSON, WARREN & ASSOCIATES, INC.

D. R. McKeel

D. R. McKeel

A. D. Warren

A. D. Warren

ANDERSON, WARREN & ASSOCIATES, INC.
CONSULTING MICROPALEONTOLOGY
11526 Sorrento Valley Road Suite G
San Diego, California 92121
(714) 755-1524
Cable: Micropaleo San Diego

August 19, 1977

TO: Southern California Edison

RE: Outcrop Samples; 8-77
San Onofre Area
California

CALCAREOUS NANNOFOSSIL REPORT

The following 12 outcrop samples were examined for occurrences of calcareous nannofossils for the purpose of age and zonal determination:

33D1*	F6A
41A1	F6B
26C1	33D4
41C1	41A2
33B1*	SO 2/3; site 1
41B1	SO 2/3; site 2

The samples listed above followed by an asterisk contained calcareous nannofossils and are discussed below. For proper zonal placement, interrelationships between fossil groups, and selected references, the reader is requested to refer to the calcareous and siliceous microplankton correlation chart enclosed.

Sample Analysis

33D1

Coccolithus cf. doronicoides (R), C. miopelagicus (R),

RE: S.C.E. - Outcrop Samples 8-77; San Onofre Area

33D1 (con't.)

Coccolithus pelagicus (C), C. cf. pliopelagicus (R), C. cf. carteri (F), Cyclococcolithina leptopora (R-F), C. neogammation (R), C. macintyrei (R), Helicopontosphaera intermedia (VR), H. kamptneri (R).

AGE: Early Middle Miocene

ZONE: Sphenolithus heteromorphus to Discoaster exilis (Coccolithus miopelagicus Subzone)

DISCUSSION: The calcareous nannofossil assemblage, although frequent in numbers, is not diverse and consists mainly of cold water species. The presence of Coccolithus miopelagicus, Cyclococcolithina neogammation, and Helicopontosphaera intermedia suggests an age of Lower Mohnian or older. The additional occurrence of good specimens of Cyclococcolithina macintyrei and specimens showing a close affinity to Coccolithus carteri and C. pliopelagicus, if indigenous, would not permit an age as old as Relizian.

33B1

Coccolithus miopelagicus (R), C. pelagicus (C-A), C. cf. pliopelagicus (R), C. cf. carteri (F-C), Cyclococcolithina leptopora (R), C. macintyrei (R), C. neogammation (F), Helicopontosphaera kamptneri (F), Sphenolithus moriformis (VR).

RE: S.C.E. - Outcrop Samples 8-77; San Onofre Area

33B1 (con't.)

AGE:	Early Middle Miocene
ZONE:	Sphenolithus heteromorphus to Discoaster exilis (Coccolithus miopelagicus Subzone)
DISCUSSION:	Same as Sample 33D1.

Interpreted by:

J. H. Newell

J. H. Newell

ANDERSON, WARREN & ASSOCIATES, INC.

A. D. Warren

A. D. Warren

ANDERSON, WARREN & ASSOCIATES, INC.
CONSULTING MICROPALEONTOLOGY
11526 Sorrento Valley Road Suite G
San Diego, California 92121
(714) 755-1524
Cable: Micropaleo San Diego

August 24, 1977

TO: Southern California Edison

RE: Outcrop Samples; 8-77
San Onofre Area
California

SILICEOUS MICROFOSSIL REPORT

During analysis of outcrop samples for calcareous nannoplankton, 6 samples were found to contain siliceous microfossil fragments and were then processed and analyzed further for siliceous microfossil age determinations. The 6 samples examined are as follows:

33D1	41B1
41C1	F6A
33B1	F6B

These samples are discussed in detail below. For proper zonal placement, interrelationships between fossil groups and selected references, the reader is referred to the calcareous and siliceous microplankton correlation chart enclosed.

Sample Analysis

33D1

Radiolaria:

Eucyrtidium calvertense (R), Heliodiscus sp. (VR), Stylatractus universus (VR).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

33D1 (con't.)

Diatoms:

Actinocyclus ingens (C), A. tsuguruensis (R), Arachnoidiscus manni (R), Coscinodiscus marginatus (A), C. oculus-iridis (C), Denticula lauta (A), Hemiaulis polymorphus (R), Stephanogonia hanzawae (R).

Silicoflagellates:

Cannopilus hemisphaericus (R), C. sphaericus (VR), Distephanus crux (A).

Ebridians:

Ammodochium rectangulare (VR), Ebriopsis antiqua (VR), Parathranium tenuipes (R).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

41C1

Radiolaria:

Cyrtocapsella cornuta (R), Eucyrtidium calvertense (R), Lychnocanium grande (R), Spongodiscus sp. (R).

ANDERSON, WARREN & ASSOCIATES, INC.
CONSULTING MICROPALEONTOLOGY
11526 Sorrento Valley Road Suite G
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Cable: Micropaleo San Diego

August 24, 1977

TO: Southern California Edison

RE: Outcrop Samples; 8-77
San Onofre Area
California

SILICEOUS MICROFOSSIL REPORT

During analysis of outcrop samples for calcareous nannoplankton, 6 samples were found to contain siliceous microfossil fragments and were then processed and analyzed further for siliceous microfossil age determinations. The 6 samples examined are as follows:

33D1	41B1
41C1	F6A
33B1	F6B

These samples are discussed in detail below. For proper zonal placement, interrelationships between fossil groups and selected references, the reader is referred to the calcareous and siliceous microplankton correlation chart enclosed.

Sample Analysis

33D1

Radiolaria:

Eucyrtidium calvertense (R), Heliodiscus sp. (VR), Stylatractus universus (VR).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

33D1 (con't.)

Diatoms:

Actinocyclus ingens (C), A. tsuguruensis (R), Arachnoidiscus manni (R), Coscinodiscus marginatus (A), C. oculus-iridis (C), Denticula lauta (A), Hemiaulis polymorphus (R), Stephanogonia hanzawae (R).

Silicoflagellates:

Cannopilus hemisphaericus (R), C. sphaericus (VR), Distephanus crux (A).

Ebridians:

Ammodochium rectangulare (VR), Ebriopsis antiqua (VR), Parathranium tenuipes (R).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

41C1

Radiolaria:

Cyrtocapsella cornuta (R), Eucyrtidium calvertense (R), Lychnocanium grande (R), Spongodiscus sp. (R).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

41C1 (con't.)

Diatoms:

Actinocyclus ingens (C), A. tsuguruensis (F), Coscinodiscus marginatus (F), C. tabularis (F), Denticula lauta (R), Hemiaulis polymorphus (R), Rhizosolenia miocenica (VR), Stephanogonia hanzawae (F), Triceratium condecorum (F).

Silicoflagellates:

Cannopilus hemisphaericus (R), C. sphaericus (R), Distephanus crux (A), Mesocena elliptica (F).

Ebridians:

Ammodochium rectangulare (F), Ebriopsis antiqua (R), Parathranium tenuipes (R).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

33B1

AGE:	Indeterminate; recrystallized siliceous microfossil fragments rare

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

41B1

Radiolaria:

Actinomma sp. (VR), Heliodiscus sp. (VR), Spongodiscus sp. (R).

Diatoms:

Actinocyclus ingens (A), A. tsuguruensis (F), Arachnoidiscus manni (VR), Coscinodiscus marginatus (F), C. oculus-iridis (F), Denticula lauta (A), Hemiaulis polymorphus (R), Stephanogonia hanzawae (VR).

Silicoflagellates:

Cannopilus hemisphaericus (VR), Distephanus crux (C).

Ebridians:

Ammodochium rectangulare (VR), Parathranium tenuipes (R).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

F6A

Radiolaria:

Cyrtocapsella cornuta (R), Eucyrtidium calvertense (R), Lychnocanium grande (R), Theocorys cf. redondoensis (VR).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

41C1 (con't.)

Diatoms:

Actinocyclus ingens (C), A. tsuguruensis (F), Coscinodiscus marginatus (F), C. tabularis (F), Denticula lauta (R), Hemiaulis polymorphus (R), Rhizosolenia miocenica (VR), Stephanogonia hanzawae (F), Triceratium condecorum (F).

Silicoflagellates:

Cannopilus hemisphaericus (R), C. sphaericus (R), Distephanus crux (A), Mesocena elliptica (F).

Ebridians:

Ammodochium rectangulare (F), Ebriopsis antiqua (R), Parathranium tenuipes (R).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

33B1

AGE:	Indeterminate; recrystallized siliceous microfossil fragments rare

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

41B1

Radiolaria:

Actinomma sp. (VR), Heliodiscus sp. (VR), Spongodiscus sp. (R).

Diatoms:

Actinocyclus ingens (A), A. tsuguruensis (F), Arachnoidiscus manni (VR), Coscinodiscus marginatus (F), C. oculus-iridis (F), Denticula lauta (A), Hemiaulis polymorphus (R), Stephanogonia hanzawae (VR).

Silicoflagellates:

Cannopilus hemisphaericus (VR), Distephanus crux (C).

Ebridians:

Ammodochium rectangulare (VR), Parathranium tenuipes (R).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

F6A

Radiolaria:

Cyrtocapsella cornuta (R), Eucyrtidium calvertense (R), Lychnocanium grande (R), Theocorys cf. redondoensis (VR).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

F6A (con't.)

Diatoms:

Actinocyclus ingens (C), A. tsuguruensis (F), Coscinodiscus oculus-iridis (C), Denticula lauta (F), Hemiaulis polymorphus (F), Lithodesmium californicum (VR), Rhizosolenia miocenica (VR), Stephanogonia hanzawae (R), Triceratium condecorum (F).

Silicoflagellates:

Cannopilus hemisphaericus (R), C. sphaericus (R), Distephanus crux (C).

Ebridians:

Ammodochium rectangulare (R), Ebriopsis antiqua (R), Parathranium tenuipes (R).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

F6B

Radiolaria:

Spongodiscus sp. (R).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

F6B (con't.)

Diatoms:

Actinocyclus ingens (F), A. tsuguruensis (F), Coscinodiscus robusta (R), C. tabularis (R), Denticula lauta (R), Stephanogonia hanzawae (VR), Triceratium condecorum (F).

Silicoflagellates:

Cannopilus hemisphaericus (VR), Distephanus crux (F).

Ebridians:

Ammodochium rectangulare (VR), Ebriopsis antiqua (VR).

AGE:	Middle Miocene (Provincial)
STAGE:	Probable Luisian
ZONE:	NPD zone 20-23 (Schrader, 1973) Denticula lauta zone (Koizumi, 1975) Corbisema triacantha zone (Bukry, 1975)

Discussion

The siliceous microfossil assemblages recorded from samples 33D1, 41C1, 41B1, F6A and F6B are essentially identical and were assigned the above age determinations using the following criteria:

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

1. The co-occurrence of abundant Actinocyclus ingens and abundant Denticula lauta suggests an age no younger than North Pacific Diatom (NPD) zone 20 (Barron, 1976).

2. The presence of Rhizosolenia miocenica suggests an age no older than NPD zone 23 (Schrader, 1973).

3. The abundant occurrence of Denticula lauta without Denticula hustedtii suggests a correlation with Koizumi's (1975) Denticula lauta zone.

4. The presence of Cannopilus hemisphaericus (=Distephanus speculum hemisphaericus of Bukry, 1975) indicates a correlation with the Corbisema triacantha zone as discussed by Bukry (1975).

5. The marked affinity, faunistic and floristic, between the siliceous assemblages reported here and one recovered from sample NEW5 of the Newport Bay section (Barron, 1976; Casey and Price, 1973; Warren, 1973; and Wornardt, 1973) suggests a correlation with the Luisian Stage (provincial middle Miocene).

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RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

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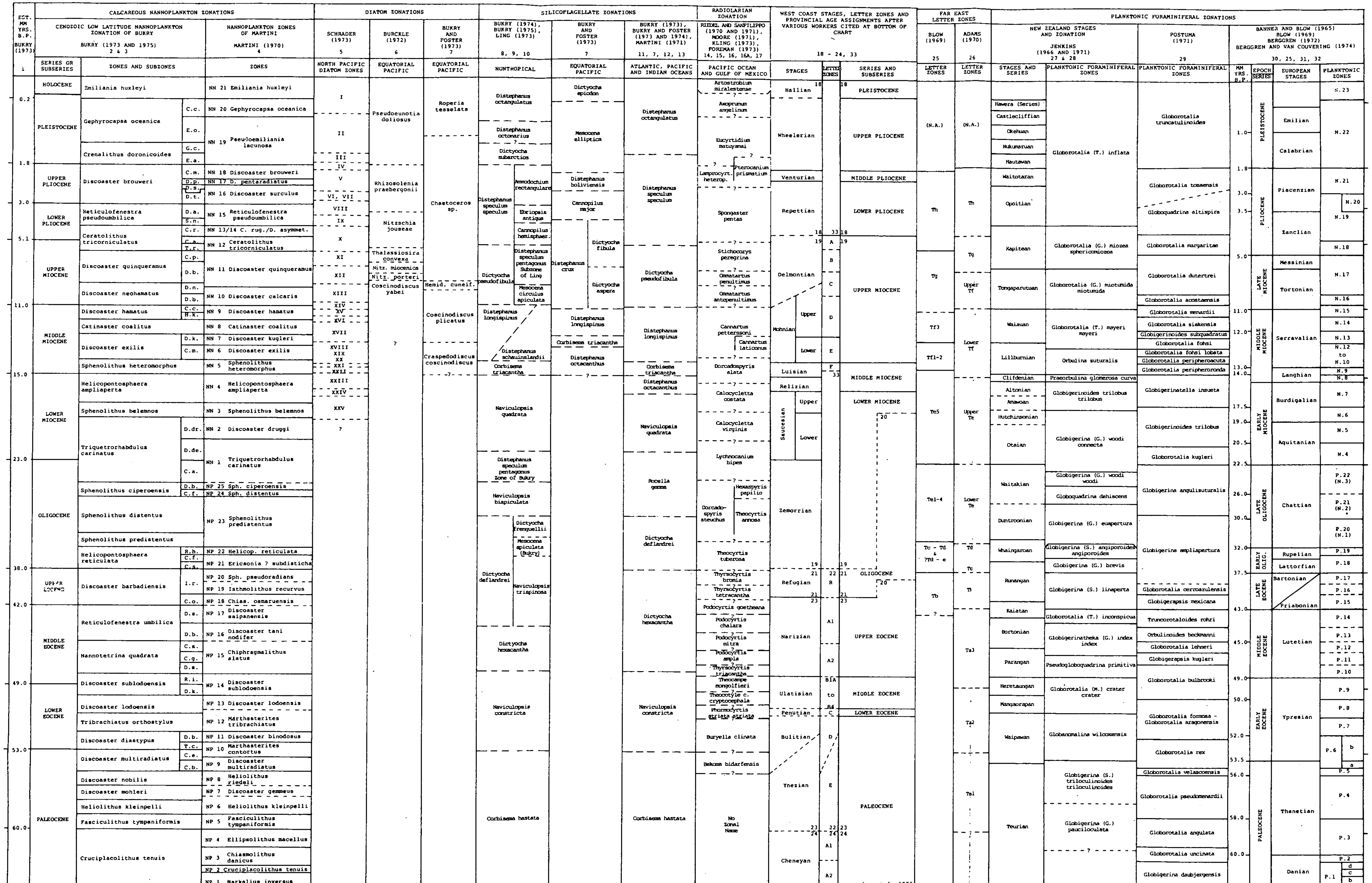
U. S. PACIFIC COAST AND INDO-PACIFIC REGION CENOZOIC CORRELATION CHART

CALCAREOUS AND SILICEOUS MICROPLANKTON

ANDERSON, WARREN & ASSOCIATES, INC.



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ANDERSON, WARREN AND ASSOCIATES

SUBMITTED

AUGUST 31, 1977

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August 31, 1977

TO: Southern California Edison

RE: Outcrop Samples, 8-77 (AWA Job 492)
San Onofre Area
California

FORAMINIFERAL REPORT

The following 10 outcrop samples were examined for occurrences of Foraminifera for the purpose of age and paleobathymetric determinations.

20D-1	49A-1*
26B-1*	49C-1
33D-2*	49C-2*
41A-4*	58A-1*
41B-2	27B-1*

Samples listed above followed by an asterisk (*) contained Foraminifera which are listed and analyzed below.

26B-1

Common casts and molds of Foraminifera are present and locked in the matrix of this sample, but only a few genera could be recognized on the rock surfaces of the unprocessed sample. These few genera are not sufficient to define an age for this sample. The processed sample is barren of Foraminifera.

AGE: Indeterminate
ENVIRONMENT: Outer Neritic to Bathyal

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

33D-2

Bolivina advena striatella (A), B. sp. (R), Buliminella curta (R), Nonion costiferum (R), Pulvinulinella subperuviana (R), Uvigerinella cf. obesa (C), Valvulineria cf. californica obesa (VA), V. sp. (R), diatoms (C), fish debris (VA).

AGE:	Provincial Middle Miocene, Relizian to Luisian Stages
ENVIRONMENT:	Middle Bathyal

41A-4

Bulimina sp. (C), Globobulimina sp. (C), Virgulina californica (C), Virgulinella miocenica (R); other indeterminate species observed locked in matrix of rock surfaces of the unprocessed sample; most of these are casts and molds.

AGE:	Probable Provincial Miocene
ENVIRONMENT:	Outer Neritic to Bathyal

49A-1

Bolivina spp. (R), Pulvinulinella? sp. (R), Uvigerina? sp. (R), Globorotalia minutissima (R), fish debris (VA), radiolaria (R).

AGE:	Probable Provincial Miocene
ENVIRONMENT:	Probably Middle Bathyal

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FORAMINIFERAL REPORT

The following 10 outcrop samples were examined for occurrences of Foraminifera for the purpose of age and paleobathymetric determinations.

20D-1	49A-1*
26B-1*	49C-1
33D-2*	49C-2*
41A-4*	58A-1*
41B-2	27B-1*

Samples listed above followed by an asterisk (*) contained Foraminifera which are listed and analyzed below.

26B-1

Common casts and molds of Foraminifera are present and locked in the matrix of this sample, but only a few genera could be recognized on the rock surfaces of the unprocessed sample. These few genera are not sufficient to define an age for this sample. The processed sample is barren of Foraminifera.

AGE: Indeterminate
ENVIRONMENT: Outer Neritic to Bathyal

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

33D-2

Bolivina advena striatella (A), B. sp. (R), Buliminella curta (R), Nonion costiferum (R), Pulvinulinella subperuviana (R), Uvigerinella cf. obesa (C), Valvulineria cf. californica obesa (VA), V. sp. (R), diatoms (C), fish debris (VA).

AGE:	Provincial Middle Miocene, Relizian to Luisian Stages
ENVIRONMENT:	Middle Bathyal

41A-4

Bulimina sp. (C), Globobulimina sp. (C), Virgulina californica (C), Virgulinella miocenica (R); other indeterminate species observed locked in matrix of rock surfaces of the unprocessed sample; most of these are casts and molds.

AGE:	Probable Provincial Miocene
ENVIRONMENT:	Outer Neritic to Bathyal

49A-1

Bolivina spp. (R), Pulvinulinella? sp. (R), Uvigerina? sp. (R), Globorotalia minutissima (R), fish debris (VA), radiolaria (R).

AGE:	Probable Provincial Miocene
ENVIRONMENT:	Probably Middle Bathyal

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

49C-2

Bolivina advena striatella (VA), B. imbricata (A), Buli-mina subfusiformis (A), Nonion costiferum (R), Uvigerin-ella cf. obesa (VA), Valvulineria californica (R), V. californica appressa (R), V. miocenica (VA), fish debris (VA).

AGE: Probable Luisian
ENVIRONMENT: Middle Bathyal

58A-1

Bolivina advena striatella (VA), B. imbricata (VA), Buli-minella subfusiformis (A), Nonion costiferum (C), Uvigeri-nella californica parva (C), Valvulineria californica (A), V. miocenica (VA), Virgulina californiensis (C), Globoro-talia minutissima (C).

AGE: Luisian
ENVIRONMENT: Middle Bathyal

27B-1

Buliminella subfusiformis (R), Valvulineria sp. (R), diatoms (R), fish debris (R).

AGE: Probable Provincial Miocene
ENVIRONMENT: Outer Neritic to Bathyal

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RE: Outcrop Samples, 8-77 (AWA Job 492)
San Onofre Area
California

CALCAREOUS NANNOFOSSIL REPORT

The following 10 outcrop samples were examined for occurrences of calcareous nannofossils for the purpose of age and zonal determination:

20D-1	49A-1*
26B-1	49C-1
33D-2	49C-2*
41A-4	58A-1*
41B-2	27B-1

The samples listed above followed by an asterisk (*) contained calcareous nannofossils and are discussed below.

Sample Analysis

49A-1

Coccolithus miopelagicus (R-F), C. pelagicus (C), C. cf. carteri (F), Cyclococcolithina leptopora (R), C. macintyrei (R), C. neogammation (R), Cyclicargolithus sp. (F),

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

49A-1 (con't.)

Discoaster cf. exilis (VR), D. moorei (VR), ?Gephyrocapsa sp. (F), Helicopontosphaera kamptneri (VR), Reticulofenestra pseudoumbilica (F-C), R. sp. (F).

AGE: Early Middle Miocene

ZONE: Sphenolithus heteromorphus to Discoaster exilis (Coccolithus miopelagicus Subzone)

DISCUSSION: Although specimens of Sphenolithus heteromorphus were not encountered, the age for this sample is here still spread to include the Sphenolithus heteromorphus Zone (Luisian) to the basal subzone of the Discoaster exilis Zone (Lower Mohnian).

49C-2

Coccolithus miopelagicus (VR), C. pelagicus (R-F), Discoaster deflandrei (VR), D. kugleri var. (VR).

AGE: Probable early Middle Miocene

ZONE: Questionable Sphenolithus heteromorphus to Discoaster exilis (Coccolithus miopelagicus Subzone)

DISCUSSION: The calcareous nannofossil assemblage is here very weak and any age determination attempted must remain tentative. The variant of Discoaster kugleri seen here would suggest an Early Mohnian to possible Luisian age.

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

58A-1

Coccolithus miopelagicus (C), C. pelagicus (A), C. cf. carteri (F), Cyclococcolithina leptopora (R), C. neogammation (R), Cyclicargolithus sp. (R), ?Gephyrocapsa sp. (C), Sphenolithus moriformis (VR).

AGE: Early Middle Miocene

ZONE: Sphenolithus heteromorphus to Discoaster exilis (Coccolithus miopelagicus Subzone)

DISCUSSION: The assemblage here consists mainly of cold water species and is more similar to the assemblages seen in samples 33D-1 and 33B-1 discussed in the report dated August 19, 1977.

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August 31, 1977

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RE: Outcrop Samples, 8-77 (AWA Job 492)
San Onofre Area
California

SILICEOUS MICROFOSSIL REPORT

The 10 outcrop samples listed below were examined for contained siliceous microfossils (i.e., radiolarians, diatoms and silicoflagellates) for the purpose of age and zonal determinations:

20D-1	49A-1
26B-1	49C-1
33D-2	49C-2
41A-4	58A-1
41B-2	27B-1

All of these samples contained age diagnostic siliceous assemblages ranging in age from Middle to Late Miocene (Luisian to Late Mohnian). It is important to note that these ages are in provincial terms as defined on the enclosed calcareous and siliceous microplankton correlation chart. In addition, the samples were related to the North Pacific diatom zonation of Schrader (1973) and its emended form (Barron, 1976).

Because of the individual nature of the recorded siliceous assemblages, each will be discussed separately below.

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

20D-1

Radiolaria:

Spongodiscus sp. (R), Theocorys redondoensis (F).

Diatoms:

Actinocyclus ingens (F), A. tsuguruensis (F), Arachnoidiscus manni (F), Aulacodiscus spp. (C), Auliscus spp. (C), Coscinodiscus marginatus (F), Denticula hustedtii (F), D. cf. lauta (VR), Hemiaulis polymorphus (VR), Navicula spp. (F), Rhizosolenia miocenica (C), Stephanopyxis cf. schenckii (R).

Silicoflagellates:

Cannopilus hemisphaericus (R), Distephanus crux (C), D. speculum (R).

AGE: Probable early Late Miocene (Provincial)

STAGE: Early Mohnian

ZONE: NPDZ 17-20

DISCUSSION: The presence of frequent Denticula hustedtii and low relief Actinocyclus ingens suggests an age no older than NPDZ (North Pacific Diatom Zone) 20. The absence of Rhizosolenia barboi and the rare occurrence of Stephanopyxis cf. schenckii suggest an age no younger than NPDZ 17.

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

26B-1

Radiolaria:

Actinomma sp. (VR), Theocorys cf. redondoensis (VR).

Diatoms:

Actinocyclus ingens (R), Actinoptychus sp. (VR), Arachnoidiscus sp. (VR), Auliscus sp. (R), Coscinodiscus marginatus (R), Denticula cf. hustedtii (VR), Diploneis sp. (VR), Endictya robusta (F), Opephora schwartzii (VR), Stephanopyxis cf. schenckii (VR), Stictodiscus sp. (VR).

Silicoflagellates:

Distephanus crux (VR).

AGE: Probable Late Miocene (Provincial)
STAGE: Mohnian
ZONE: NPDZ 14-20
DISCUSSION: This sample contains a weak diatom assemblage dominated by benthonic and nearshore taxa. The resulting paucity in stratigraphically significant planktonic species allows only a broad correlation with NPDZ 14-20.

33D-2

Radiolaria:

Cyrtocapsella cornuta (VR), Spongodiscus sp. (F), Stylacontarium acquilonium (VR).

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

33D-2 (con't.)

Diatoms:

Actinocyclus ingens (A), A. tsuguruensis (R), Coscinodiscus marginatus (C), Denticula lauta (C), Diploneis sp. (R), Rhizosolenia miocenica (R).

Silicoflagellates:

Cannopilus hemisphaericus (R), Distephanus crux (F).

AGE: Middle Miocene (Provincial)
STAGE: Luisian
ZONE: NPDZ 20-23
DISCUSSION: This sample contains an assemblage similar to the ones discussed in the siliceous report of August 24, 1977. The occurrence of Rhizosolenia miocenica indicates an age no older than NPDZ 23, while the co-occurrence of common Denticula lauta and abundant, high-relief Actinocyclus ingens indicates an age no younger than NPDZ 20.

41A-4

Radiolaria:

Spongodiscus sp. (R), Xiphospira circularis (R).

Diatoms:

Actinocyclus ehrenbergii (R), A. ingens (F), A. tsuguruensis (F), Coscinociscus marginatus (F), C. radiatus (R),

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

41A-4 (con't.)

Diatoms (con't.):

Coscinodiscus cf. yabei (VR), Denticula hustedtii (R), D. cf. lauta (VR), Stephanogonia hanzawae (R), Stephanopyxis cf. schenckii (A).

Silicoflagellates:

Cannopilus hemisphaericus (VR), Distephanus crux (R), D. speculum (R).

AGE:	Probable early Late Miocene (Provincial)
STAGE:	Early Mohnian
ZONE:	NPDZ 17-20
DISCUSSION:	See discussion under 20D-1

41B-2

Radiolaria:

Spongodiscus sp. (R), Stylatractus universus (VR).

Diatoms:

Actinocyclus ingens (A), A. tsuguruensis (F), Coscinodiscus marginatus (C), C. oculus-iridis (C), C. radiatus (F), Denticula lauta (A), Rhizosolenia miocenica (R), Synedra jouseana (VR).

Silicoflagellates:

Distephanus crux (C).

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

41B-2 (con't.)

AGE:	Middle Miocene (Provincial)
STAGE:	Luisian
ZONE:	NPDZ 20-23
DISCUSSION:	See discussion under 33D-2

49A-1

Radiolaria:

Heliodiscus sp. (F), Lychnocanium grande (R), Spongodiscus sp. (F), Theocorys redondoensis (R), Xiphospira circularis (R).

Diatoms:

Actinocyclus ingens (C), Arachnoidiscus manni (F), Coscinodiscus asteromphalus (R), C. marginatus (F), Denticula lauta (C), Endictya robusta (C), Hemiaulis polymorphus (F), Rhizosolenia miocenica (R), Stephanogonia hanzawae (R), Synedra jouseana (R).

Silicoflagellates:

Distephanus crux (C), D. speculum (F), D. s. cf. pentagonus (F).

AGE:	Middle Miocene (Provincial)
STAGE:	Luisian
ZONE:	NPDZ 20-23
DISCUSSION:	See discussion under 33D-2

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

49C-1

Radiolaria:

Larnacantha sp. (F), Spongodiscus sp. (F).

Diatoms:

Actinocyclus tsuguruensis (F), Arachnoidiscus manni (R), Coscinodiscus marginatus (F), C. tabularis (F), Denticula hustedtii (C), Endictya robusta (C), Rhizosolenia barboi (C).

Silicoflagellates:

Distephanus crux (C), Mesocena circula v. apiculata (F), M. elliptica (R).

AGE: Late Miocene (Provincial)
STAGE: Late Mohnian
ZONE: NPDZ 13-16
DISCUSSION: The presence of Rhizosolenia barboi suggests an age no older than NPDZ 16. The presence of common Denticula hustedtii suggests an age no younger than NPDZ 13.

49C-2

Radiolaria:

Cyrtocapsella cornuta (VR), Lamprocyrtis hannai (VR), Larnacantha sp. (F), Spongodiscus sp. (F), Xiphospira circularis (F).

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

49C-2 (con't.)

Diatoms:

Actinocyclus ingens (A), A. tsuguruensis (C), Coscinodiscus marginatus (C), C. radiatus (C), Denticula lauta (A), Navicula spp. (F), Rhizosolenia miocenica (R), Stephanogonia hanzawae (R), Triceratium condecorum (R).

Silicoflagellates:

Cannopilus hemisphaericus (F), Distephanus crux (C).

AGE:	Middle Miocene (Provincial)
STAGE:	Luisian
ZONE:	NPDZ 20-23
DISCUSSION:	See discussion under 33D-2

58A-1

Radiolaria:

Actinomma sp. (R), Heliodiscus sp. (R), Lychnocanium grande (VR), Spongodiscus sp. (F).

Diatoms:

Actinocyclus ingens (C), Coscinodiscus marginatus (A), Denticula lauta (A), Diploneis sp. (F), Navicula spp. (F), Rhizosolenia miocenica (R), Stephanogonia hanzawae (R), Synedra jouseana (R), Triceratium condecorum (R).

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

49C-1

Radiolaria:

Larnacantha sp. (F), Spongodiscus sp. (F).

Diatoms:

Actinocyclus tsuguruensis (F), Arachnoidiscus manni (R), Coscinodiscus marginatus (F), C. tabularis (F), Denticula hustedtii (C), Endictya robusta (C), Rhizosolenia barboi (C).

Silicoflagellates:

Distephanus crux (C), Mesocena circula v. apiculata (F), M. elliptica (R).

AGE: Late Miocene (Provincial)
STAGE: Late Mohnian
ZONE: NPDZ 13-16
DISCUSSION: The presence of Rhizosolenia barboi suggests an age no older than NPDZ 16. The presence of common Denticula hustedtii suggests an age no younger than NPDZ 13.

49C-2

Radiolaria:

Cyrtocapsella cornuta (VR), Lamprocyrtis hannai (VR), Larnacantha sp. (F), Spongodiscus sp. (F), Xiphospira circularis (F).

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

49C-2 (con't.)

Diatoms:

Actinocyclus ingens (A), A. tsuguruensis (C), Coscinodiscus marginatus (C), C. radiatus (C), Denticula lauta (A), Navicula spp. (F), Rhizosolenia miocenica (R), Stephanogonia hanzawae (R), Triceratium condecorum (R).

Silicoflagellates:

Cannopilus hemisphaericus (F), Distephanus crux (C).

AGE:	Middle Miocene (Provincial)
STAGE:	Luisian
ZONE:	NPDZ 20-23
DISCUSSION:	See discussion under 33D-2

58A-1

Radiolaria:

Actinomma sp. (R), Heliodiscus sp. (R), Lychnocanium grande (VR), Spongodiscus sp. (F).

Diatoms:

Actinocyclus ingens (C), Coscinodiscus marginatus (A), Denticula lauta (A), Diploneis sp. (F), Navicula spp. (F), Rhizosolenia miocenica (R), Stephanogonia hanzawae (R), Synedra jouseana (R), Triceratium condecorum (R).

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

58A-1 (con't.)

Silicoflagellates:

Cannopilus hemisphaericus (R), Corbisema triacantha (R), Distephanus crux (A).

AGE:	Middle Miocene (Provincial)
STAGE:	Luisian
ZONE:	NPDZ 20-23
DISCUSSION:	See discussion under 33D-2

27B-1

Radiolaria:

Larnacantha sp. (R), Lychnocanium cf. grande (VR).

Diatoms:

Actinoptychus spp. (F), Aulacodiscus sp. (F), Cladogramma dubium (VR), Coscinodiscus marginatus (F), Denticula hustedtii (C), Endictya robusta (F), Rhizosolenia miocenica (R), Stephanopyxis cf. schenckii (R).

Silicoflagellates:

Cannopilus hemisphaericus (F), C. sphaericus (VR), Distephanus crux (F), D. speculum (R).

AGE:	Probable early Late Miocene (Provincial)
STAGE:	Early Mohnian

RE: S.C.E. - 8-77 Outcrop Samples, San Onofre Area (#492)

27B-1 (con't.)

ZONE: NPDZ 17-20

DISCUSSION: See discussion under 20D-1

Interpreted by:

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SUBMITTED

SEPTEMBER 20, 1977

ANDERSON, WARREN & ASSOCIATES, INC.
CONSULTING MICROPALEONTOLOGY
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San Diego, California 92121
(714) 755-1524
Cable: Micropaleo San Diego

September 20, 1977

TO: Southern California Edison

RE: Outcrop Samples; 8-77 (AWA #501)
San Onofre Area
California

FORAMINIFERAL REPORT

The following six (6) outcrop samples were examined for occurrences of Foraminifera for the purpose of age and paleobathymetric determinations.

57B-1	57D-2
57B-2	SO2/3-3
57D-1	SO2/3-4

The results of this examination are listed below.

57B-1

Radiolaria (VR). Barren of Foraminifera.

AGE: Indeterminate
ENVIRONMENT: Probable Marine

57B-2

Statoliths (VR), volcanic glass shards (VVA). Barren of Foraminifera.

AGE: Indeterminate
ENVIRONMENT: Indeterminate

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

57D-1

Diatoms (R), radiolaria (C). Barren of Foraminifera.

AGE: Indeterminate
ENVIRONMENT: Marine

57D-2

Barren of microfossils.

AGE: Indeterminate
ENVIRONMENT: Indeterminate

SO2/3-3

Barren of microfossils.

AGE: Indeterminate
ENVIRONMENT: Indeterminate

SO2/3-4

Barren of microfossils.

AGE: Indeterminate
ENVIRONMENT: Indeterminate

Interpreted by:

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September 20, 1977

TO: Southern California Edison

RE: Outcrop Samples; 8-77 (AWA #501)
San Onofre Area
California

CALCAREOUS NANNOFOSSIL REPORT

The following six (6) outcrop samples were examined for occurrences of calcareous nannofossils for the purpose of age determination:

57B-1	57D-2
57B-2	SO2/3-3
57D-1	SO2/3-4

None of the above samples contained any distinguishable calcareous nannofossils.

Interpreted by:

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RE: Outcrop Samples; 8-77 (AWA #501)
San Onofre Area
California

SILICEOUS MICROFOSSIL REPORT

The six (6) outcrop samples listed below were examined for contained siliceous microfossils (i.e., radiolarians, diatoms and silicoflagellates) for the purpose of age and zonal determinations.

57B-1	57D-2
57B-2	SO2/3-3
57D-1	SO2/3-4

Siliceous microfossil assemblages were recovered from only four of the samples (57B-1, 57B-2, 57D-1, and 57D-2) and are described below:

57B-1

Radiolaria:

Lychnocanium grande (R), Spongodiscus sp. (F), Stylatractus universus (R).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

57B-1 (con't.)

Diatoms:

Actinocyclus ingens (F), Cladogramma dubium (R), Coscinodiscus obscurus (C), Denticula dimorpha (F), D. hustedtii (F), D. lauta (F), Rhizosolenia cf. barboi (R), R. miocenica (VR), Stephanopyxis cf. schenckii (F), Triceratium condecorum (R).

Silicoflagellates:

Cannopilus cf. hemisphaericus (VR), C. sphaericus (VR), Dictyocha aspera (VR), Distephanus crux (F), D. speculum (R).

AGE: early Late Miocene (Provincial)
STAGE: Mohnian
ZONE: NPDZ 15-18
DISCUSSION: The presence of Denticula dimorpha indicates correlation with NPD Zones 15-18 (North Pacific diatom zonation of Schrader, 1973). The occurrence of Denticula lauta suggests an age no younger than NPDZ 15.

57B-2

Radiolaria:

Lychnocanium grande (R), Spongodiscus sp. (F), Stylatractus universus (R).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

57B-2 (con't.)

Diatoms:

Actinocyclus ingens (F), A. tsuguruensis (R), Cladogramma dubium (R), Coscinodiscus obscurus (F), C. radiatus (F), Denticula hustedtii (F), D. lauta (F), Rhizosolenia cf. barboi (VR), Stephanogonia hanzawae (R), Stephanopyxis cf. schenckii (C), Triceratium condecorum (R).

Silicoflagellates:

Cannopilus sphaericus (F), Dictyocha aspera (R), Distephanus crux (R).

AGE: early Late Miocene (Provincial)
STAGE: Mohnian
ZONE: NPDZ 15-20
DISCUSSION: The co-occurrence of Denticula lauta and D. hustedtii indicates a correlation with NPD Zones 15-20.

57D-1

Radiolaria:

Lychnocanium grande (VR), Spongodiscus sp. (F), Stichocorys cf. delmontensis (R), ?Theocorys cf. redondoensis? (VR).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

57D-1 (con't.)

Diatoms:

Actinocyclus cubitus (R), A. ehrenbergii (R), Actinoptychus spp. (F), Arachnoidiscus ornatus (R), A. ehrenbergii (R), Cladogramma dubium (R), Coscinodiscus marginatus (C), Lithodesmium californicum (R), Stephanopyxis sp. (F), Thalassionema nitzschioides (A).

Silicoflagellates:

Dictyocha aspera (F), D. fibula (R), D. pentagona (VR), D. pseudofibula (VR), Distephanus crux (R), D. speculum (F).

AGE: Probable Late Miocene (Provincial)
STAGE: Indeterminate
ZONE: Indeterminate
DISCUSSION: The presence of Cladogramma dubium, Lithodesmium californicum, Lychnocanium grande, and Stichocorys cf. delmontensis allows only a general correlation to the provincial Late Miocene. The lack of additional short-ranging diatom species prohibits recognition of any North Pacific diatom zones.

57D-2

Radiolaria:

Actinomma spp. (R), Spongodiscus sp. (R), Stichocorys cf. delmontensis (F), Stylatractus universus (VR).

RE: S.C.E. - Outcrop Samples; 8-77, San Onofre Area

57D-2 (con't.)

Diatoms:

Actinocyclus cf. ingens (R), Arachnoidiscus ornatus (VR), Coscinodiscus marginatus (A), Navicula sp. (R), Opephora schwartzii (VR), Stephanopyxis sp. (VR), Thalassionema nitzschioides (F).

Silicoflagellates:

Distephanus crux (R), D. speculum (F).

AGE: Possible Late Miocene (Provincial)

STAGE: Indeterminate

ZONE: Indeterminate

DISCUSSION: The presence of Stichocorys cf. delmontensis suggests an age of Middle to Late Miocene. The floral resemblance (diatoms and silicoflagellates) to the assemblage recovered from 57D-1 indicates a possible restriction to the Late Miocene.

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ENCLOSURE 4

GEOMORPHIC ANALYSIS OF FAULT "E"
CAMP PENDLETON, CALIFORNIA

FOR:

SOUTHERN CALIFORNIA EDISON COMPANY
Rosemead, California 91770

BY:

ROY J. SHLEMON AND ASSOCIATES, INC.
Newport Beach, California 92663

September, 1977

GEOMORPHIC ANALYSIS OF FAULT "E"

CAMP PENDLETON, CALIFORNIA

for

Southern California Edison Company

Rosemead, California

Roy J. Shlemon and Associates, Inc.
P. O. Box 3066
Newport Beach, Calif. 92663
(September 1977)

CONTENTS

ILLUSTRATIONS

INTRODUCTION

A fault displacing Tertiary bedrock has recently been mapped (Ehlig, 1977) in the northwestern part of Camp Pendleton California (Figure 1). This fault, generally trending north-south, when projected toward the coast would pass near a truck weigh station on U.S. Interstate Highway I-5. For this report, the fault is informally designated "E".

The youngest geological unit definitely displaced is the Tertiary Monterey Formation. According to the mapping of Ehlig (Figure 2), fault E passes beneath a thin veneer of marine terrace gravels overlying the Monterey Formation at an elevation of about 350 feet. The fault cannot be traced into younger sediments toward the coast. At question, therefore, is the time of last displacement of fault E.

An assessment of fault age can be made by an analysis of its geomorphic expression and stratigraphic relationships in two distinct terranes: (1) the "upland topography" of the coastal mountains east of Interstate Highway I-5; and (2) the San Onofre Bluffs area, west of the highway where the fault trend, though unseen, can be projected.

A geomorphic study, described in following sections, indicates that last movement of the fault occurred more than 25,000 to 30,000 years ago, and more likely, at least 100,000 years before present. These ages are documented in this report by a review of the basic geomorphic relationships within those portions of Camp Pendleton and the San Onofre State Beach near fault E; by pointing out field procedures used in the analyses; and by reconstructing the late Quaternary geomorphic history of the area as it bears upon the fault age.

FIELD PROCEDURES

The entire trace of fault E, from its projection near the coast to its northernmost mapped expression in the coastal range above San Onofre Creek (Figures 1 and 2), was inspected by low-level helicopter overflights. In particular, coastal bluffs and inaccessible, steep-walled arroyos were readily viewed along their entire extent using binoculars from the helicopter which itself often could hover within 15 feet of cliff faces (Figure 3).

In addition to aerial observations, cliffs and canyons were examined from the ground, specifically to note stratigraphy or buried soils which, individually or in sets, could be traced laterally for at least several hundred feet and thereby record continuity of sediments across projections of the fault.

Also, in conjunction with aerial and ground survey, geomorphic relationships along the fault were interpreted with respect to their expression on geological and topographic maps, and on aerial photography.

GEOMORPHIC AND STRATIGRAPHIC RELATIONSHIPS

The geomorphic surfaces and underlying geological units along the northeastern part of Camp Pendleton have become increasingly better known in the last several years as a result of regional mapping and of specific investigations for the Southern California Edison Company, Nuclear Generating Station Units 2 and 3 (Blanc and Cleveland, 1968; Converse-Davis and Associates, 1970; Morton and others, 1973; and Moyle, 1973). The most recent detailed mapping is by Ehlig, (1977).

In general, the coast mountains rise to over 1,000 feet in elevation within about four miles from the coast. This upland is underlain primarily by the Miocene San Onofre, and Monterey Formations, and locally by the Pliocene San Mateo Formation (Ehlig, 1977). Marine terrace deposits, usually to several feet thick and containing well-rounded cobbles and boulders, occur as discontinuous remnants from the youngest at about 350 feet to successively older ones at more than 900 feet above sea level.

The absolute age of the marine terrace deposits at about elevation 350 feet is presently unknown. However, these deposits occupy a geomorphic position well above a marine platform and related beach sediments near elevation 30 feet associated with the last major glacioeustatic high stand of sea level, about 120,000 to 130,000 years ago (marine oxygen isotopic stage 5 of Emiliani, 1955 and 1966; and stage 5e of Shackleton and Opdyke, 1973). Assuming that these marine terrace gravels at 350 feet represent uplifted deposits laid down during the high stand of sea level immediately preceeding stage 5, then they would be related to either isotopic stage 7 or 9; that is, laid down approximately 200,000 to 300,000 years ago (Shackleton and Opdyke, 1973, p. 48 and 49; 1976).

Between the coastal cliffs and uplands is a gently undulating constructional terrace (San Onofre bluffs), generally less than 2,000 feet wide, at an elevation of about 140 to 200 feet. This terrace surface is underlain by 60 to 100 feet of continental, non-marine sediments and interbedded buried paleosols, increasing in thickness eastward where overlain by Holocene debris and mudflows emanating from canyons along the adjacent mountain front (Figure 3). The continental deposits (non-marine sediments of Ehlig, 1977) rest on 10 to 20 feet of beach sediments which, in turn, overlie the 120,000 year old basal marine gravel and a clearly-defined platform cut on siltstone and sandstone of the Tertiary Monterey Formation (Figure 4). The age of the marine platform sediments is derived from numerous amino-acid dates of shells and from uranium series assay of corals from several localities along the southern California coast (Veeh and Valentine, 1967; Valentine and Veeh, 1969; Ku and Kern, 1974; Lajoie and others, 1975).

Not uncommonly, some 100 to about 400 feet of bluff sediments along the coast have been deformed by massive landslides. Many of these slides are rotated blocks, detached from the main body of continental sediments, yet of sufficient size and preservation so that individual beds within the slide debris are commonly laterally traceable for hundreds of feet.

Though not as "clean" as the continually eroding backscarps of the slides, the face of the continental deposits clearly expose at least 25, and generally 50 to 60 feet of bedded sediments useful to assess any possible displacement along the seaward projection of fault E (Figure 3).

In addition to cliff and backscarp faces, the post-120,000 year old continental deposits are clearly exposed in an almost vertically walled arroyo here informally deemed "Trail 3 Canyon" owing to its proximity to that trail within San Onofre State Beach (Figures 2 and 3). Trail 3 Canyon extends headward directly across projections of the fault. In this canyon the marine platform and overlying beach deposits crop out only near the mouth; however some 55 to 60 feet of overlying continental deposits and buried soils are well exposed near the head, permitting assessment of any fault displacement.

AGE OF FAULT E

The time of last movement of fault E can be ascertained by geomorphic expression on the present landscape, and by dating overlying undisplaced sediments. Topography best recording any possible recent fault displacement is the upland or coastal range between about Interstate Highway I-5 on the south and San Onofre Creek on the north (Figure 1). The best exposed sediments to date possible late Quaternary movement are the post-120,000 year old continental deposits underlying the San Onofre Bluffs terrace between Interstate I-5 and the coast (Figures 3 and 4).

Upland Topography

The recent detailed mapping of Ehlig (1977) shows that the youngest unit clearly displaced is the Miocene Monterey Formation. Should large scale faulting have continued into late Pleistocene time, one or all of three distinct geomorphic relationships would likely be associated with the trace of the fault.

First, vertical offset on the order of about 10 to 20 feet within the last 200,000 years would have displaced marine terrace deposits at elevations of 350 feet and the underlying bedrock (Figure 2). However, this is not evident, at least within the resolution of map scale and preservation of terrace deposits along the trace of fault E.

Second, the fault trace is not typified by landslides, spring lines, faceted spurs, or other geomorphic features commonly associated with youthful displacement. Landslides do occur in the upland area, but are related to steep slopes along modern canyon walls, or to ancient mass-movements within the San Onofre Formation.

And third, any displacement of the fault within at least the last several thousand years would likely be recorded by preservation of topographic saddles or minor depressions along drainage divides. This, however, is not the case. Breaks in slope along knife-like ridges are not aligned whatsoever with the fault but rather with differential weathering along juxtaposed, unlike lithologic units.

In summation, the geomorphic expression of fault E across the upland topography of the coastal range indicates that last displacement must have occurred on the order of perhaps tens of thousands of years ago.

San Onofre Bluffs

To assure complete examination of all possible projected trends of fault E, over one mile of San Onofre bluffs exposures were viewed in sea cliffs and canyons (Figures 2 and 3). Although, typically lenticular and locally cross-bedded, the gravels, sands and silts of the continental deposits display remarkable continuity in cliff and canyon exposures (Figures 5, 6 and 7). Nowhere visible are deeply buried gullies or old channel fills typical of major unconformities within the section. On the contrary, the broadly fining-upward sequence of gravels and sands, and their distance from the upland source area represents seasonally intermittent fluvial deposition characterizing distal segments of piedmont alluvial fans. Nowhere, within the resolution afforded by helicopter and ground inspection, were any sedimentary beds or soils within these continental deposits displaced.

Because of rotated slide blocks on the immediate coastal bluffs, the marine platform is not exposed completely across projections of the fault. However, a minimum 50 feet of continental deposits and buried soils, and an additional 13 feet of underlying beach sands are exposed in Trail 3 Canyon, directly across the fault projection, or discontinuously in cliffs or in other trail and roadcut exposures (Figures 5, 6 and 7).

The age of these undisplaced continental deposits is approximated by their stratigraphic relationship to the 120,000 year old marine platform. Marine beach deposits grade transitionally upward into the continental section characterized by reworked beach sediments, and overlying oxidized fluvial deposits and several weakly-to moderately-developed buried soils (Figure 4). The presence of minor cuts and fills and soils in the continental deposits attests to intermittent deposition, probably related to climatic and related vegetation changes over the last 100,000 years. Over 100 feet of these deposits occur above the marine platform at approximately 30 feet above sea level to about 140 feet at top of the bluffs near the weigh station.

Deposition of about 100 feet of continental deposits in the last 100,000 years yields an average sedimation rate of one foot per 1,000 years. This estimate is borne out for at least the basal section of the continental deposits by an infinite radiocarbon date (greater than 37,000 years b.p) of charcoal obtained approximately 26 feet above the marine platform in "Dead Dog Canyon," about 1.7 miles southeast of the projected trend of fault E (Geochron Lab. No. GX-4953; Figure 4).

A sedimentation rate of one foot per 1,000 years is inherently conservative in that it assumes that the top of the present San Onofre Bluffs (elevation 140 feet; Figures 3 and 4) is still receiving sediments and is thus of "zero" age. However, in reality, there has probably been no sedimentation on the coastal bluffs in this area for at least the last several thousand years because: (1) contemporary fluvial sediments are being carried down deeply incised canyons to sea level, (Figure 2); (2) sediments being laid down as piedmont fans and mudflows immediately adjacent to the mountain front (Figures 2 and 4); and (3) the present surface soil in this area (Figure 7) has an argillic horizon commensurate with an age of at least several thousand years old. Thus continental sediments at the top of the bluff are likely at least early Holocene in age, laid down possibly well before the sea reached its present level about some 5,000 years ago. In essence, the average sedimentation rate may be about ten percent faster than calculated, and the age of the continental deposits, in reality, should be increased by a corresponding amount. However, a "young" age of the deposits is assumed in order to assess conservatively the last time of possible fault displacement.

The more than 50 feet of continental deposits exposed in Trail 3 Canyon directly across the projection of the fault are not displaced. Therefore, according to age of these sediments (established by a conservative rate of deposition), no offset has occurred in this area for at least the last 50,000 years. Elsewhere along bluff faces, landslides have obscured some lower continental deposits, but even here, at least 25 to 30 feet are visible and similarly appear undisplaced (Figures 3 and 8).

In summation, exposures of continental deposits in the San Onofre Bluffs, undisplaced as determined from helicopter and ground observation, indicate the last movement of fault E must have occurred more than 25,000 to 30,000 years ago, probably more than 50,000 years ago, and very likely at least 100,000 years before present.

SUMMARY AND CONCLUSIONS

The Miocene Monterey Formation is the youngest unit displaced by fault E in the northwestern part of Camp Pendleton. Marine terrace deposits at least 200,000 years old, occurring at an elevation of 350 feet, appear not displaced within the resolution afforded by their preservation and elevation. Upland topography in the coastal range contains no landslides, spring lines, truncated spurs, saddles or similar geomorphic and topographic expression associated with the fault. This suggests that last displacement must have occurred on the order of tens of thousands of years before present.

Continental deposits exposed in sea cliffs, bluffs and canyons are similarly not visibly offset. These deposits overlie a radiometrically dated 120,000 year old marine platform (oxygen isotope stage 5) cut across the Monterey Formation. Basal continental deposits are beyond the range of radiocarbon assay. A conservative rate of sedimentation is calculated as approximately one foot per 1,000 years. At least 50 feet (50,000 years) of continental sediments are undisplaced in Trail 3 Canyon extending directly across the seaward projection of the fault. Elsewhere on coastal bluffs at least 25 to 30 feet of sediments are similarly undisplaced. Therefore, last displacement of fault E probably occurred more than 25,000 to 30,000 years ago, if not at least 50,000, and very likely more than 100,000 years before present.

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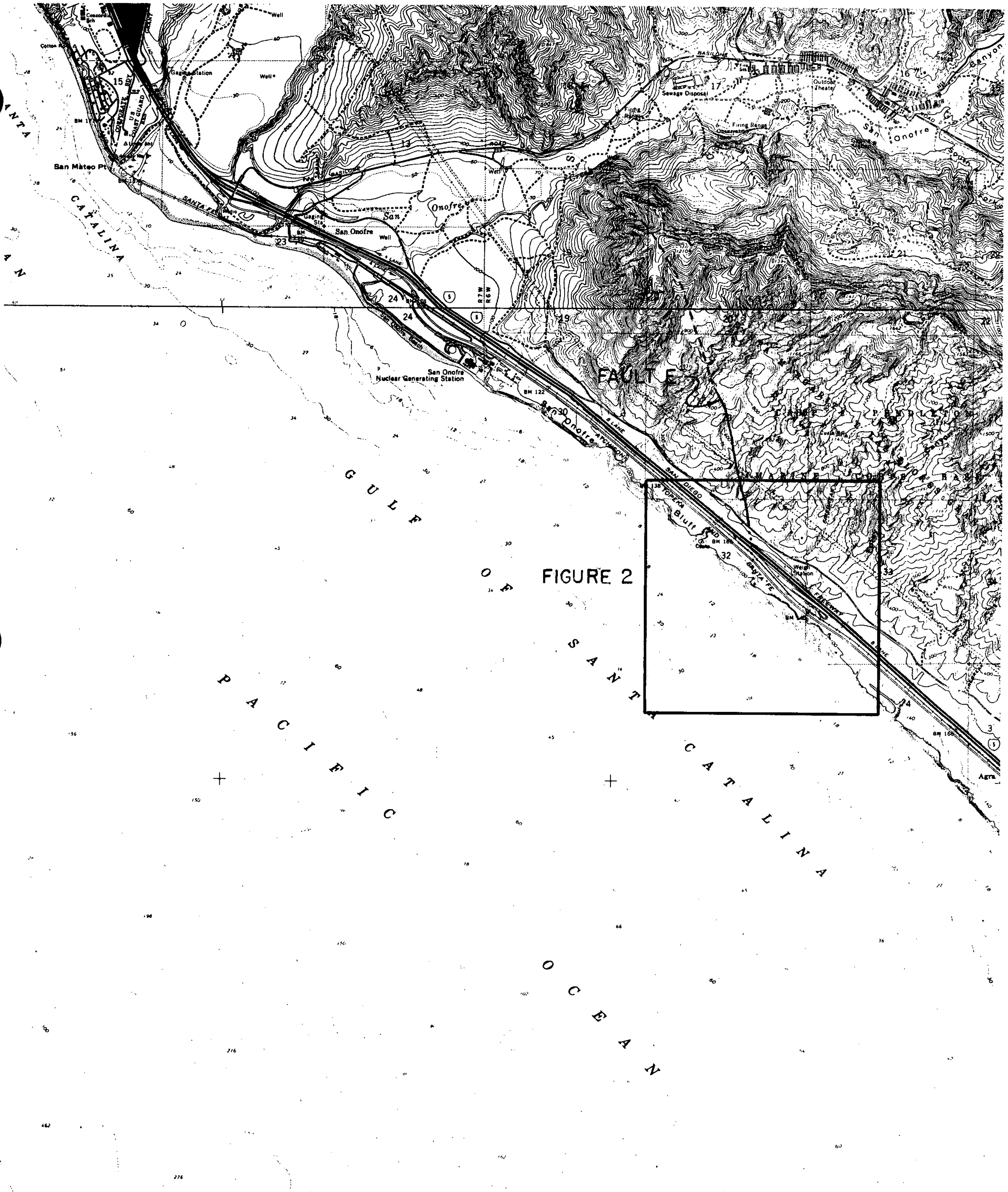
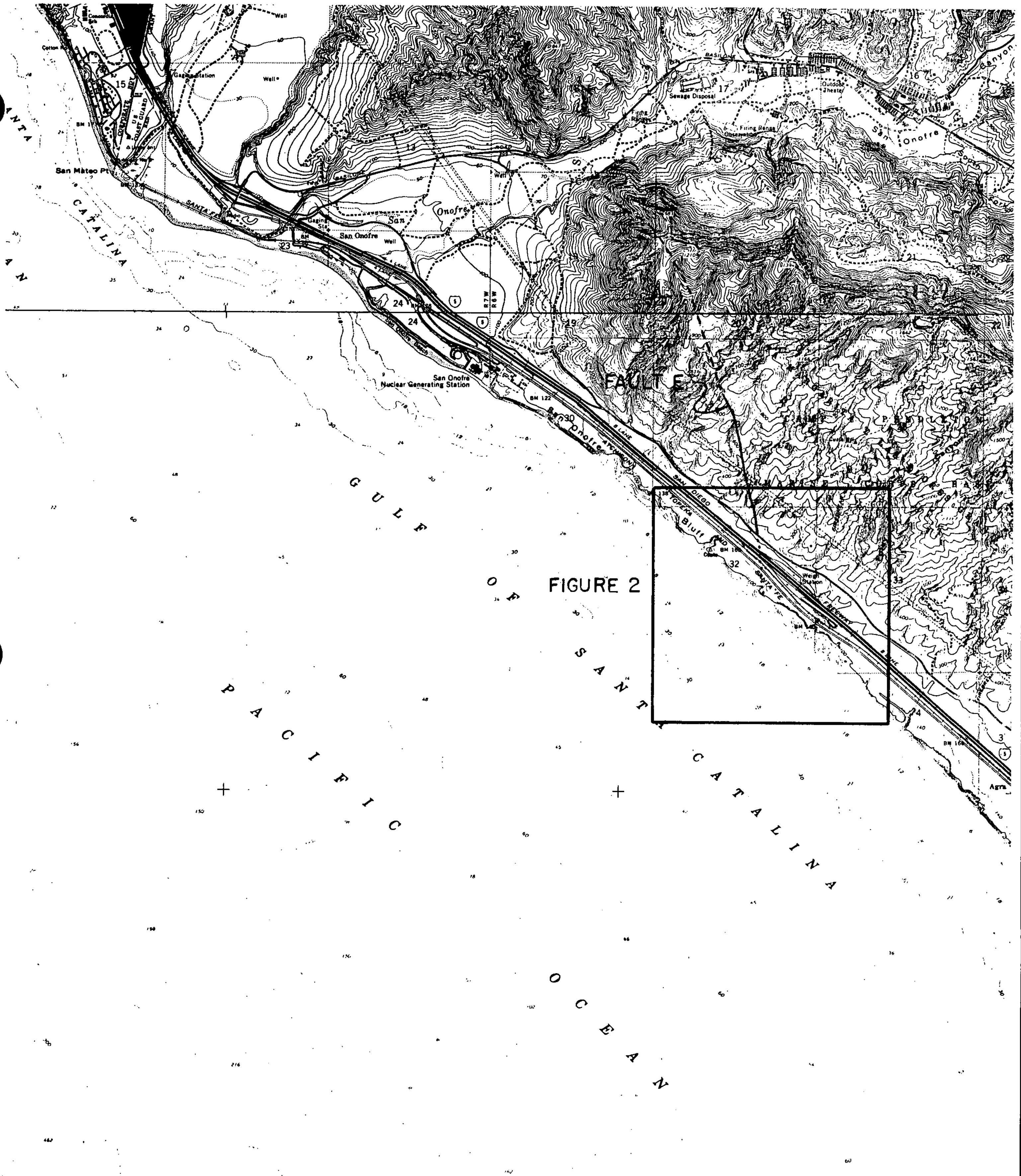


FIGURE I. REGIONAL GEOLOGICAL MAP, NORTHWESTERN CAMP PENDLETON, CALIFORNIA SHOWING FAULT E AND AREA OF GEOMORPHIC ANALYSIS



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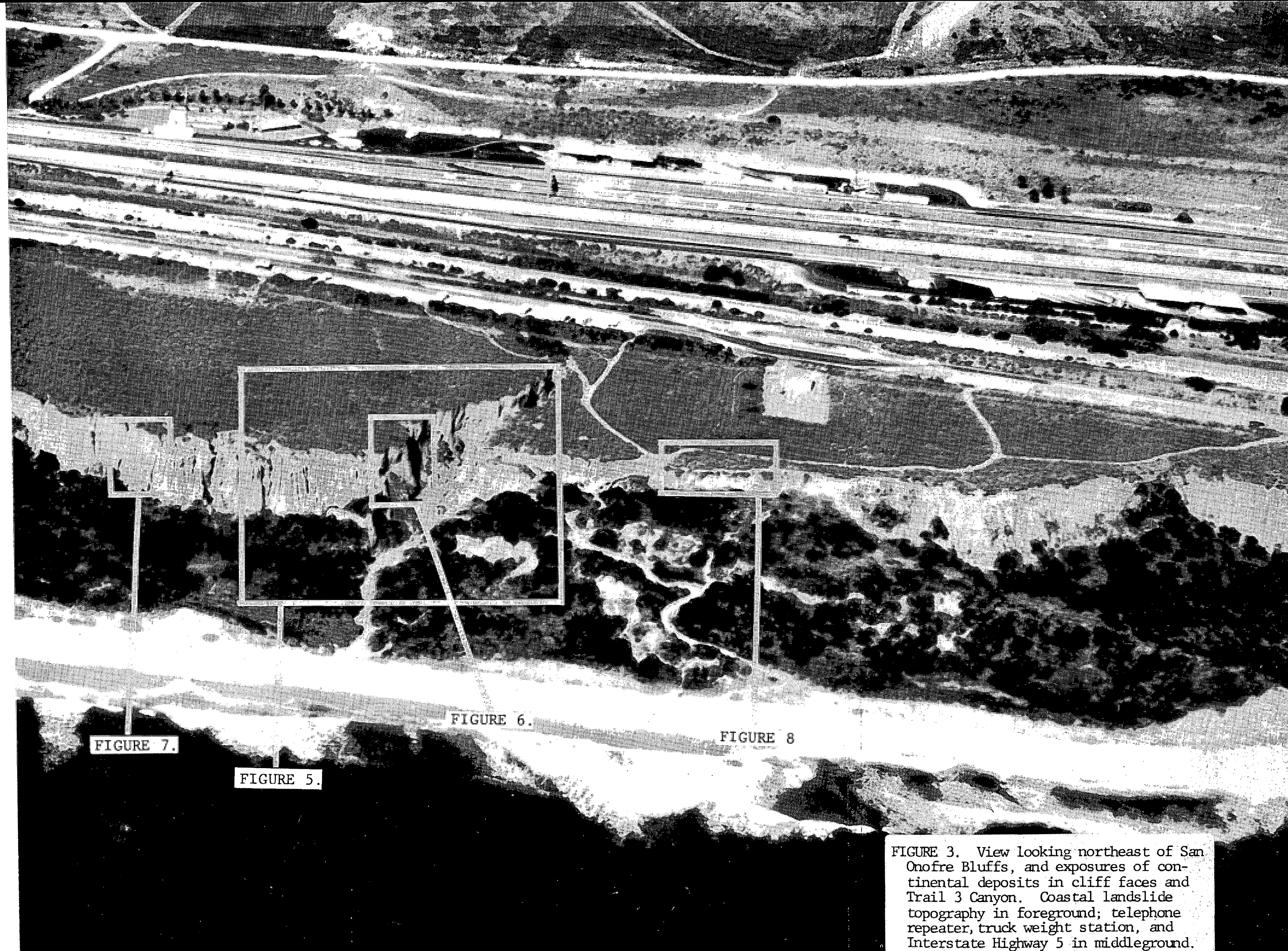
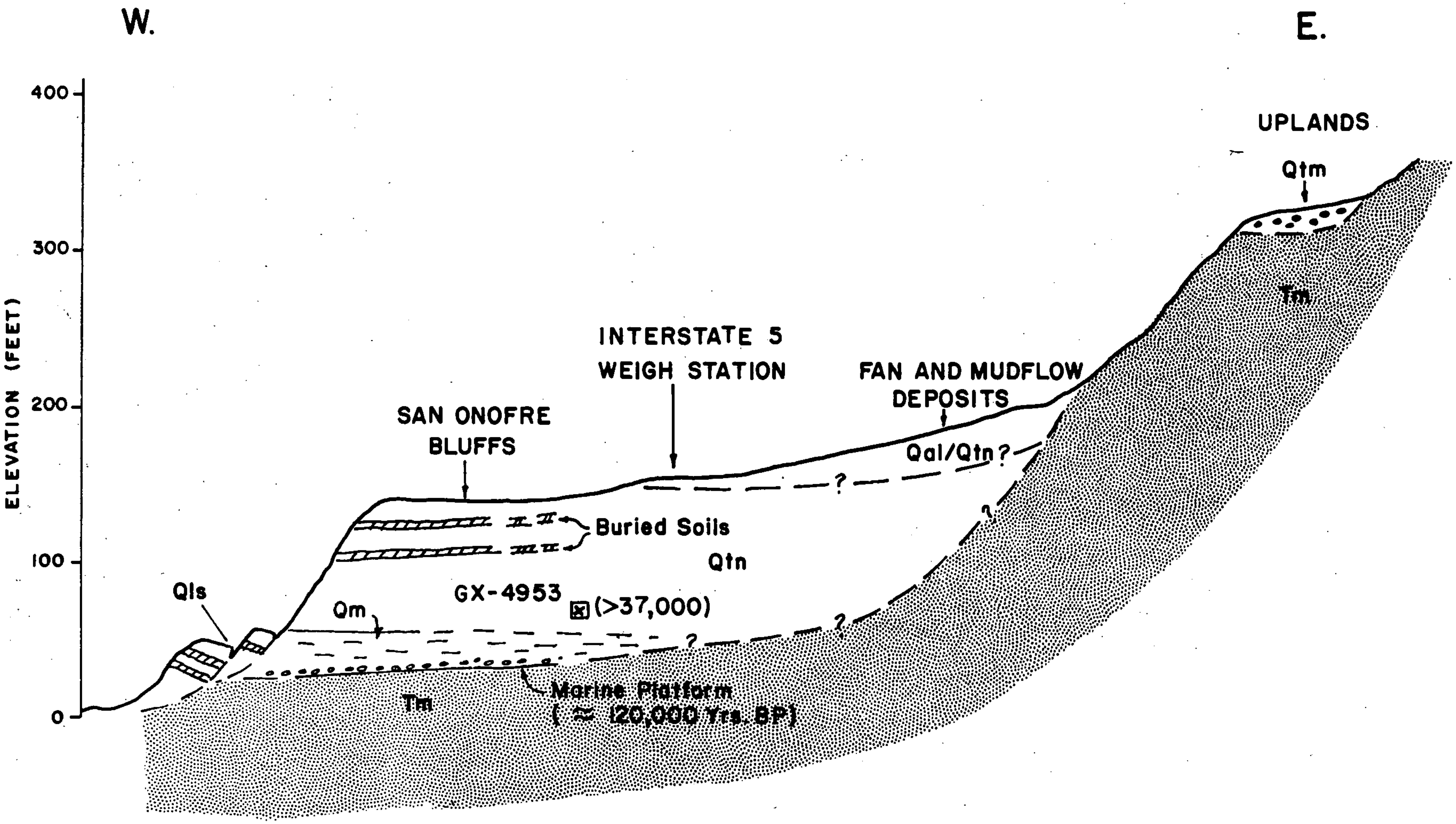


FIGURE 3. View looking northeast of San Onofre Bluffs, and exposures of continental deposits in cliff faces and Trail 3 Canyon. Coastal landslide topography in foreground; telephone repeater, truck weight station, and Interstate Highway 5 in middleground.



Qal/Qtn ---- Holocene Fan and Mudflow Deposits
Qtn ---- Continental Deposits and Buried Soils
Qls ---- Landslides
Qm ---- Marine Beach Deposits
Qtm ---- Marine Terrace Deposits
Tm ---- Miocene Monterey Formation
⊠ ---- Radiocarbon sample

FIG. 4. Diagrammatic sketch, stratigraphic and geomorphic relationships in area of Fault E. Radiocarbon date above base of continental deposits (Qtn) indicated by laboratory number; marine platform dating after Lajoie and others (1975). Vertical scale exaggerated.

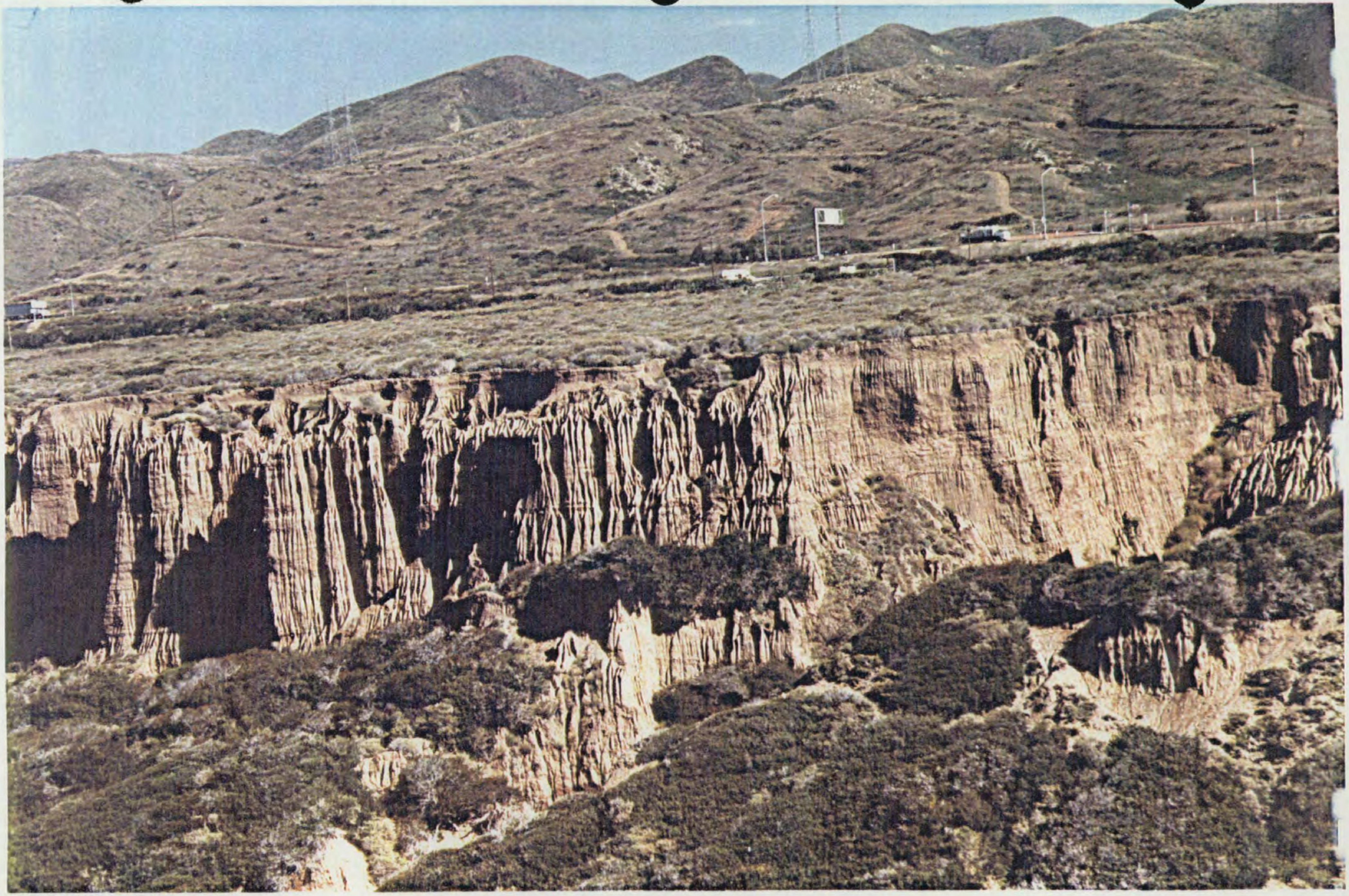


FIGURE 5 Mouth of Trail 3 Canyon. Lateral continuity of soil and gravel is seen. View is looking north.

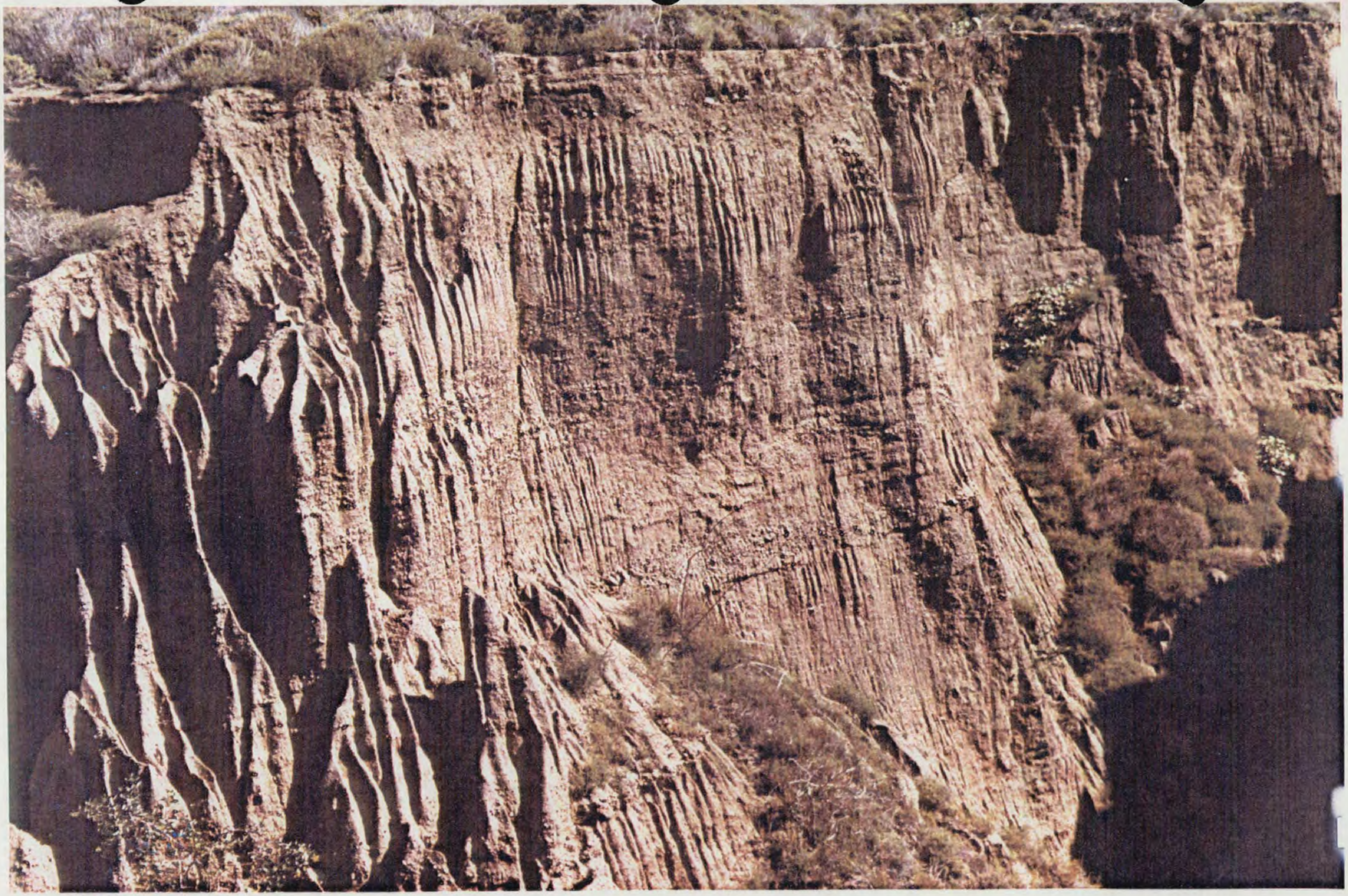


FIGURE 6 View of the mouth of Trail 3 Canyon. A minimum of 50 feet of continental deposits and buried soils are exposed in Trail 3 Canyon, directly across the fault projection and show no displacement.

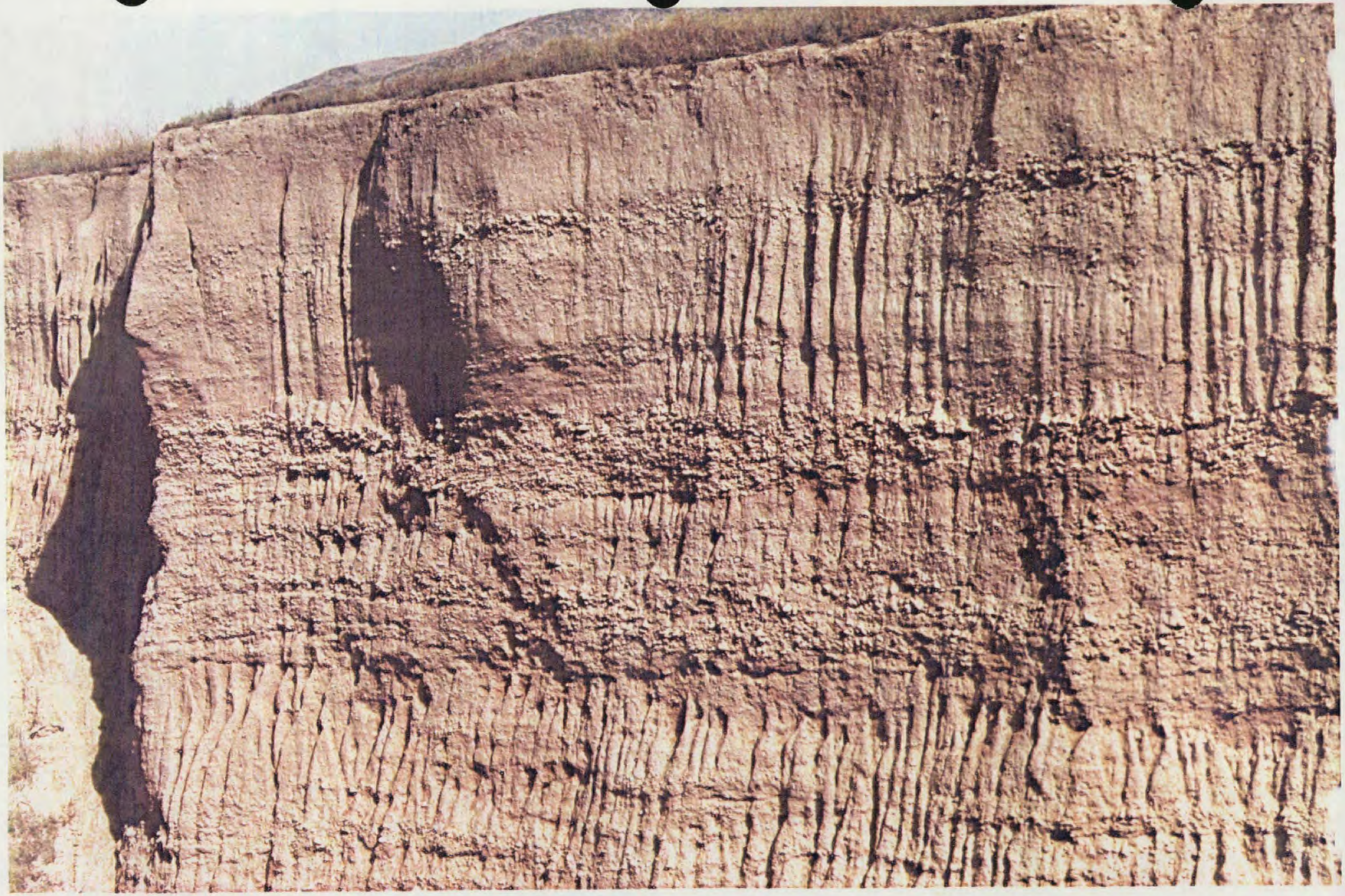


FIGURE 7 Typical exposure of continental terrace deposits showing continuity of gravel beds. Height of exposure is about 40 feet. View is looking north.

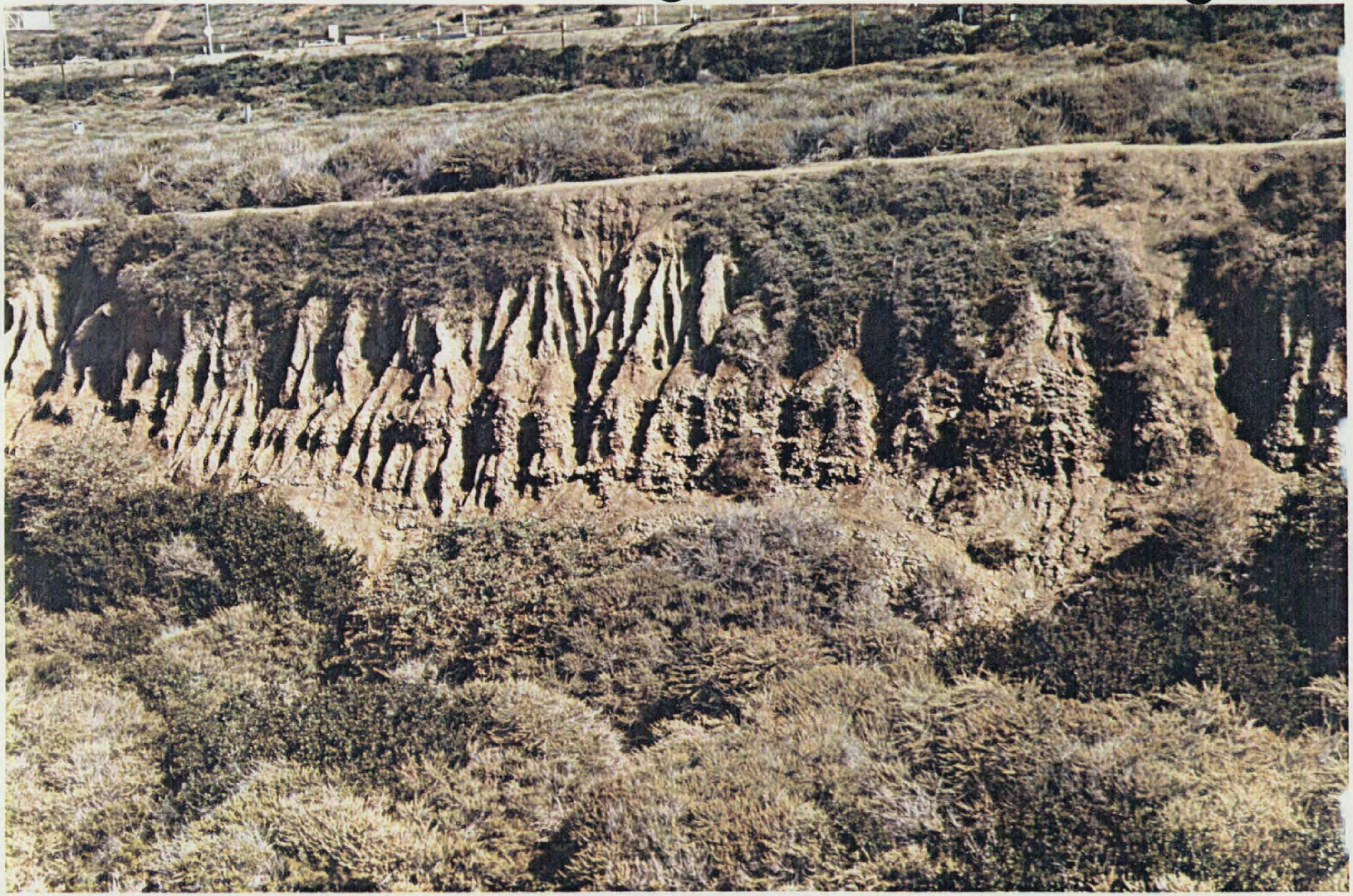


FIGURE 8 View just southeast of Trail 3 showing 25 to 30 feet of continental terrace deposits. Erosion resistant gravel lenses along exposure.