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SAN ONOFRE
NUCLEAR GENERATING STATION
UNITS 1, 2 & 3

RECENT GEOTECHNICAL STUDIES
SOUTHERN ORANGE COUNTY, CALIFORNIA

FEBRUARY 1976

VOLUME I

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VOLUME I

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RECENT GEOTECHNICAL STUDIES
SOUTHERN ORANGE COUNTY, CALIFORNIA

DISCUSSION

This report documents the results of Southern California Edison's investigative program which was initiated as a result of two small earthquakes occurring at 5:54 and 6:01 GMT on January 3, 1975 near San Juan Capistrano, California. In addition, Enclosure 1 of this report includes responses to NRC questions of August 19, 1975 which pertained to investigations of the Cristianitos fault zone. The information contained in this report was presented in a meeting among the NRC, USGS, ACRS Consultants, representatives of California state agencies and SCE on October 15-16, 1975. This summary presents a brief discussion of the January events followed by a discussion of SCE's investigative program.

California Institute of Technology (CIT) indicated that the above earthquakes were shallow events (less than 15 kilometers deep) located several kilometers west of the Cristianitos fault with local magnitudes of 3.8 and 3.3. Portions of Mission Viejo, Laguna Niguel, and San Juan Capistrano reported the occurrences; however, no damage was reported. The strong motion instruments at San Onofre Nuclear Generating Station, approximately 20 kilometers away, were not triggered indicating that ground motion had attenuated to less than 0.01g. A field survey in a region around the epicenters and along the Cristianitos fault did not locate any ground surface rupture.

As a result of the above earthquakes, SCE initiated a program to investigate the significance of these events to the San Onofre Nuclear Generating Station and to determine whether they were related to the Cristianitos fault which is considered non-capable. The following discussion summarizes this program which is described in detail in Enclosures 1 through 4 of this report.

Earthquake Location - The crustal model available for use in analysis was a standard Southern California model utilized in CIT epicenter determinations. A new crustal model for a more limited region was therefore developed to more accurately locate the epicenters and fix limits on the hypocentral depths. Two calibration shots were detonated east of the epicentral area permitting development of a specific crustal model as discussed in Enclosure 4. This permitted accurate determination of epicenter locations and restricted the hypocentral depths to between 2.03 and 4.60 km. Based upon the epicenter locations and depth, the January events were too far west and much too shallow to have originated on the steeply dipping Cristianitos fault. Projection of the focal mechanism to the surface from the hypocenter is located between Trabuco and San Juan Canyons. A geologic inspection of this area revealed no features which could be associated with the January earthquakes.

Earthquake Motion - The focal mechanisms were also reconstructed based upon the new crustal model. The fault plane was determined to have strike-slip motion with a significant thrust component regardless of the plane chosen from the solutions. The direction of movement is oblique to the Cristianitos fault and is significantly different from the motion which would be expected to result from movement on a normal, dip-slip fault such as the Cristianitos. This study is discussed in detail in Enclosure 4.

Reanalysis of Prior Events - Four nearby earthquakes which occurred since 1960 were reanalyzed based upon the new crustal model. As discussed in Enclosure 4, it was determined that their focal mechanisms were not consistent with either the January earthquakes or the motion characteristic of any known geologic structure.

Microseismic Investigation - A portable seismographic array was installed around the epicentral area to investigate microseismicity. This array was operated simultaneously with a larger CIT permanent array and the data from both were analyzed together. During 6,000 hours of recording time with the portable array, only 13 microseismic events were recorded. This data is presented in Enclosure 4. The recorded events were generally located away from the Cristianitos fault in the northwest direction. This small number of events indicates virtually no activity when compared to most areas along active faults in Southern California.

Subsurface Geology - The subsurface geology in the region of the epicenters was evaluated based upon data available from various oil companies. This data included boring logs, seismic refraction lines, gravity and aeromagnetic surveys. A structural contour map and five geologic cross-sections were prepared based upon this data. The results indicate that no major geologic structures exist in the vicinity of the epicenters. This study confirmed that the Cristianitos fault is a normal fault with the west side down and dips westerly between 60° and 75°. A downward projection of this dip from the surface outcrop indicates that the fault passes significantly to the east of the lowest possible location of the hypocenters.

Geophysical Data - Available geophysical data including gravity and aeromagnetic surveys was assimilated and interpreted as discussed in Enclosure 4. The magnetic data indicated some large-scale magnetic anomalies within the Capistrano embayment. An example of this is the large positive anomaly near El Toro caused by Tertiary basic igneous dikes. The magnetic map (Figure 23 of Enclosure 4) indicates a general change in the basement rock complex from the east to the west side of the Cristianitos fault. These same patterns are confirmed by the gravity map

(Figure 24 of Enclosure 4). The structure of the Capistrano embayment is a general synclinal trough with the Cristianitos fault clearly delineated by elongated gravity maxima along the eastern margin. As in the case of the subsurface structural study, no other major geologic features can be seen in the geophysical data in the vicinity of the epicenters.

Trench Mapping - A trench was excavated across the Cristianitos fault at the proposed site of the Viejo Substation in Aliso Canyon. Four elements of the Cristianitos fault were exposed in the excavation as discussed in Enclosure 1. Each element was overlain by undisturbed and unfaulted Pleistocene fluvial terrace deposits. No indication of displacement or expression of shearing in the terrace deposits were found. All evidence tended to confirm that the Cristianitos is not a capable fault.

Geomorphic Study - An analysis was conducted of fluvial terraces and the marine counterparts at the coast to determine the recency of movement across the Cristianitos fault zone. This geomorphic study and analysis is discussed in Enclosure 2. The analysis was made by reconstructing terrace profiles, drawing cross-sections through the canyons to the coast, and determining the relationship of the fluvial and marine terraces. Terrace levels maintain a constant gradient to the sea unless they are faulted. This study demonstrated that two dominant stream terrace levels exist and are continuous and undisturbed through the Cristianitos fault zone. Based upon the estimated age of terrace materials, the study demonstrates that no discernible warping, tilting, or faulting of the profiles have occurred for at least 120,000 years.

CONCLUSIONS

1. The location and motion of the January 3, 1975 events indicate that these earthquakes did not occur on the Cristianitos fault. This conclusion is based upon the following:

    A. The January events were located too far west and were too shallow to have occurred on the Cristianitos fault.

    B. The motion of the January events is significantly different from the motion that would be expected from a normal dip-slip fault such as the Cristianitos, and the motion occurred in a direction oblique to the Cristianitos fault.

2. Earthquakes of this magnitude in California often cannot be associated with geologic structures mapped at the surface. These earthquakes were probably manifestations of minor readjustments in the crustal rocks resulting from residual compressional stresses which cannot be identified with

regional tectonic strain patterns in Southern California. The January 3, 1975 earthquakes were associated with a structural feature sufficiently small that its presence could not be detected using the following methods:

A. Analysis of geophysical data which included gravity data, aeromagnetic surveys, boring logs, and seismic refraction lines.

B. Microseismic study.

C. Field reconnaissance.

3. There is substantial evidence that the Cristianitos fault has had no movement within at least the last 120,000 years. This is based on the following:

   A. Trenching at three locations along the fault traces indicates that the fault is overlain by unbroken Pleistocene fluvial terrace deposits which are estimated to be more than 120,000 years old.

   B. A geomorphic study of fluvial terrace deposits which cross the Cristianitos fault indicate that no discernible warping or faulting has occurred in at least the last 120,000 years.

4. There is no evidence for displacement at the ground surface in the past 120,000 years or movement of a recurring

nature in the past 500,000 years; no instrumentally determined macro-seismicity that can be directly related to the Cristianitos fault; and no evidence for a structural relationship with a capable fault. Accordingly, the Cristianitos fault is concluded to be a non-capable fault in accordance with the criteria of 10CFR100, Appendix A.

ENCLOSURE 1

RESPONSE TO NRC QUESTIONS

Enclosure No. 1

NRC COMMENTS AND QUESTIONS REGARDING INVESTIGATION OF THE CRISTIANITOS FAULT SAN ONOFRE NUCLEAR GENERATING STATION

UNITS 1, 2, AND 3

Introduction

The following questions and background, regarding investigation of the Cristianitos fault, were received from the NRC on August 19, 1975.

Background

Fife (1974)* reported on a trench which cut the Cristianitos fault near the north end of the Oso Valley. The trench exposed a lime-filled crack extending from the fault plane in the bedrock upward through the overlying colluvium and into the "root zone". Fife indicated that the crack was not the result of movement on the Cristianitos fault because neither slickensides, deformation, nor offset were observed in the soft lime filling. He considered the crack to result from differential seismic shaking between the Oso member of the Capistrano formation and the LaVida member of the Puente formation which are juxtaposed across the fault. He suggested that such differential seismic shaking could result from the different properties of two juxtaposed formations,

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*Fife, D. L., "Geology of the South Half of the El Toro Quadrangle, Orange County, California", California Division of Mines and Geology, Special Report 110, 1974.

and may have been caused by ground vibration during a strong southern California earthquake.

During our April 9, 1975 site visit, we observed a similar condition in the trench dug by Southern California Edison Company at the north end of Aliso Valley which cut the Cristianitos fault approximately one mile north of the Oso Valley trench. We observed several traces of the fault (four had clearly distinguishable surfaces), which showed displaced material in the bedrock evidenced by fault gouge and mineralization. Mullion structure and slickenside development indicated both vertical and strike-slip movement on these faults. Where they were observed to intersect, the fault planes with strike-slip movement offset those having vertical movement. We observed a linear separation (or crack) located immediately above and along the projection of one of the fault planes in a river terrace deposit. Although the linear separation appeared to be a continuation of faulting in the bedrock into the overlying terrace material, no apparent displacement could be observed in two clay inclusions which straddle the separation.

NRC QUESTIONS DATED AUGUST 19, 1975

1. With respect to the trench which we inspected on April 9, 1975, your investigation should include the following:
    a) A complete and detailed geologic map of the trench exposure.
    b) A discussion of the significance of the horizontal and vertical displacements in the bedrock exhibited by the faults and the truncation of the latter by the former.
    c) A discussion of the origin and safety significance of the lime-filled crack and the linear separation in the river terrace above the fault plane.
    d) A determination of whether or not the crack could have been created by movement on the Cristianitos fault and later filled with lime with no further movement taking place.
    e) Is an analysis feasible which would simulate the lime-filled crack and the juxtaposed Oso and LaVida formations on opposite sides of the fault, and possibly demonstrate that such a crack may or may not result from differential or out of phase response of the strata juxtaposed along the fault? If so, perform such an analysis and provide a summary of the results.

2. With respect to the recent reports from the State of California:

a) Investigate and determine the significance of the statement on page 10 of the Fife report, "Stream terraces four miles north of the study area on Santiago Road, between Silverado Canyon and Williams Canyon, have been tilted on end, suggesting that the frontal fault system may have moved during Holocene time in that area. The nearest direct evidence of Holocene faulting was found a mile south of the study area at Cousteau Park. Wade Miller (oral communication, 1971) estimates the age of displaced terrace deposits as between 30,000 and 100,000 years before present."

b) Morton (1974)** mentions on page 9 a back-hoe trench placed in 1971 by the Division of Mines and Geology which succeeded in exposing a western branch of the Cristianitos fault. He states that this trench showed apparent displacement of a two-foot thick slope-wash cover along two shears a few feet apart. Maximum dislocation of the soil-bedrock interface was approximately two feet. As this evidence suggested possible late Holocene movement, additional trenching was placed in the same area by the Southern California Edison Company in June 1972 in order to check this possibility. These excavations suggested that the apparent

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**Morton, P. K., et al, "Geology and Engineering Geologic Aspects of the San Juan Capistrano Quadrangle, Orange County, California", California Division of Mines and Geology, Special Report 112, 1974.

displacement of the soil cover may have been due to a combination of animal borings and differential erosion of the bedrock surface with subsequent soil deposition. However, "Holocene movement has not been ruled out." Additional Trenching is necessary to satisfactorily resolve the questions raised by these indicators of recent movement on the Cristianitos in this area. The placement of trenches should be made after careful consideration of where the potential would be favorable for obtaining definitive results, perhaps in consultation with others who have worked in the area.

3. With regard to the site excavation:

   a) Provide clarification of the stratigraphic relationship of the marine (Qm) and non-marine (Qt) terrace deposits in the San Onofre area. What is the sedimentologic relationship of these units in terms of geologic history of the area, including considerations of shoreline movements and fluvial erosion?

   b) Provide clarification of radiometric dating of the marine terrace deposits (Qm). Included in this clarification should be a discussion of the reliability of the thorium-protactinium method when used for mollusk dating. In addition, provide a discussion of the difference between dating of "shell material" and "mollusks" as referred to in the PSAR and later reports.

NRC QUESTIONS DATED AUGUST 19, 1975
AND CORRESPONDING RESPONSES

Question 1

With respect to the trench which we inspected on April 9, 1975, your investigation should include the following:

a. A complete and detailed geologic map of the trench exposure.

b. A discussion of the significance of the horizontal and vertical displacements in the bedrock exhibited by the faults and the truncation of the latter by the former.

c. A discussion of the origin and safety significance of the lime-filled crack and the linear separation in the river terrace deposits above the fault plane.

d. A determination of whether or not the crack could have been created by movement on the Cristianitos fault and later filled with lime with no further movement taking place.

e. Is an analysis feasible which would simulate the lime-filled crack and the juxtaposed Oso and LaVida formations on opposite sides of the fault, and possibly demonstrate that such a crack may or may not result from differential or out of phase response of the strata juxtaposed along the fault? If so, perform such an analysis and provide a summary of the results.

Response to Question 1

The Viejo Substation trench which was inspected by the NRC on April 9, 1975 is discussed in the answers to Questions 1a, 1b, and the part of 1c which refers to the linear separation in the stream terrace deposits.

The lime-filled crack referred to in Question 1c, 1d and 1e was found in the Mission Viejo trench, which the NRC inspected on October 16, 1975. Therefore, the answer to the part of 1c concerning the lime-filled crack and the answers to 1d and 1e refer to the Mission Viejo trench.

Response to Question 1 (continued)

a. A revised report (dated November 1, 1975) of the findings and conclusions from the Viejo Substation trench with complete and detailed geologic maps of the trench exposure is included as Appendix A and Drawings 1, 2 and 3.

b. Four prominent shears which are elements of the Cristianitos fault were recognized in the Viejo Substation excavation (Drawing 3, Appendix A). These include: (1) the main trace, which juxtaposes the late Miocene Soquel member of the Puente Formation against the late Miocene--early Pliocene Oso member of the Capistrano Formation, (2) one shear within the Puente Formation, and (3) two shears within the Capistrano Formation. The four shears range in trend from N3E to N25W, subparallel to one another, and do not intersect within the excavation.

On the southeast end of the northeast wall of the excavation several subordinate shears within the Puente Formation trend from N5E to N89E (Drawing 1, Appendix A). The absence of these shears on the south wall of the excavation indicates that (1) some are minor discontinuous features, indistinct or not present on the south wall, and (2) some are truncated by movement on the Cristianitos fault zone which trends oblique to these features.

The direction of last movement on the prominent shears as evidenced from the slickensides indicates both near vertical and oblique movements. The plunge of the slickensides is highly variable not only between the different shears but also between different localities on the same shear (Drawing 3, Appendix A). Other slickensides on the same shear surface range from (1) 5 to 64 degrees north (shear in Puente Formation), (2) 72 to 60 degrees south (Oso Formation), and (3) vertical to 89 degrees south (Oso Formation). Since the shears within the Cristianitos fault do not intersect one another within the excavation there is no example of truncation or dominance of shears with particular slickensides over others. Our conclusion on the observed slickensides is that they are not entirely reliable, and should not be considered conclusive evidence as to the overall sense of movement on the fault. The following statement from Hills (1963) Elements of Structural Geology substantiates this point:

> "Slickensides may form under quite superficial conditions, as for instance on the clay coatings of blocks or rock involved in soil slides, at the base of landslides, or even in masses of ore dislodged during sloping in mines. Quite small movements, of the order of an inch or less, produce excellent slickensides, so that they offer no guidance as to the total displacement on faults."

A much better indicator of the overall sense of movement on the Cristianitos fault is the geology in the vicinity of Viejo Substation site. Areal geology and available subsurface data indicates that the Cristianitos fault zone has a normal sense of movement, juxtaposing Eocene and Middle Miocene rocks against upper Miocene and Pliocene (?) rocks in the area of maximum displacement. Maximum displacements (east side up) occur in the central section of the fault, with the amount of displacement decreasing to the north and south. Analysis of displacements along the northern and southern portions of the fault zone also indicates apparent normal displacements. No evidence is observed to indicate lateral displacement on the zone.

c. (Viejo Substation Excavation).

Approximately three weeks after the Viejo Substation excavation was opened, a linear separation in the river terrace deposits developed near Station 175 (Drawing 1, Appendix A). The linear separation developed during the third day of a rain storm which had saturated the walls of the trench. Detailed logging and photographs during the two-week inspection period after the trench was excavated confirmed that the linear separation did not exist prior to the rain storm. Water ponding on a service road adjacent to the trench continued to pour over the northeast wall for some time after the storm, saturating the walls and filling the lower parts of the excavation.

The linear separation developed in the lower part of the river terrace deposits about 1 foot above the basal contact and extended about five feet upward to within about six inches of an interbedded sand lense (Drawing 1, Appendix A). The linear separation, which trended approximately N-S, roughly aligned with and was subparallel to a subordinate shear mapped in the bedrock approximately two feet from the main trace of the Cristianitos fault. The trend of the linear separation formed an acute angle of about 30 degrees with the trench wall.

A detailed examination of the terrace deposits indicated that the linear separation was an irregular, fresh surface with no mineralization, and contained no aligned or fractured pebbles or grains which might indicate shearing associated with the feature. Careful examination of large rocks and stratification within the river terrace deposits along the projection of the feature indicated no displacement along the linear separation other than tensional separation. A sand lense within the terrace deposits between Station 176 and 166 was clearly continuous across the projection of the linear separation. A careful inspection of the terrace materials on the opposite wall of the trench (southwest) revealed no evidence of cracking, separation or mineralization, indicating the linear separation was not a continuous feature. It was concluded from the examination that the linear separation was the result of purely tensional movement most likely caused by incipient failure of the saturated trench wall. Therefore, the linear separation is not related to tectonic movement on the fault and has no safety significance to the site.

c (Mission Viejo Trench). & d.

The original Mission Viejo trench (locality of lime-filled crack described by Fife, 1974) was excavated and investigated by F. Beach Leighton and Associates during September, 1971. The excavation was designated Geologic Pit No. 57, Oso Viejo Tract. The original log of the excavation provided by F. Beach Leighton and Associates (**Drawing** 1, Appendix B) shows the Cristianitos fault zone exposed on the floor of the excavation, but apparently the excavation was not actually deep enough to expose the Cristianitos fault on the north wall. The original log indicates a "prominent caliche-coated fracture" exposed on the north wall, approximately 12 feet southwest of the fault zone.

Approximately six months after the original excavation was opened, Donald L. Fife, Geologist with the California Division of Mines and Geology, inspected the trench and described a single lime-filled crack projecting upward through the colluvium into the overlying root zone. Trench exposures at the time of his investigation were poor and he could not accurately locate the crack with respect to the Cristianitos fault, but he believed the two were coincident (Donald Fife, personal comm.). He also believed that the origin of the crack was due to possible differential seismic shaking of Oso and La Vida members on opposite sides of the fault, probably occurring during one of the stronger historic earthquakes felt locally.

A comparison of the Leighton trench log with a photograph of the lime-filled crack described by Fife, (1974, Photo 2) indicates that the crack is probably more accurately located southwest of the fault zone.

To resolve this location problem, prior to re-excavating the trench, Fugro, Inc., examined the partially backfilled excavation. Using the photographs presented in Fife's report, the existing north wall of the trench was examined and lime coatings were observed in the colluvium at the approximate locality of Fife's lime-filled crack (Plates 1, 2 and 3, Appendix B).

The re-excavation, September, 1975, was cut as close as possible to the original north wall and deepened to adequately expose the bedrock - colluvial relationships in the north wall. Due to erosion and sloughing of the original trench wall, it was necessary to cut into the original north wall up to four feet. A south wall exposure was also created in an effort to be conclusive about the origin of the lime-filled crack. The purpose of the new trench was specifically to resolve the question of the lime-filled crack described by Fife (1974).

The new trench exposed the Oso member of the Capistrano Formation juxtaposed by the Cristianitos fault against the La Vida member of the Puente Formation. On the north wall of the excavation clayey sand colluvium unconformably overlies Oso-La Vida bedrock (Drawing 4, Appendix B). The bedrock colluvial contact is sharp, and has smooth erosional irregularities. The contact is continuous and there is no evidence of displacements across the Cristianitos fault.

A detailed inspection of the colluvial material shows hairline cracks developed randomly throughout the colluvium ranging from a few inches to five feet in length. Only three of these cracks are lime-filled or have lime coatings associated with them. The three lime coated cracks trend N-S, N45W, N60W and are near vertical. The remaining cracks are short in length (6 inches to 4 feet) and have variable orientations. The cracks are distributed over an area approximately 15 to 20 feet on either side of the fault, and restricted to the colluvium. Laboratory tests (particle size analysis and expansion tests) on the colluvial material indicates a 1.5 to 7% shrinkage capacity, which is believed to account for the occurrence of the randomly distributed short hairline cracks. These cracks were noted after the trench had been open for several days, cleaned and the walls dried out. The longest of the lime-filled cracks is a fine crack about five feet long. It begins and ends entirely within the colluvium and does not extend to the bedrock or the ground surface. The crack is near vertical, and located about 12 feet southwest of the Cristianitos fault. The two remaining lime-filled cracks are located approximately 8 to 9 feet southwest of the fault and are about two feet in length. These occur within the central portion of the colluvial unit (Drawing 4, Appendix B).

Carbonate (caliche) is distributed in many areas of the trench both near and well removed from the Cristianitos fault. Some significant concentrations have been noted up to 10 or 12 feet below the ground surface indicating a much greater penetration of calichification than can be accounted for under the present climatic conditions. Based on the depth of lime development, the fillings may be as old as the last major climatic change (about 30,000 to 50,000 years b.p.).

The exposures on the south wall of the trench (Drawing 5, Appendix B) contrasted sharply with the north wall. The south wall exposes approximately 1 to 5 feet of slump debris directly overlying the bedrock. The slump debris is in turn overlain by several feet of the light brown clayey sand colluvium that is exposed on the north wall of the excavation. The slump debris is composed of weathered bedrock (silt and clay) and a dark brown to black sandy clay deposit, rich in organic material. Downslope movement of this material is evidenced from the convolute relationship of the weathered bedrock and sandy clay deposit, and the contorted bedding and rotated fragments of siltstone within the weathered bedrock zone. The buried bedrock topography (much steeper than the modern ground surface) and the adverse bedrock dips (siltstone dipping nearly parallel to the paleo-topography) indicate that conditions were suitable for downslope movement prior to deposition of the light brown clayey sand colluvium. The clayey sand colluvium overlying the slump debris post dates most if not all the downslope movement. The colluvium fills cracks and channels developed in the slump debris, and locally displays crude horizontal stratification indicating that very little if any downslope movement has occurred since the deposition of the colluvium.

Based on the comparison of the trench log by F. Beach Leighton and Associates, the photo of the lime-filled crack described by Fife and the findings from the re-excavation of the original trench, it is concluded that the lime-filled crack described by Fife did not coincide with the Cristianitos fault but was more likely several feet southwest of the fault, and is probably correlative with one of the three lime-filled cracks described in the re-excavation.

Since (a) lime deposits are ubiquitous in the trench, (b) the lime-filled cracks in the colluvium are not directly associated with the Cristianitos fault, and (c) the basal contact of the colluvium clearly shows no evidence of displacements over the fault, it is concluded that the origin of the lime-filled crack is not related to movement on the Cristianitos fault.

The hairline cracks in the excavation are short, discontinuous and widely distributed. Based on laboratory tests, the expansiveness of the colluvial materials is sufficient to cause this type of shrinkage cracks.

The lime-filled cracks are interpreted as being older than the small hairline cracks observed in the excavation. This interpretation is based on the deep penetration of the carbonate which fills the cracks and indicates that these cracks and the age of filling may be as old as the last major climatic change approximately 30,000 to 50,000 years b.p.

The origin of the lime-filled cracks in the clayey sand colluvium is most likely related to the consolidation creep or other slight movements in the underlying slide debris. Slight spreading or downslope movement would create cracking in the relatively brittle clayey sand colluvium and provide the environment for deposition of thin lime fillings.

Since the lime-filled cracks do not coincide with the Cristianitos fault, and are not related to movement on the fault, it is concluded that they do not indicate the existence of conditions significant to the safety of the site.

e. A finite element analysis which would model differential or out-of-phase responses of different formations across the Cristianitos fault, would be severely limited by the following considerations:

   1. Available two-dimensional finite element programs would not accurately model the complex three-dimensional hillside situation represented by the actual trench location.
   2. Appropriate three-dimensional dynamic programs which would evaluate the various topographic and subsurface conditions involved at the site are not available at the present time, for geotechnical purposes.

The other conclusions about the lime-filled cracks which have become apparent from the analysis of the trench (viz. lack of coincidence between the fault and the crack, the expansiveness of the clayey colluvial materials and the presence of slump debris below the colluvium) suggest more plausible explanations for the lime-filled cracks than any mathematical models incorporating many questionable assumptions.

Question 2

2. With respect to the recent reports from the State of California:

    a. Investigate and determine the significance of the statement on page 10 of the Fife report, "Stream terraces four miles north of the study area on Santiago Road, between Silverado Canyon and Williams Canyon, have been tilted on end, suggesting that the frontal fault system may have moved during Holocene time in that area. The nearest direct evidence of Holocene faulting was found a mile south of the study area at Cousteau Park. Wade Miller (oral communication, 1971) estimates the age of displaced terrace deposits as between 30,000 and 100,000 years before present."

    b. Morton (1974)* mentions on page 9 a backhoe trench placed in 1971 by the Division of Mines and Geology which succeeded in exposing a western branch of the Cristianitos fault. He states that this trench showed apparent displacement of a two-foot thick slope-wash cover along two shears a few feet apart. Maximum dislocation of the soil-bedrock interface was approximately two feet. As this evidence suggested possible late Holocene movement, additional trenching was placed in the same area by the Southern California Edison Company in June 1972 in order to check this possibility. These excavations suggested that the apparent displacement of the soil cover may have been due to a combination of animal borings and differential erosion of the bedrock surface with subsequent soil deposition. However, "Holocene movement has not been ruled out." Additional trenching is necessary to satisfactorily resolve the questions raised by these indicators of recent movement on the Cristianitos in this area. The placement of trenches should be made after careful consideration of where the potential would be favorable for obtaining definitive results, perhaps in consultation with others who have worked in the area.

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*Morton, P. K., et al., "Geology and Engineering Geologic Aspects of the San Juan Capistrano Quadrangle, Orange County, California," California Division of Mines and Geology, Special Report 112, 1974.

Response to Question 2

a. An investigation by Fugro geologists of all the exposed fluvial terrace deposits along the north side of Santiago Road between Silverado and Williams Canyons, revealed no evidence of tilted stream terrace deposits. Several road cuts provide good exposures of the terrace deposits and indicate that the crudely to well stratified material is virtually horizontal. At several localities erosional cut and fill relationships were observed between fluvial terrace deposits and bedrock, and within fluvial terrace deposits, however, the steeply dipping contacts are clearly erosional features when inspected carefully. At four localities between Silverado and Williams Canyons, it is noted that the upper surfaces of these elevated fluvial terrace deposits are well preserved and slope very gently approximately 3° to 5° toward Santiago Creek.

Subsequent to the field investigation, Messrs. Don Fife and Paul Morton, California Division of Mines and Geology, were contacted to determine the exact locality of the postulated tilted stream terrace deposits.

A visit to this locality, guided by Paul Morton, produced the following findings:

1. The feature described by Fife is located approximately 2 miles north of the last

mapped trace of the Cristianitos fault.

2. The feature is exposed in both walls of the road cut, and is defined by a steeply dipping (45° - 50° N) zone of transition between moderately stratified fluvial terrace deposits and unstratified terrace deposits.

3. This zone of transition is indistinct, about 12 to 18 inches wide and trends approximately N60E, near perpendicular to the trend of the Cristianitos fault. The transition is roughly coincident with, and subparallel to a tributary drainage entering Santiago Creek at this locality.

4. Detailed examination indicated no evidence of a surface or shearing within the transition zone.

5. No evidence of tilting of the fluvial terrace deposits was observed on either side of the feature. Stratification on the southeast side of the feature is virtually horizontal; northwest of the feature the deposits are indistinctly stratified, but no indication of tilting was observed.

6. In discussing the origin of the feature with Paul Morton, he stated that he saw the feature when the road cut was originally opened, and interpreted it as an erosional feature (i.e., channeling within the fluvial terrace materials).

Based on findings from field investigations it is concluded that there is no evidence of tilted terrace deposits along Santiago Road between Silverado and Williams Canyons. Cut and fill relationships are common in the fluvial terrace deposits observed in this area and the feature described by Fife probably represents channeling within these deposits.

Costeau Park is approximately 3 miles west of the Cristianitos fault. The original report of faulting in Pleistocene deposits was made by Dr. Wade Miller (1971) Pleistocene Vertebrates of the Los Angeles Basin and Vicinity (exclusive of Rancho La Brea), Los Angeles County Museum of Natural History and Science, Bulletin No. 10, while he was conducting paleontological studies in the excavated areas for the park.

One fault was observed in the excavation which cut overlying alluvial and lacustrine deposits; a second fault was inferred by Dr. Miller based on stratigraphic relationships observed in the excavation. The visible fault had a trend of N65E, nearly normal to the Cristianitos fault, with a near vertical dip. The sense of displacement was normal, displacing the basal contact of the overlying Pleistocene deposits approximately 7 feet. The shearing was clearly expressed in the Pleistocene deposits. Miller also noted that joints in the bedrock were also expressed in the overlying Pleistocene deposits. Radiocarbon dating of the Pleistocene deposits indicated an age greater than the C^{14} range; Dr. Miller estimates the age of the deposits to be 60,000 to 80,000 years b.p. based on Pleistocene fauna collected from the deposits (Dr. Wade Miller, personal communication).

Since Dr. Miller's studies, the original excavation has been filled and the exposures of faults are no longer visible. A reconnaissance field investigation conducted by Fugro confirmed that there is no evidence left of faulting or deformation.

While the faults observed by Dr. Miller may show evidence for Pleistocene movement no evidence was observed to determine whether or not holocene movement has occurred.

b. We (S.C.E.) would like to emphasize our position with regard to additional trenching across the Cristianitos fault. To date, at least five areas along the Cristianitos fault including the Coastal Bluff, Plano Trabuco, north Oso Valley, and Aliso Creek have been trenched. Of these, three were excavated in areas displaying a clear terrace/bedrock contact and two in areas displaying inconclusive soil/bedrock contact. Based on this experience, we have searched for additional areas where terrace deposits can be found so that trenches could be excavated that would yield useful data. SCE agrees with the NRC's position stated in question 3b which indicates that placement of trenches should be in areas suitable for obtaining definitive results.

We have completed a thorough study of possible additional trenching sites and have found none which meet the above criterion. Therefore, no further excavating is planned.

Question 3

With regard to the site excavation:

a. Provide clarification of the stratigraphic relationship of marine (Qm) and non-marine (Qt) terrace deposits in the San Onofre area. What is the sedimentologic relationship of these units in terms of geologic history of the area, including considerations of shoreline movements and fluvial erosion?

b. Provide clarification of radiometric dating of the marine terrace deposits (Qm). Included in this clarification should be a discussion of the reliability of thorium-protactinium method when used for mollusk dating. In addition, provide a discussion of the difference between dating of "shell material" and "mollusks" as referred to in the PSAR and later reports.

Response to Question 3

The response to question 3a is provided as Sections II and III of Appendix C, Summary of Geomorphic and Age Data for the First Emergent Terrace (Qt_1) at the San Onofre Nuclear Generating Station.

The response to question 3b is provided as Section V of Appendix C.

APPENDIX A

GEOLOGIC INVESTIGATION OF THE BULLDOZER EXCAVATION AT THE PROPOSED VIEJO SUBSTATION SITE

By:

Fugro, Inc.

For:

Southern California Edison Company

Revised November 1, 1975

FUGRO
CONSULTING ENGINEERS AND GEOLOGISTS

Jack J. Schoustra, President
Jay L. Smith, Executive Vice President
John D. Scott, Vice President

F-SCE-75-22
Revised November 1, 1975

Mr. Gail S. Hunt
Southern California Edison Company
P.O. Box 800
Rosemead, California 91770

Dear Mr. Hunt:

This letter presents a summary of findings from the investigations of the Cristianitos fault exposed by the bulldozer excavation at the proposed Viejo Substation site. The following drawings are submitted herewith:

- A comprehensive log of both the northeast and southwest walls of the excavation; scale 1" = 5', with detailed areas enlarged to 1" = 2'.
- Plot plan of surveyed location and elevations of the excavation.

The site is located in the south half of the El Toro Quadrangle, within the Aliso Creek drainage near the northern terminus of the Cristianitos fault (Plate 1). Field activities began on March 20, 1975 and included:

1. Inspection and logging of the northeast and southwest walls of the excavation.
2. 35mm color photography of critical areas of the excavation.
3. Collection of organic materials useful in dating the fluvial terrace deposits.
4. Inspection of the excavation by NRC personnel on April 9, 1975.

The following is a brief summary of findings of the investigation.

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Branch Offices in Redwood City, California and Houston, Texas

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Lithologies within the excavation include:

1. Puente Formation (Soquel member, late Miocene) a gray-green sandy, silty clay interbedded with massive yellow to gray, angular, arkosic sandstone.
2. Capistrano Formation (Oso member, late Miocene to early Pliocene), a white to light gray, massive, arkosic sandstone with interbedded gray to orange-brown sandy siltstone, bedding trends N30E, 40NW.
3. Fluvial terrace deposits (Pleistocene) dark brown, bouldery, cobbly, silty sand and sandy silt unconformably overlies the Puente and Capistrano Formations.

Four elements of the Cristianitos fault occur within the excavation. The fault planes undulate and attitudes are variable; strikes range from N3^{O}E to N25^{O}W, and dips range from 77^{O}SW to 57^{O}NE. Projecting the faults across the excavation indicates an overall strike of about N3^{O}W.

The faults are expressed as gouge zones 1/4" to 1/2" in thickness. Polished planar surfaces have mullion or slickensides which indicate both vertical and oblique slip. The amount of displacement is interpreted as being relatively minor on three of the fault planes; two of these are within the Capistrano Formation, the third is within the PUente Formation. The fourth fault juxtaposes the Puente Formation with the Capistrano and is believed to be the main element. The total amount of displacement is unknown but the west side is down dropped based on mapping by D. L. Fife, 1974.

Careful examination of the basal contact of the overlying Pleistocene fluvial terrace deposits indicates no evidence of displacements on the contact, or expression of shearing in the terrace deposits.

Should you require any additional details or written description of the excavation, please contact me.

Sincerely,

John D Scott

John D. Scott
Vice President, Operations

JDS/vv

cc: B. Strand
P. West
G. Hawkins

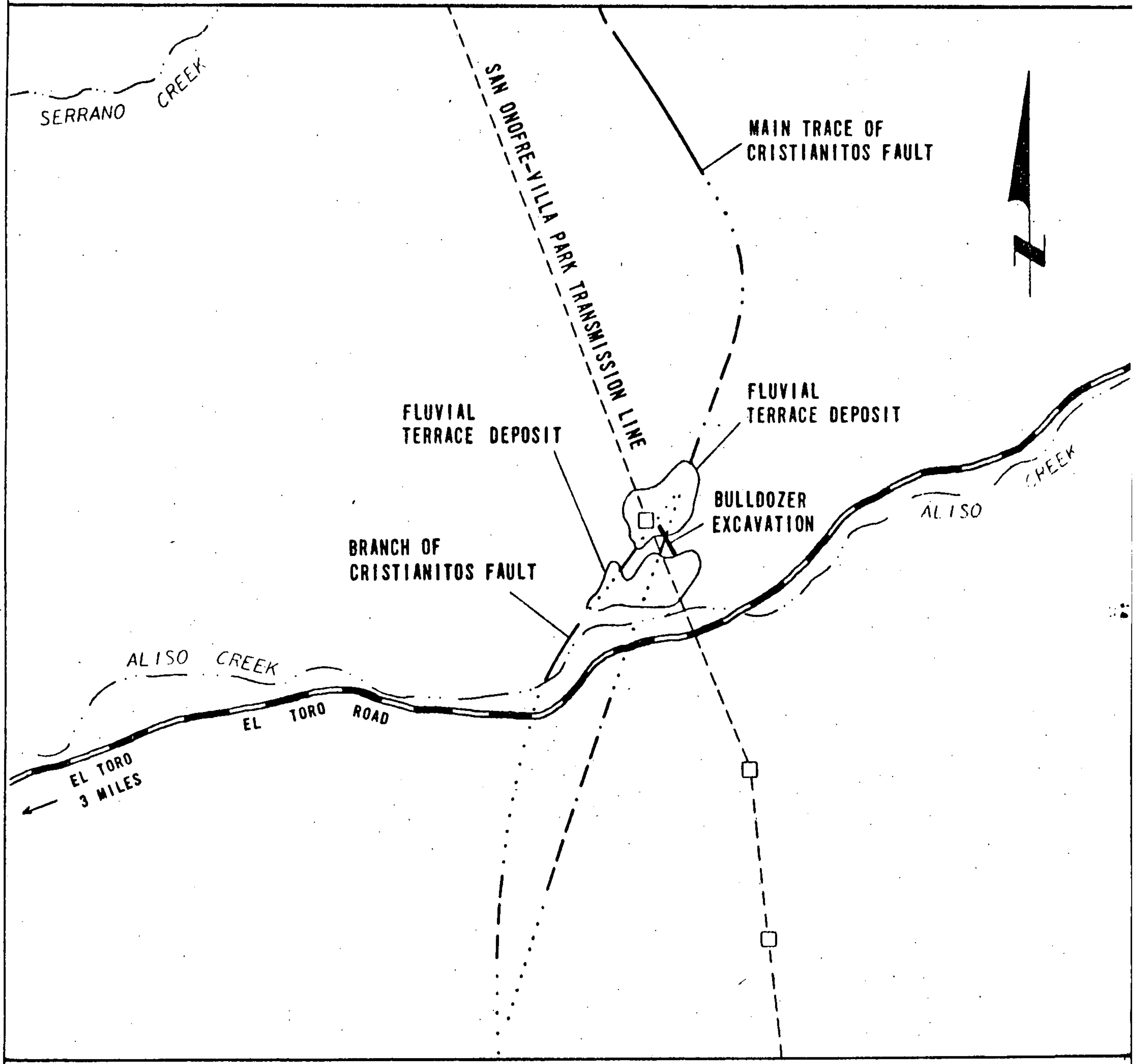
SO 75-8211-E1

APPROVED BY: DATE: PREPA BY: CHECKED BY:

PROJECT NO: 74-069-EG

LOCATION MAP BULLDOZER EXCAVATION VIEJO SUBSTATION SITE

NOV. 1, 1975



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REFERENCE: Fife, 1974, Geology of the South Half of the El Toro Quad. Orange Co., Calif., Calif. Div. Mines and Geol. Spec. Rpt. 110.

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Richard J. McCarthy
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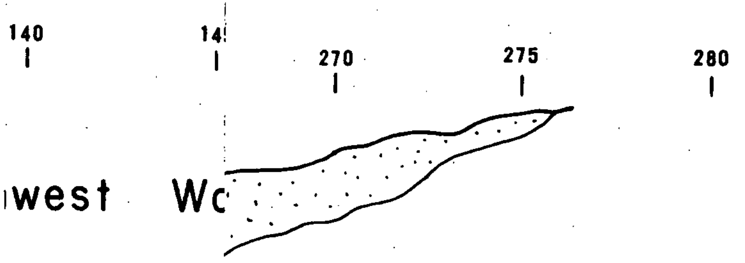
J.V. Scott

LOG OF BULLDOZER EXCAVATION
VIEJO SUBSTATION SITE

PROJECT 74-069-EG April 18, 1975

FUGRO

DRAWING NO.: 1



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LOG OF BULLDOZER EXCAVATION
VIEJO SUBSTATION SITE

PROJECT 74-069-EG April 18, 1975

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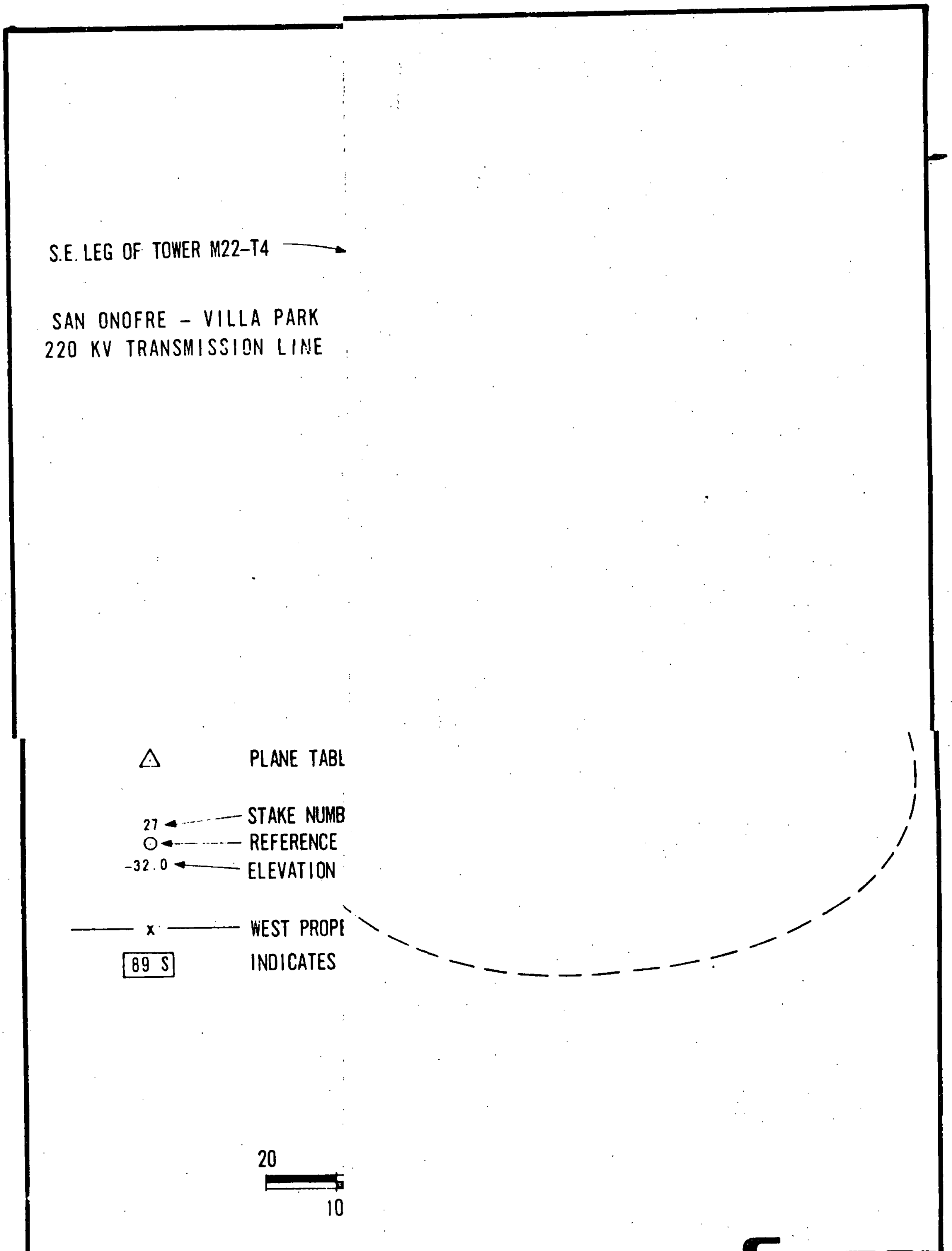

FUGRO

DRAWING NO.

3

BULLDOZER EXCAVATION
VIEJO SUBSTATION SITE

T 74-069-EG

Rev. Nov. 1, 1975

APPENDIX B

GEOLOGIC INVESTIGATION OF THE MISSION VIEJO (F. BEACH LEIGHTON) BULLDOZER EXCAVATION

By:

Fugro, Inc.

For:

Southern California Edison Company

November 14, 1975

FUGRO

CONSULTING ENGINEERS AND GEOLOGISTS

Jack J. Schoustra, President
Jay L. Smith, Executive Vice President
John D. Scott, Vice President

November 14, 1975

Mr. Gail S. Hunt
Southern California Edison Company
P.O. Box 800
Rosemead, California 91770

Dear Mr. Hunt:

This letter presents a summary of findings from the investigation at the Mission Viejo trench (F. Beach Leighton excavation of September, 1971) which was re-excavated during September, 1975. The following drawings and plates are included:

- o Comprehensive logs of both the southeast and northwest walls of the bulldozer excavation: scale 1" = 2'.
- o Comprehensive logs of both walls of the backhoe extension which was excavated nearly perpendicular to the east wall of the bulldozer trench: scale 1" = 2'.
- o A plot plan of the excavation: scale 1" = 20'.
- o The F. Beach Leighton log of the original excavation, dated September 10, 1971.
- o Photographs of the original trench before re-excavation and the location of lime concentrations observed (Plates 1, 2 and 3).

Field activities began on September 23, 1975 to investigate more fully the lime-filled crack reportedly found by Donald L. Fife, geologist with the California Division of Mines and Geology, in the original bulldozer excavation. The field investigation included the following activities:

- o Careful examination of the original partially back-filled trench (before re-excavation) for evidence of the lime-filled crack (Plates 1, 2 and 3).
- o The inspection and logging of both the east and west walls of the bulldozer excavation, and the north and south walls of the secondary backhoe extension.

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- Photo logging (polaroid black and white, and 35 mm color) of both the east and west walls of the bulldozer excavation
- Collection and analysis of colluvium samples for clay content and shrink-swell capacity.
- The inspection of the excavation by NRC personnel on October 16, 1975.

Following is a brief summary of the findings of the investigation:

1. The Oso member of the Capistrano Formation (late Miocene - early Pliocene) is down-faulted against the La Vida member of the Puente Formation (late Miocene) along the Cristianitos fault.

2. The Cristianitos fault zone is defined primarily by two major shears. The shear defining the western edge of the zone trends approximately N5W to N15W, dipping 75 to 80W; the shear which defines the eastern edge of the zone trends from N10W, to N8W, and dips from 60W to 87E.

   The general strike of the zone across the trench is approximately N5W.

   Slickensides are best preserved on the westermost shear (Drawing 4). The slickensides plunge 85N, indicating dominantly vertical movement on the fault plane. Total displacement on the Cristianitos fault (vertical) is estimated to be on the order of one thousand feet at this locality (Fife, personal communication).

3. Trench exposures show undisturbed colluvium overlying the faulted bedrock. On the northwest wall of the excavation, the bedrock-colluvium contact is continuous and shows no evidence of displacement across the fault. The southeast wall shows the colluvium overlying an accumulation of slump debris (Drawing 4).

4. Detailed examination of the northwest wall revealed three lime- (carbonate) filled cracks in the colluvium in the area of stations 35 and 40. No lime-filled crack was found over the Cristianitos fault. A comparison of the original F. Beach Leighton trench log (Drawing 1) and photograph no. 2 in Fife (1974) California Division of Mines and Geology Special Report No. 110, indicates that the lime-filled crack described by Fife (1974) does not coincide with the Cristianitos fault. It is more accurately located 10 to 12 feet west of the western edge of the fault, and is probably correlative with one of the three carbonate-filled cracks observed in the present trench (Drawing 4).

5. Laboratory analyses of colluvium samples collected from the northwest wall of the excavation indicate that the colluvium has a clay content ranging between 10% and 18% and a shrinkage capacity ranging between 1.5% and 7%. Thus, the colluvial material is subject to cracking upon drying, and the expansiveness of the colluvial material is sufficient to cause the small hairline cracks observed on the northwest wall of the excavation.

6. The origin of the lime-filled cracks in the clayey sand colluvium is most likely related to consolidation creep or slight movements in the underlying slump debris (i.e. slight downslope movement would create cracking in the relatively brittle clayey sand colluvium and provide the surfaces for the deposition of the lime fillings.

Based on our findings, it is concluded that:

1. The lime-filled crack described by Fife (1974) does not coincide with the Cristianitos fault, but actually lies about 8 to 12 feet southwest of the fault.

2. The lime-filled cracks in the colluvium are not directly associated with the Cristianitos fault or related to movement on the fault.

3. There is no evidence in this trench for Holocene movement on the Cristianitos fault.

Should you require any additional details of the re-excavation, please contact us.

Sincerely,

Robert L. Strand

Robert L. Strand
Project Geologist

John D. Scott

John D. Scott
Project Manager

RLS/JDS/ga

Enclosures

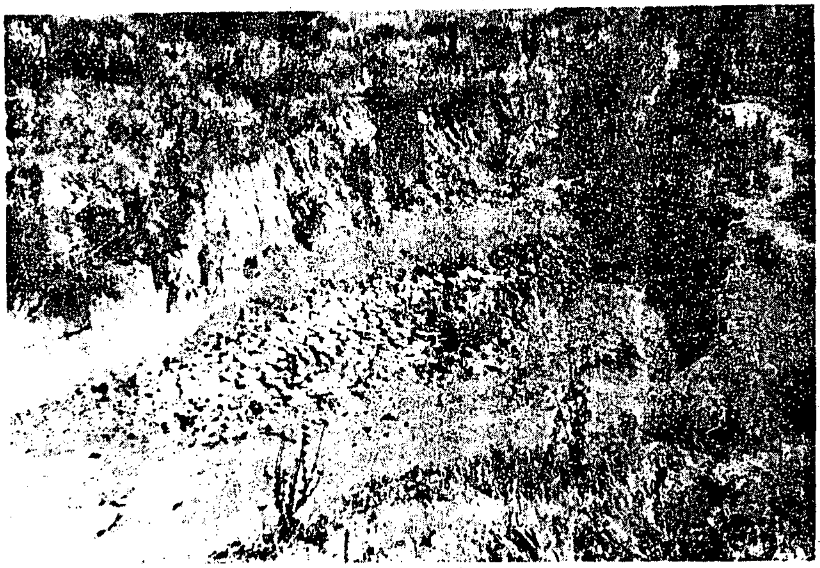

PLATE 1, Partially backfilled Mission Viejo trench, before re-excavation, Sept. 1975.

MISSION VIEJO TRENCH BEFORE EXCAVATION
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY
FUGRO, INC. Long Beach, California

Project No.: 74-069-04
Date NOV. 11, 1975
COMPILED BY J. Bell
PREPARED BY AL Smith
CHECKED BY RAhdl.
APPROVED BY ALS
PLATE NO 1

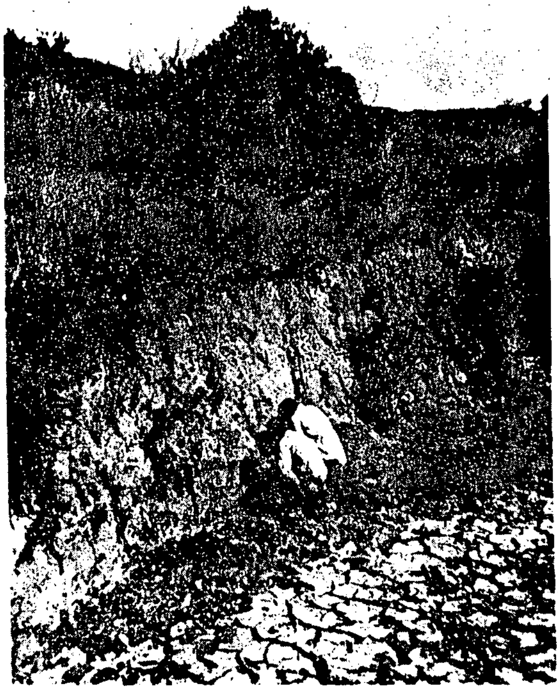

PLATE 2 FUGRO geologists locate lime concentrations, before re-excavation. Using Photograph No. 2 from Fife (1974), the location of the lime-filled crack described by Fife was determined.

MISSION VIEJO TRENCH BEFORE EXCAVATION	Project No.: 74-069-04
SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 and 3 SOUTHERN CALFIRONIA EDISON COMPANY	Date NOV. 11, 1975
FUGRO, INC. Long Beach, California	COMPILED BY J. Bell PREPARED BY AL Smith CHECKED BY M K Ardelin APPROVED BY r/s
	PLATE NO. 2

PLATE 3 Close-up of lime concentrations observed in the old excavation.

MISSION VIEJO TRENCH BEFORE EXCAVATION
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY
FUGRO, INC. Long Beach, California

Project No.: 74-069-04
Date NOV. 11, 1975
COMPILED BY J. Bell
PREPARED BY AL SMITH
CHECKED BY W.F. Andelin
APPROVED BY J.L.S.
PLATE NO. 3

Logged by ____
Notes by ____
Type of Rig ____
(See Abbreviation List Attached)

ATTITUDES	ENGIN
fault trend N5°E (mod?)	● Sand, brn, crse. gr. frogs to
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b N75W, 23S	
b. N50W, 10SW	● brn, sl. c (Oso)
b N80E, 10N	

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ed by D.O. Asquith of F. Beach Leighton and
Mission Viejo Company, in 1971. This log
ne lime-filled cracks are not coincident
as discussed in the text of this report.

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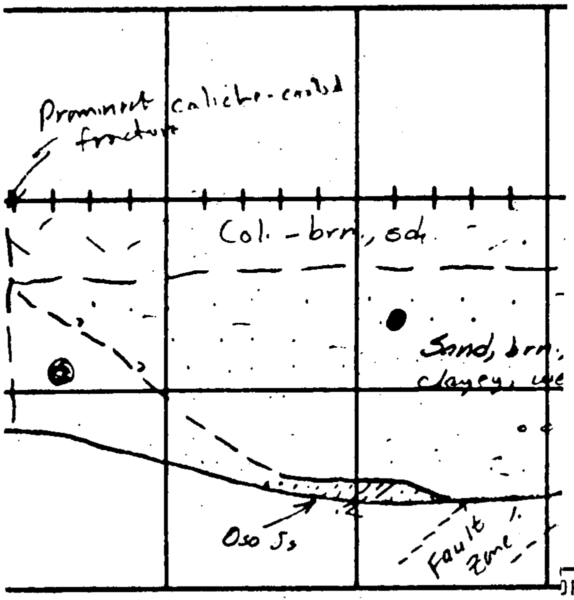
e same location as the lime-filled fracture
t excavation log (Drawing 4). Scale is as
Leighton and Associates.

Scale - 1" = 10'



ORIGINAL BEACH-LEIGHTON LOG
INOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
JTHERN CALIFORNIA EDISON COMPANY
GRO, INC. Long Beach, California

Project No 74-069-04
Date NOV 11, 1975
COMPILED BY J. Bell
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CHECKED BY
APPROVED BY
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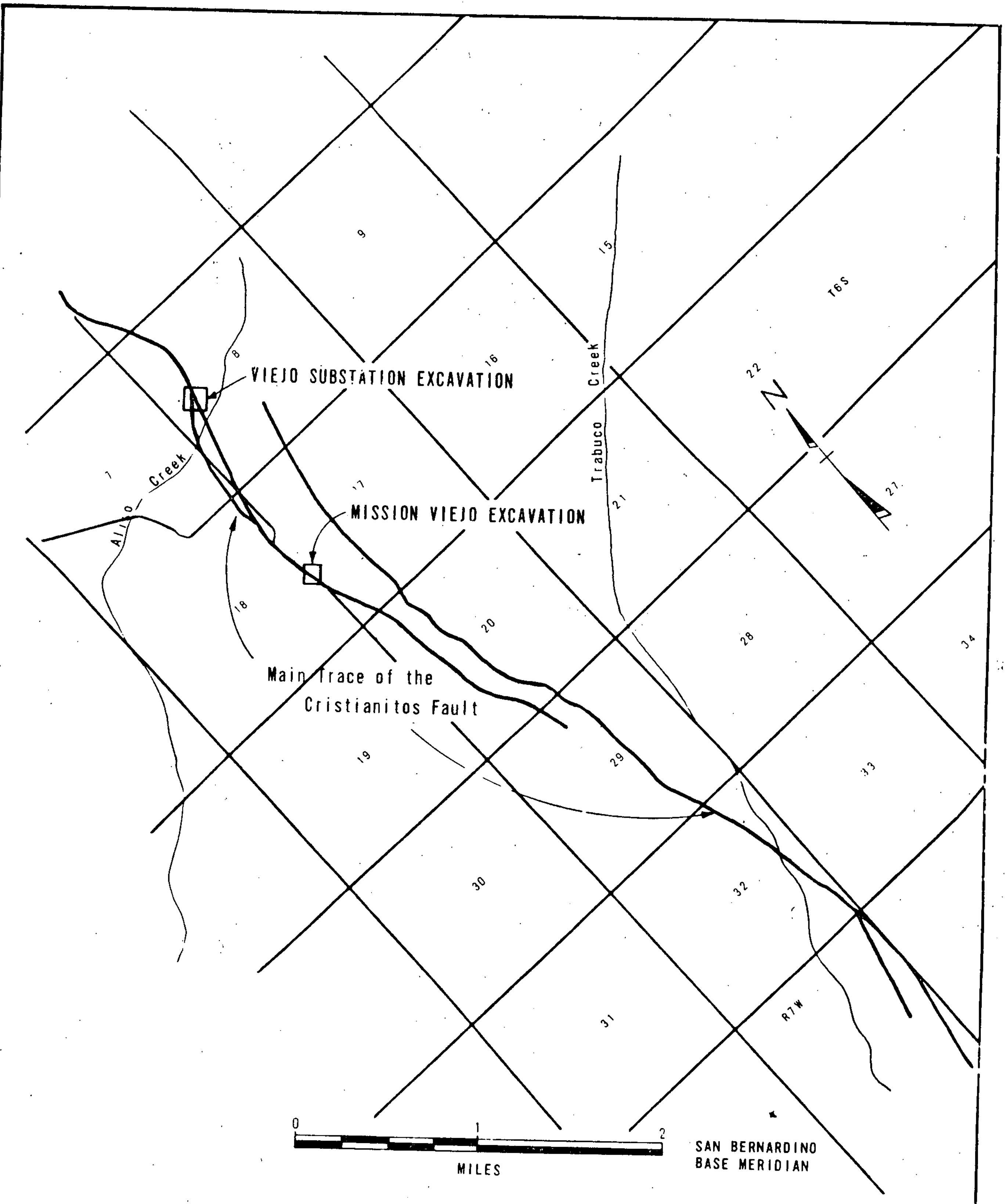

LOCATION MAP MISSION VIEJO BULLDOZER EXCAVATION	Project No 74-069-04
SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 AND 3 SOUTHERN CALIFORNIA EDISON COMPANY	Date NOV 1, 1975
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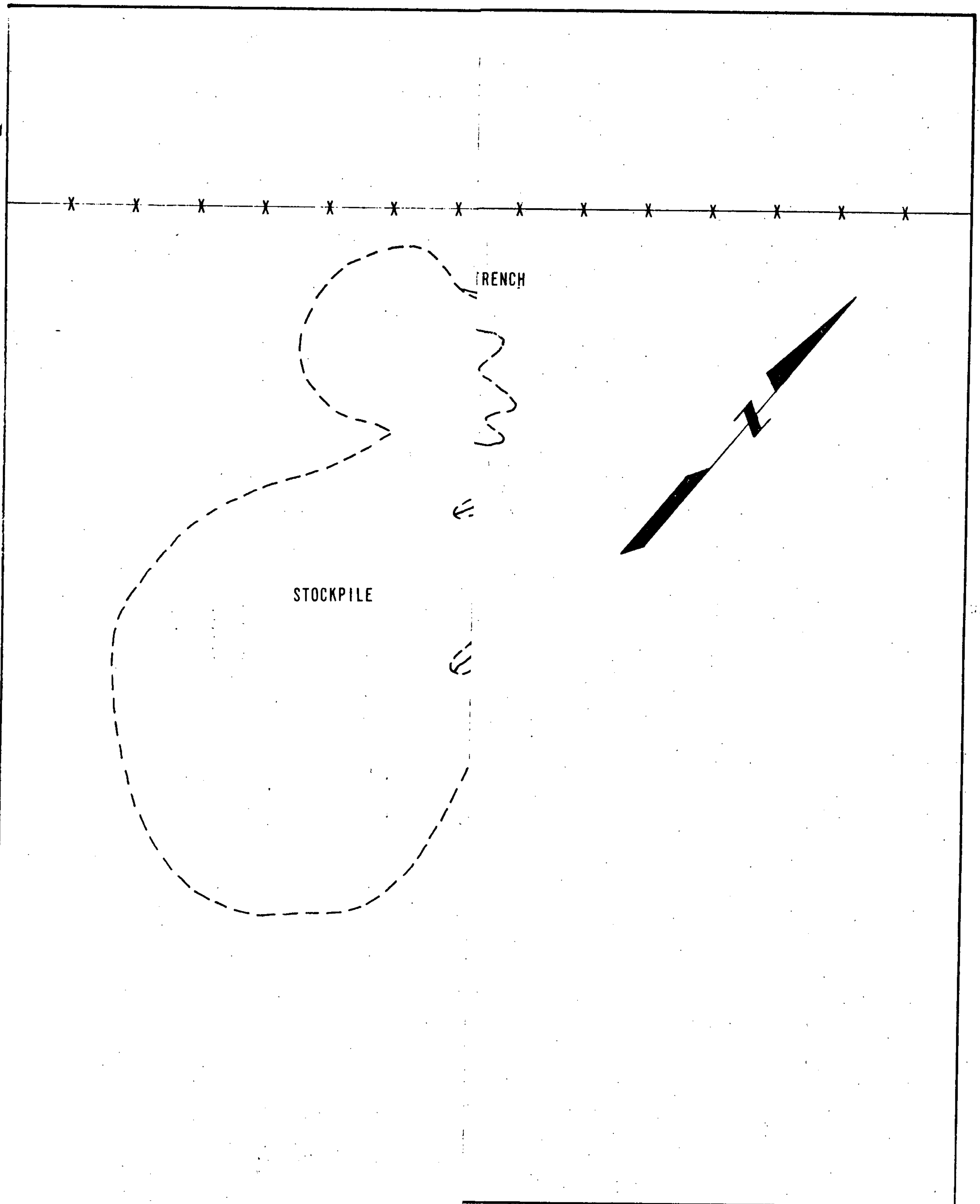

PLOT PLAN
NOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
THERN CALIFORNIA EDISON COMPANY
RO, INC. Long Beach California

Project No 74-069-04
Date NOV 11, 1975
OMPILED BY B. STRAND
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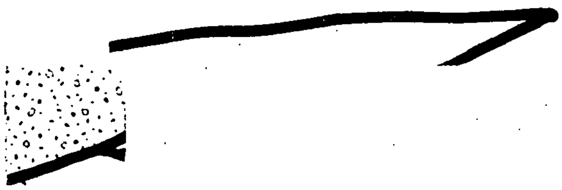
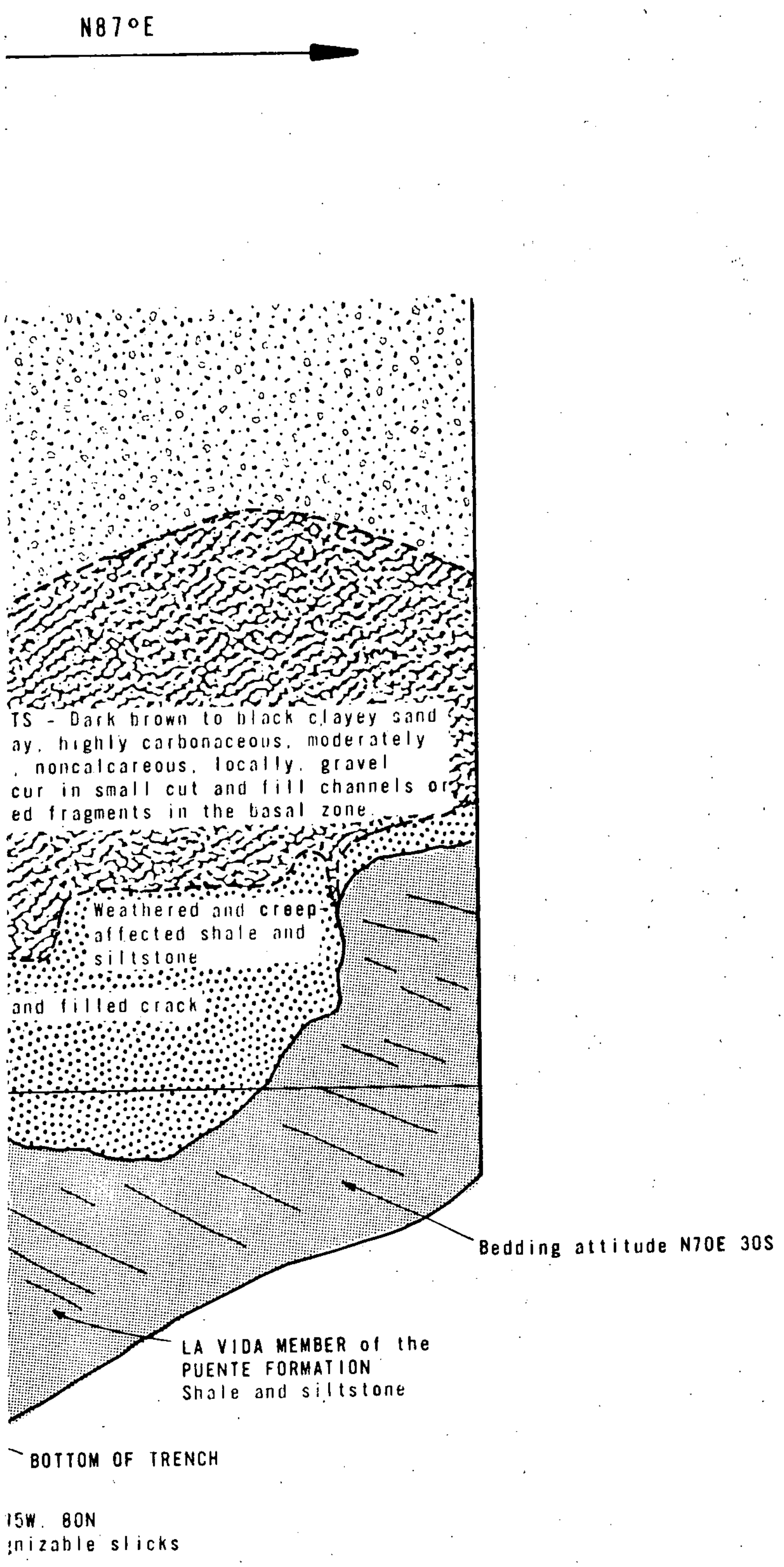
APPROVED BY ds
DRAWING NO 3



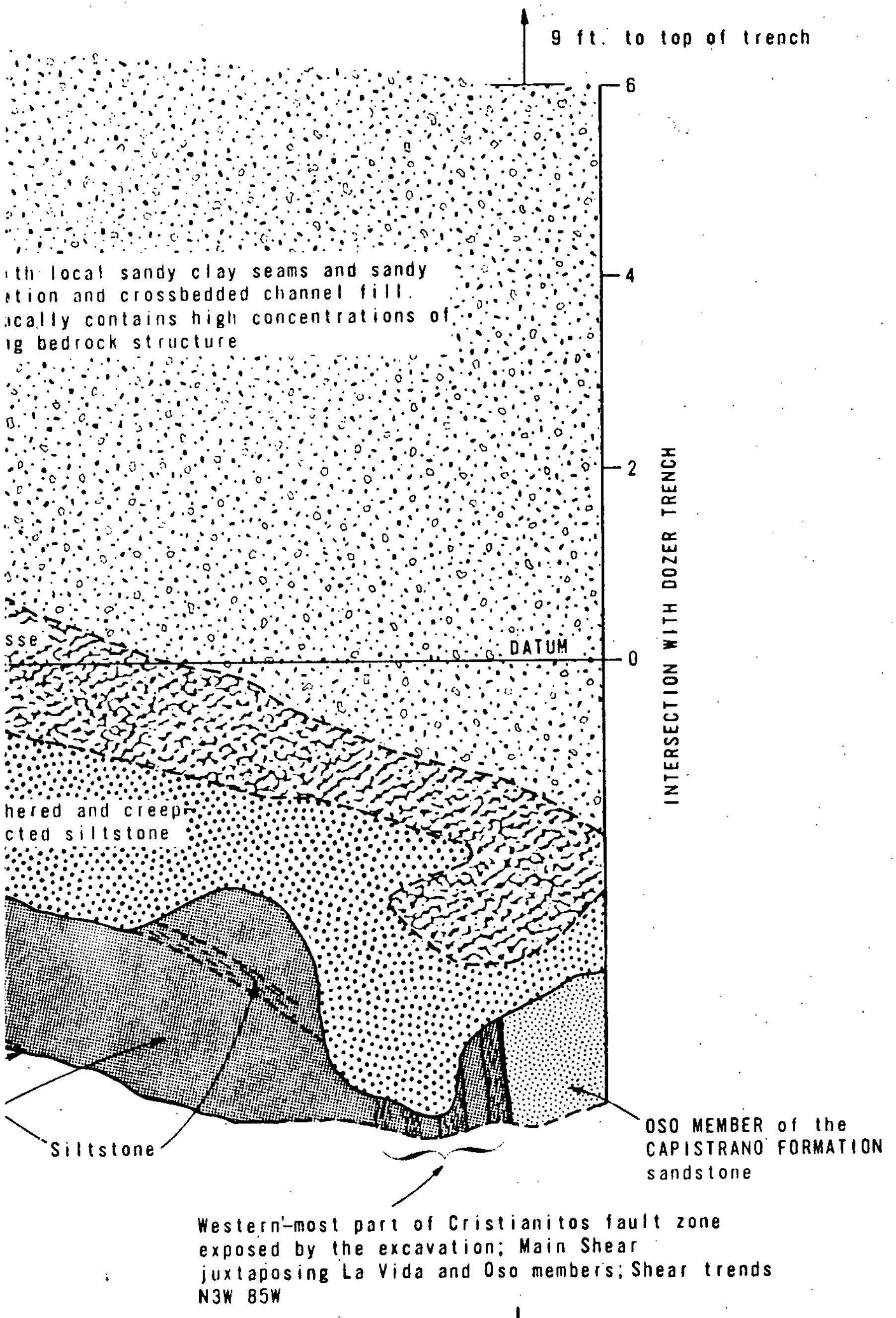
SOUTHEAST WALL – BULLDOZER
NUCLEAR GENERATING STATION
UNITS 2 and 3
CALIFORNIA EDISON COMPANY
D, INC. Long Beach California

Project No 74-069-04
Date NOV. 11, 1975
COMPILED BY J. Bell
PREPARED BY SAO/Pk.
CHECKED BY M.P.
APPROVED BY JLS
DRAWING NO
5



2'

LOG OF NORTH WALL - BACKHOE	Project No 74-069-04	
SAN ONOFRE NUCLEAR GENERATING STATION	Date NOV 11, 1975	
UNITS 2 and 3	COMPILED BY J. Bell	DRAWING NO
SOUTHERN CALIFORNIA EDISON COMPANY	PREPARED BY PK L.H.	6
	CHECKED BY M.R. [illegible]	
FUGRO, INC. Long Beach California	APPROVED BY r/s	



SCALE: 1" = 2'

LOG OF SOUTH WALL - BACKHOE
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY
FUGRO, INC. Long Beach, California

Project No 74-069-04
Date NOV. 11, 1975
COMPILED BY J. Bell
PREPARED BY PK L. H
CHECKED BY MK
APPROVED BY A/S
DRAWING NO 7

APPENDIX C

SUMMARY OF GEOMORPHIC AND AGE DATA FOR THE FIRST EMERGENT TERRACE (QT_1) AT THE SAN ONOFRE NUCLEAR GENERATING STATION

By:

FUGRO, INC.
Consulting Engineers and Geologists
Long Beach, California

For:

SOUTHERN CALIFORNIA EDISON COMPANY
P. O. Box 800
Rosemead, California 91770

Project No. 74-069-02

September 12, 1975

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I. INTRODUCTION

As described by Southern California Edison (1970, Appendix 2A) and in reports by Fugro (1974a, 1974b) to Southern California Edison, a major Pleistocene terrace deposit (Qt_1) has been recognized in the site vicinity. Qt_1 deposits contain interbedded marine and nonmarine sediments and occupy topographic benches above the modern beach and San Mateo and San Onofre Canyons. The unit has been previously dated between 70,000 and 130,000 years old (Southern California Edison, 1970, Section 2.9) and used as a stratigraphic horizon of known age.

As a result of a NRC field trip to San Onofre Nuclear Generating Station (SONGS) on April 9, 1975, the following items concerning unit Qt_1 required clarification:

1. Rationale for geologic division of unit Qt_1.
2. Stratigraphic relationships and geologic history of the Qt_1 marine terrace materials and the Qt_1 nonmarine deposits.
3. Distribution of Qt_1 marine terrace deposits near the Cristianitos fault, and age of deposits used to establish lack of movement on the fault.
4. Correlations of the dated marine terrace deposits to those at or near the site, and the locations of the fossil sites.
5. Reliability of the radiometric methods used and a

clarification of the material tested;
evidence for the _in situ_ position of
reworking of the dated fossils.

In response, this report will clarify these questions.

II. CONCLUSIONS

- Unit Qt_1 is a local designation (Southern California Edison, 1970, Appendix 2A) for part of an extensive, widely recognized coastal terrace formed during the last major high stand of sea level (Sangamon time), approximately 120,000 years ago.

- In the SONGS vicinity, unit Qt_1 contains interfingering marine and nonmarine sediments (30 to 50 feet thick) overlying a wave-cut platform and a stream-channeled bedrock surface.

- A basal bouldery terrace gravel overlying the Cristianitos fault is a marine platform deposit of Qt_1 age. This deposit indicates that the fault has not moved in the last 120,000 years.

- Unit Qt_1 in the SONGS vicinity is correlative with other radiometrically dated terrace deposits.

- Although some of the uranium-series age determinations on mollusks are at present questionable, the age dates obtained on corals and the grouping of all age dates indicate that the Qt_1 deposits are approximately 120,000 years old.

- Although the dated fossils were not in growth positions, reworking was due solely to local wave action and movement within the surf zone during Qt_1 time.

III. RATIONALE FOR GEOLOGIC DIVISION OF UNIT Qt_1

A. Discussion

The stratigraphic relationships observed at SONGS consist of a complex interfingering of marine and nonmarine deposits. In response to questions posed concerning the relationship of nonmarine stream material to marine terrace deposits the following discussion will show that:

1. The complex interfingering of marine and continental material is not unusual in this area.
2. Nonmarine detritus is the dominant terrace deposit at the SONGS site, and it can be used as a stratigraphic horizon of known age--stratigraphically equivalent to radiometrically dated marine terrace deposits.
3. The detrital material which directly overlies the Cristianitos fault at the San Onofre Bluff, although being originally of stream origin, was reworked in the surf zone during Sangamon time and represents a marine stratigraphic horizon of known age.

B. Marine Terraces

The California Coast is notched by a series of Pleistocene, marine, wave-cut benches formed during stillstands of sea level. The benches are recognized from as much as 300 feet below sea level to as much as 1000 feet above. Some of these marine terraces are eustatically derived (formed as the result of Pleistocene sea level fluctuations) and some are tectonically derived (formed as the result of tectonic uplift of the land relative to sea level). The higher terraces may be as old as 1.0 m.y. (Lajoie and others, 1975a), and the lowest, submerged terraces are probably of Wisconsin age (Buffington and Moore, 1963).

The most prominent and best preserved terrace level is commonly referred to as the "first emergent terrace" or the "Sangamon-age terrace". At SONGS, this marine terrace and its deposits have been identified as part of unit Qt_1 (Southern California Edison, 1970, Appendix 2A).

The Sangamon-age terrace is widely recognized along much of the California coast. Although it ranges in elevation from about 25 feet to over 150 feet, owing to both local tectonic activity and broad coastal emergence, the terrace can be widely traced and correlated. In areas of late Pleistocene and Holocene tectonic activity, this terrace may not actually be the lowest emergent terrace, but it can still be recognized on geomorphic and paleontologic grounds (refer to section on "Correlation of the Sangamon-age Terrace by Surficial Mapping" of this report). The commonly observed elevation of the terrace is about 100 feet (30 m), although some of the terrace deposit frequently consists of a nonmarine colluvial cover. In the vicinity of SONGS the Sangamon level (Qt_1) has a wave-cut platform elevation of about 55 feet. The platform is overlain by a variable thickness (generally 40 to 50 feet) of marine and nonmarine terrace material.

C. Nonmarine (Stream) Terraces

In response to fluctuating Pleistocene sea levels, major streams adjusted their regimens by either aggrading or degrading their valleys. These aggradational-degradational cycles are represented by a eries of cut and fill stream terraces in almost all major coastal drainages. At the coast where the streams entered the sea, nonmarine material was graded within the streams to the prevailing sea level. Thus, at the mouths of the streams, the stream terraces coalesce with equivalent marine terraces and represent the former sea level altitudes as do the marine terraces.

In the vicinity of SONGS, San Onofre and San Mateo stream deposits of Sangamon age grade into marine deposits of similar age and onto the Sangamon-age terrace platform; these units are all included as unit Qt_1 (Southern California Edison, 1970, Appendix 2A, Figure 1). Although consisting primarily of stream deposits, unit Qt_2 is similar to unit Qt_1, but occurs topographically higher than unit Qt_1 (Figures 1 and 2).

D. Description of Qt_1 Deposits at SONGS

As described by Southern California Edison (1970, Appendix 2A) and in a report by Fugro (1974a) to Southern California Edison, Qt_1 terrace deposits consist of nonmarine sediments and small pods of marine deposits overlying a scoured bedrock platform. The nonmarine deposits are crudely stratified, poorly sorted mixtures of gravel, cobbles and boulders with silty and gravelly sand. The recognized marine deposits consist of well-sorted sand and gravel.

The only marine terrace deposits previously believed to occur in the site excavation were located near the sea bluff and have been removed during grading. Recent field investigations have shown, however, that the plant east wall of the site excavation contains a series of alternating marine and continental sediments. Poorly sorted, bouldery gravel (stream gravel) is interbedded with well-sorted, crossbedded sand (marine sand) and a sandy silt that is believed to be an estaurine deposit (Drawing 1).

This sequence overlies an irregular erosional surface (4 to 5 feet of relif) cut on the San Mateo Formation, and the deposits represent a channel fill of San Onofre Creek. The maximum depth of channeling can be seen approximately 1/2 mile northwest of SONGS along San Onofre Beach where the San Mateo Formation has been scoured nearly to sea level. Located on the eastern margin of San Onofre Canyon, the SONGS excavation exhibits less channeling than the center of the canyon. Southeast of SONGS along the coastal bluff, the channeled surface grades into a uniform, wave-cut marine platform (Figure 1).

As described in "Summary of the Geomorphic History of the SONGS Area" of this report, the filling of the channeled creek valley was contemporaneous with the formation of the Sangamon-age Terrace. The Qt_1 nonmarine deposits are therefore of Sangamon age.

The interfingering relationships of marine and continental material within terrace deposits are also recognized at several adjacent localities northwest of SONGS. In the area of maximum channeling by San Onofre Creek along San Onofre Beach, a sandy silt containing marine shells (estuarine deposit) is overlain and underlain by San Onofre stream gravel (Drawing 2). At the mouth of Prima Deschecha Cañada, approximately 7 miles northwest of SONGS, stream gravels overlie a well-sorted marine sand and a fossiliferous, sandy, marine gravel. The stream gravels underlie a sandy silt that is an estuarine deposit. At the mouth of San Juan Creek at Dana Point, approximately 10 miles northwest of SONGS, a fossiliferous sandy silt (estuarine deposit) is interbedded with bouldery San Juan Creek gravel (Drawing 3).

E. Basal Terrace Gravel Overlying Cristianitos Fault

Three-quarters of a mile southeast of SONGS, the Cristianitos fault is exposed in the sea bluff and is overlain by an undisturbed sequence of nonmarine-type terrace (Qt_1) material (Southern California Edison, 1970, Appendix 2A, Drawings 3, 4 and 5). Whereas the bulk of the overlying terrace deposit is locally derived continental material, a thin basal bouldery gravel, as illustrated in Drawing 6 of Appendix 2A of Southern California Edison (1970), overlies the wave-cut platform between the Cristianitos fault and SONGS (Drawing 4). The 1- to 5-foot thick gravel was originally derived from San Onofre stream deposits, but it is a wave-cut platform deposit and not a channel deposit because of:

- High degree of sorting,

- Lack of bedrock channeling,
- Uniform mantling of the terrace platform, and
- Persistence of the gravel along-shore for at least 5 miles.

The stream gravel was reworked in the surf zone of the Qt_1 terrace level, just as stream gravel is being reworked on the present beach. This basal gravel is therefore interpreted as a marine platform deposit of Sangamon (Qt_1) age.

The fact that the gravel is undisturbed where it overlies the Cristianitos fault confirms the lack of movement on the fault since Sangamon time, approximately 120,000 years ago (refer to following section on "Age Data for the Sangamon-Age Terrace").

F. Summary of the Geomorphic History of the SONGS AREA

The late Cenozoic geomorphic history of the SONGS area is dominated by the Eustatic fluctuations of sea level. In the site area, a series of wave-cut marine terraces occur up to several hundred feet above sea level and represent former high stands of the Pacific Ocean. Some of the higher marine terraces may entirely be tectonically rather than eustatically derived, but the two major lower marine benches in the Dana Point-San Onofre area (Qt_1, Qt_2) can most likely be related to climatically controlled (glacio-eustatic) sea level altitudes.

These lower terraces have, however, probably been uplifted subsequent to each of the high stands of the sea. Although little is known about the maximum elevation of the sea during Qt_2 time, the maximum height of the sea during Qt_1 (Sangamon) time is believed to have been about 30 feet above the present level (for example, Ku and others, 1974; and Steinen and others, 1973). Since the Qt_1 terrace occurs at elevations of 75 to 100 feet, regional or hydro-isostatic warping may have occurred.

The same geomorphic relationships of stream terraces to marine terraces exist at the mouth of the San Onofre Creek as at the mouth of San Juan Creek at Dana Point (Fugro, 1975). Stream terraces are graded to former high sea level altitudes and can be traced laterally to marine terraces. Because each terrace level represents a long-term sea level stand, the relationship of stream deposits to marine deposits is complex. Sea level probably fluctuated slightly during each of these intervals and the volume of stream material entering the sea probably varied. Therefore, a complex interfingering of marine and nonmarine sediments is present at each level.

The block diagram of the mouth of San Onofre Creek (Fig. 1) and the diagrammatic composite cross sections along San Onofre Creek (Fig. 2) illustrate the middle to late Pleistocene history of the SONGS area.

Based on the geomorphic history that has been developed for San Juan Creek, on the radiometric and terrace correlation data contained in this report, on published and unpublished literature, and on the observed geologic relationships in the site area, the following geomorphic history can be outlined. It should be noted that the major aggradational episodes occurred during the interglacial high sea level stands, and no deposits of glacial low stands are definitely recognized. This does not exclude the possibility, however, that some of the basal stream gravels were deposited immediately following incision of the streams to the eustatically lowered sea level.

1. Early to middle Pleistocene time is primarily represented by a sequence of marine terraces 300 to 600 feet in elevation. These high terraces are highly dissected and poorly preserved, but best exhibited near Dana Point, about 10 miles north of the site, and near Las Pulgas Canyon, about 6 miles south of the site. They do not occur in the immediate site area.

2. Middle to late Pleistocene time is represented by a sequence of marine and stream terraces containing interfingering deposits. From Yarmouth (?) time through the present, sea level has successively risen and fallen (transgression-regression), and tributary streams have consequently aggraded and degraded.

    a. Approximately 200,000 years ago (Yarmouth (?) time; Broecker and Van Donk, 1970), sea level stood perhaps as much as 150 feet higher than

Late Cenozoic Geologic Time Scale

Geologic Time Units				
Period	Epoch	Age		SONGS Geologic Units
Quaternary	Holocene			Qal, Qb, Qf, Qsw
			10,000 yrs. b.p.	
	Pleistocene	Wisconsin Glacial		Degradational period, no recognized deposits
		Sangamon Interglacial		Qt_1
		Illinoian Glacial		Degradational period; no recognized deposits
		Yarmouth Interglacial		Qt_2
		Kansan Glacial		No recognized deposits
		Aftonian Interglacial		No recognized deposits
		Nebraskan Glacial		No recognized deposits
		?	1.8 m.y.b.p.*	?
Tertiary	Pliocene			Tsm

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* The Plio-Pleistocene boundary is placed at 1.8 m.y. after Grichuk and others (1969).

present (Fig. 2A). San Onofre Creek was aggrading and contributing sediments (Qt_2 terrace deposits) into the transgressing area.

b. Between about 120,000 and 200,000 years ago (Illinoian time; Fairbridge, 1966) sea level dropped resulting in the deep incision of the streams (Fig. 2B).

c. About 120,000 years ago (Sangamon time; refer to section on "Radiometric Data for the Sangamon-Age Terrace") sea level rose to 30 feet above the present level, marine waters transgressed, and San Onofre Creek aggraded (Fig. 2C). A wave-cut platform was beveled across the Tertiary formations and the Quaternary alluvial deposits, and a sea cliff was cut into the higher Qt_2 material. Qt_1 stream deposits filled the previously scoured creek valley and were graded to the Qt_1 marine terrace level. Continental Qt_1 sediments interfingered with marine Qt_1 deposits at sea level and continental sediment volume fluctuated.

d. Between about 20,000 and 70,000 years ago (Wisconsin time; Buffington and Moore, 1963; Steinen and others, 1973), sea level dropped several hundred feet from the Qt_1 altitude (Fig. 2D). Sea level was approximately 200 to 300 feet below the present level and a wave-cut platform was formed several miles off the present shoreline. This platform is now recognized as a submerged, offshore terrace. During this interval, San Onofre Creek downcut 200 feet or more below the present creek level.

e. Since the maximum lowering of sea level during Wisconsin time, sea level has gradually risen to the present level, and the deeply scoured creek valleys have been backfilled to their present level (Fig. 2E).

3. With the attainment of the present sea level, the present wave-cut platform has been progressively encroaching on the Qt_1 terrace, exposing the marine/nonmarine relationships. At the mouth of San Onofre Creek, the sea cliff now exhibits marine and nonmarine interlayers overlying the channeled San Mateo Formation.

The Qt_1 stream terrace deposits pinch out laterally (Fig. 1) as the channel deposits grade out onto the Qt_1 wave-cut platform. Beyond this gradational contact, the San Mateo Formation, as seen in the Qt_1 bluff, is no longer channeled but is uniformly beveled by the Qt_1 wave-cut platform. The wave-cut platform slopes gently toward the sea, and it is mantled by a thin (1 to 5 feet) basal, bouldery beach gravel and a variable thickness of marine sediment and continental cover.

IV. CORRELATION OF THE SANGAMON-AGE TERRACE BY SURFICIAL MAPPING

The Sangamon-age Terrace has been locally identified and radiometrically dated at many localities along the California coast (refer to section on "Age Data for the Sangamon-Age Terrace" of this report). None of the previously published reports, however, have correlated all of these widely separated localities. Therefore, the following terrace correlation has been developed from a compilation of published and unpublished mapping for the California coast and recent field observations in the SONGS area. The correlation demonstrates that:

1. Widely separated terraces are correlative based on published and unpublished surficial mapping.
2. Mapped terraces of known Sangamon age (radiometrically dated) are correlative with the Qt_1 units at SONGS.

Figure 3 illustrates the extent of published and unpublished mapping of the Sangamon-age Terrace along the coast from San Diego to Santa Cruz. None of the individual maps extend continuously along the entire coast, but the overlap of data established a composite continuity. In some cases, the terrace has been included in an undifferentiated unit or has been given various formational names. Although some of the maps do not specifically identify the terrace as being of Sangamon age, all of the individually mapped areas can be related to the published radiometric data (Figure 4; Tables 1-9) which establish the age as Sangamon.

The following describes the extent of terrace mapping along the California coast from San Diego to Monterey Bay, graphically shown in Figure 3.

A. San Diego Bay to Del Mar

Ellis (1919) and Hertlein and Grant (1944) identified two probable levels of the Sangamon-age Terrace near San Diego: the upper "Nestor Terrace", and the lower "Tia Juana Terrace". These two levels were included in a more extensive undifferentiated unit by Ellis and Lee (1919) and Hertlein and Grant (1954), and combined into a single unit (La Jolla Terrace) by Hanna (1926) and Peterson (1970). Only the major level, the Nestor level, was mapped by Ku and Kern (1974). The most extensive and detailed mapping in this area is that of Kennedy (1973b) who recognized both levels and mapped both terrace deposits as the Bay Point Formation.

B. Del Mar to Oceanside

The Sangamon-age level was included with a series of undifferentiated terraces by Ellis and Lee (1919) and Hertlein and Grant (1954). Phillips (1933) included it as part of a series of unnamed beach ridges and "marine river terraces" found along the coastal plain. The most detailed description was that of Palmer (1967) who traced a single level as an unnamed coastal plain through this area as part of a regional study.

C. Oceanside to San Clemente

North along the coast from Oceanside, the Sangamon-age Terrace is recognized as a single, broad, colluvial-covered bench. It was undifferentiated by Ellis and Lee (1919), Hertlein and Grant (1954), Ball (1961), and Blanc and Cleveland (1968). It was also undifferentiated through the Camp Pendleton area by Moyle (1973), but it can be recognized on his map as an unnamed coastal plain. Palmer (1967) also described the terrace as an unnamed coastal plain, and he documented the continuity of the single surface through the area. Verma (1973) also established a correlation of the first emergent terrace through this area by using map parameters.

From Oceanside through the SONGS area, the terrace was mapped in detail as unit Qt_1 by Southern California Edison (1970, Appendix 2A) and in present field investigations.

D. San Clemente to Newport Beach

North along the coast from SONGS to Newport Beach, the first emergent terrace is well preserved and easily identifiable. It was undifferentiated by Ball (1961) and Blanc and Cleveland (1968), but was mapped in detail by Vedder and others (1957), Hoskins (1957) and Fugro (1975). Although the terrace is tectonically warped through the San Joaquin Hills area, continuity was demonstrated by Szabo and Vedder (1971) and Palmer (1967).

E. Newport Beach to Santa Cruz

Upcoast from the boundary of the Peninsular Province at

Newport Beach, the Sangamon-age Terrace is tectonically deformed, discontinuous, and difficult to trace by surficial mapping. Hoskins (1957), however, successfully demonstrated that the first emergent terrace levels at isolated localities can be mapped and correlated through paleoecologic methods. He pointed out that widely separated terraces are correlative on the basis of fossil assemblages and reconstructed paleo-isotherms, and he concluded that the separated segments are part of a single terrace formed during Sangamon time.

V. RELIABILITY OF URANIUM-SERIES AGE DETERMINATIONS

A. Description of Methods

Uranium-series techniques have been widely used to date carbonate material from the Sangamon-age Terrace, and they have yielded varying results depending upon the method used:

1. Uranium-thorium-protactinium method on corals,
2. Uranium-thorium-protactinium method on mollusks,
3. Uranium-helium method on mollusks (rarely used).

As described by Szabo (1969) and Rosholt (1972), the Th^{230}-Pa^{231} deficiency method is based on the assumption that carbonate material when formed takes in uranium and insignificant amounts of thorium and protactinium. Age determinations are made by measuring the amount of Th^{230} and Pa^{231} produced by the parent elements, U^{234} and U^{235}, respectively. The ages that are independently derived from the growth of the Th^{230} and Pa^{231} should be concordant, thus providing a conclusive age date.

Helium -4 (alpha emission) is produced through the decay of uranium and thorium and other daughter nuclides in the decay series. The concentration of helium can therefore be used for determining radiometric ages.

For any result to represent a true age, two assumptions must be valid:

1. A measurable amount of the uranium was incorporated

into the specimen during its formation or in a period of time that was short compared to the age of the specimen.

2. No measurable uranium, thorium, protactinium, or helium has entered into or been leached from the material (closed-system condition).

Whereas these conditions appear to be met in corals, they are not generally met in mollusks.

B. Analysis of Uranium-Series Results

1. Uranium-thorium-protactinium

a. Corals. As described by Szabo (1969), solitary corals can be successfully used for uranium-series dating of Quaternary material because:

(1) Uranium-238 is a primary trace element in coral (incorporated in the living organism).

(2) The Th^{230}/Th^{232} ratios are generally high (i.e., very low Th^{232} contents), thus enabling accurate correction factors to be made for nonradiogenic Th^{230}.

(3) Crystallographically unaltered samples form a closed system with respect to the Th^{230}, Pa^{231}, and uranium isotopes.

As Ku (1968), Ku and Kern (1974), Ku and others (1974), and Kaufman and others (1971) found, unaltered corals will yield concordant Th^{230}/U^{234} and Pa^{231}/U^{235} dates, thus providing accurate absolute ages.

b. Mollusks. Molluscan shells do not generally meet the closed system requirements outlined under "Description of Methods" because:

(1) Uranium-238 is a secondary trace element in mollusks (incorporated after death).

(2) Uranium and perhaps, to a lesser extent, thorium and protactinium are commonly mobile, migrating both in and out of the sample in unpredictable degrees.

Although uranium-238 is secondary, it will lead to erroneous results only if assimilation has not occurred in a period of time that is short compared to the age of the sample. Broecker (1963) found that uranium-238 was incorporated in the mollusks quickly after death and that the intake usually ceases after a few thousand years. Kaufman and others (1971) concluded that whereas uranium-238 uptake by mollusks ceases before an age of 10,000 years, a further addition (on the order of 50 percent) does occur during the following several thousand years. Szabo (U.S. Geological Survey, 1975, oral communication) estimates that the uranium-238 is incorporated generally within 5,000 years of death, and Ku (University of Southern California, 1975, oral communication) believes that the uranium addition is close enough to the time of death to have only a slight effect on the ages of interest (greater than

50,000 years). In any case, the resultant age dates, if reliable, will still represent only minima.

As found by Blanchard and others (1967), the average uranium content in fossil mollusks is generally higher than in modern shells, thus indicating after-death uranium addition. They concluded, based on a comparison of uranium-series age dates with known age dates, that uranium-series disequilibrium measurements are sometimes valid, but in general are not likely to give reliable results for isolated shells. Similar conclusions were reached by Szabo and Rosholt (1969) and Szabo and Vedder (1971).

Kaufman and others (1971) have analyzed the uranium-series technique on mollusks most thoroughly. They found through the analysis of over 200 molluscan samples that:

(1) In addition to the assimilation of secondary U^{238} after death, a process exists which adds U^{234} relative to U^{238} to most mollusks for possibly hundreds of thousands of years after death. This addition is over and above the U^{234} that should decay during this time.

(2) More than half of the mollusks put to the test show a discordance between Pa^{231}/U^{235}

and Th^{230}/U^{234} ages which cannot be explained by analytical error.

(3). Where independent ages are available, these disagree with Th^{230}/U^{234} ages by more than twice the analytical uncertainty in at least half the cases. When C^{14} ages (which may be questionable) are excluded, this disagreement occurs in about 70 percent of the cases.

An analysis of 17 Pleistocene mollusks from Southern California lead Szabo and Rosholt (1969) to conclude that a closed-system assumption is not applicable. Based on Th^{230}/Pa^{231} age disparities in their samples, they concluded that in the absence of Pa^{231} ages (such as in Bradley and Addicott, 1968) closed-system Th^{230} ages are highly suspect. The lack of Th^{230}-Pa^{231} concordance in the samples precluded a closed-system model, but allowed the development of an open-system model that would presumably compensate for the isotopic contamination.

The open-system model was developed as a result of a measured excess of Pa^{231} relative to Th^{230} in the samples. The excess Pa^{231} was attributed to the presence of mobile uranium that migrated into the shell, produced Pa^{231} and Th^{230} daughter elements, but was not assimilated into the shell.

Based on this uranium mobility, a mathematical solution for the age determination of the open-system samples was developed which allowed the calculation of the open-system ages for the analyzed samples (Table 1).

Szabo and Vedder (1971) similarly analyzed 22 molluscan samples from Southern California and found that use could be made of the open-system model only under certain conditions (some of their results are listed in Table 2). In numerous cases they found a Pa^{231} deficiency relative to Th^{230} rather than a Pa^{231} excess as in Szabo and Rosholt's model. This deficiency was explained by assuming that the fossils had assimilated an additional amount of uranium, thus lowering the values of both Th^{230}/U^{234} and Pa^{231}/U^{235}. In such situations, where there was a Pa^{231} deficiency, they concluded that the open-system model was not applicable, and that no reliable means of absolutely dating individual samples was possible.

This open-system model of Szabo and Rosholt (1969) has been thoroughly evaluated in Kaufman and others (1971). They concluded that based on analyses of over 200 molluscan samples the open-system model is invalid in that the model does not cope adequately with the more complicated and variable conditions occuring in nature; it does not yeild any more reliable ages than the closed-system model.

At present, the status of the open-system model is still in question. However, B. J. Szabo (U.S. Geological Survey, 1975, oral communication) believes that a good working model can be successfully developed.

In the absence of concordant Th^{230} and Pa^{231} ages and reliable open-system dates for individual mollusk samples, an approximate age for a deposit can be determined if a series of uranium-thorium mollusk dates cluster around the same age (T. L. Ku, University of Southern California, 1975, oral communication). Even though the data (as listed in Tables 1-9) may not contain individually reliable ages, it can, in total, be used to establish the approximate age of the deposit by grouping of dates (Table 11).

2. Uranium-helium. Uranium-helium analyses are also subject to closed system requirements. The age determinations of Fanale and Schaeffer (1965) for the Palos Verdes Hills were based on closed-system assumptions and, although the derived ages agree well with other correlative deposits, no detailed evaluation of these ages is available.

C. Conclusions

1. Unrecrystallized corals provide the most accurate means of uranium-series absolute age determinations because they possess primary uranium and remain closed systems with respect to uranium, thorium and protactinium following burial.

2. Mollusks are less than ideal for uranium-series dating:

   a. Age determinations are regarded as reliable only if concordant Th^{230} and Pa^{231} ages are obtained on individual samples, and then they are only minimum ages because uranium addition to the sample is of a secondary nature.

   b. The isotopes of interest, in particular those of uranium, are commonly mobile, migrating both in and out of the sample, thus resulting in erroneous closed-system ages.

   c. An open-system model which corrects for isotope migration was developed by Szabo and Rosholt (1969), and it was suggested by them that it can be successfully used in determining accurate ages on mollusks that have discordant Pa^{231} and Th^{230} ages. Kaufman and others (1971), however, demonstrated that this open-system model cannot be valid.

3. Uranium-series dates on mollusks can be used as an approximate age indicator for a deposit if a series of dates cluster around the same age.

VI. AGE DATA FOR THE SANGAMON-AGE TERRACE

The available published age dates for the Sangamon-age Terrace are presented in Tables 1 to 9 and are plotted by locality in Figure 4. As listed, there are several types of reported age dates:

- Th^{230} ages
- Th^{230}-Pa^{231} (concordant) ages
- Calculated open-system uranium-series ages
- Uranium-helium ages
- Amino-acid ages

As previously described in "Reliability of Uranium-Series Age Determinations," the only ages shown to be of absolute value are:

- Th^{230} ages of corals
- Concordant Th^{230} - Pa^{231} ages of mollusks

Ten such absolute ages have been reported at present (Table 10). The ages range from about 70,000 to 130,000 years and agree well with documented world-wide stands of Sangamon sea level. For example, Veeh (1966) and Ku and others (1974) established that a high stand of sea level occurred on Hawaii 120,000 years ago. Ku (1968) documented three distinct Sangamon sea levels on Barbados at 80,000, 105,000 and 120,000 years; of these high stands, the only one that occurred above the present level was the one at 120,000 years (Steinen and others, 1973). Such ages are also in agreement with world-wide climatic cycles as interpreted by Broecker and Van Donk (1970) who established that a major deglaciation occurred at 127,000 ± 6,000 years ago.

Although some of the absolute ages are as young as 69,000 years, the Qt_1 terrace deposits at SONGS are interpreted as being about 120,000 years old because:

- The coral ages cluster around 120,000 years, (Table 11).
- The Th^{230} mollusk ages cluster around 100,000 to 120,000 years (Table 11).
- The Th^{230}-Pa^{231} concordant mollusk ages are only minimum ages since the uranium is secondary.
- The Qt_1 terrace has been shown to be correlative to the Nestor Terrace, dated at an average thorium-protactinium coral age of 120,000 ± 10,000 years (Ku and Kern, 1974).
- Although multiple high stands of the Sangamon-age sea have been documented world-wide the only high stand believed to have occurred above the present sea level has been dated at approximately 120,000 years (Steinen and others, 1973).

Amino-acid age dates are included in the data (Table 8), but most of the yielded ages appear to be slightly high. These ages were determined by Lajoie and others (1975a and 1975b) through amino-acid stereochemistry. The estimated amino-acid ages of 140,000 to 150,000 years that are derived for this set of terraces are slightly high due either to the use of a kinetic model (as opposed to calibration of the ratios with a known radiometric date) or just to analytical error, which is probably ± 20 percent (K. R. Lajoie, U. S. Geographical Survey, 1975, oral communication).

Table 1

SANGAMON-AGE TERRACE
AGE DATA FROM SZABO AND ROSHOLT (1969)

Location	Sample	Fossil	Closed System Th^{230} Age ($x10^3$ yr)	Closed System Pa^{231} Age ($x10^3$ yr)	Open System Age ($x10^3$ yr)
First Terrace at Palos Verdes Hills	PV-S-1	Mollusk	104 ± 8	>130	86 ± 15
	PV-S-2	Mollusk	104 ± 8	$125^{+\infty}_{-30}$	95 ± 15
	PV-S-3	Mollusk	111 ± 8	108^{+30}_{-20}	110 ± 15
	PV-S-4	Mollusk	103 ± 8	>125	84 ± 15
	PV-S-5	Mollusk	93 ± 8	>130	70 ± 15
	PV-S-6	Mollusk	95 ± 8	$150^{+\infty}_{-40}$	78 ± 15
	M2017	Mollusk	92 ± 10	$113^{+\infty}_{-30}$	81 ± 15
		Avg.	100 ± 6	Avg.	86 ± 9
Point Dume Terrace	DT-S-1	Mollusk	95 ± 15	$115^{+\infty}_{-20}$	112 ± 15
	DT-S-2	Mollusk	124 ± 10	>200	101 ± 15
	DT-S-3	Mollusk	127 ± 10	>150	111 ± 15
	DT-S-4	Mollusk	117 ± 10	>140	106 ± 15
	M1710-A	Mollusk	128 ± 10	>200	103 ± 20
	M1710-B	Mollusk	178 ± 20	>200	102 ± 25
	M1710-D	Mollusk	161 ± 25	>200	95 ± 25
		Avg.	131 ± 21	Avg.	104 ± 5
Malibu Terrace "C"	CC-S-1	Mollusk	139 ± 10	>200	115 ± 15
	CC-S-2	Mollusk	184 ± 10	>200	124 ± 15

TABLE 1 (Cont.)

SANGAMON-AGE TERRACE
AGE DATA FROM SZABO AND ROSHOLT (1969)

Location	Sample	Fossil	Closed System Th^{230}Age ($x10^3$yr)	Closed System Pa^{231} Age ($x10^3$ yr)	Open System Age ($x10^3$ yr)
Malibu Terrace "C"	CWM-115	Mollusk	232±30	>200	154±30
		Avg.	185±31	Avg.	131±15

TABLE 2

Sangamon-Age Terrace
Age Data from Szabo and Vedder (1971)

Location	Sample	Fossil	Th^{230} Date ($x10^3$ yr.)	Pa^{231} Date ($x10^3$ yr.)	Open System Date ($x10^3$ yr.)	Closed System Date ($x10^3$ yr.)
Newport Beach	NB-S-2	Mollusk	115±8	170	95±18	-
	NB-S-3	Mollusk	70±5	68±7	-	69±7
	NP-S-4	Mollusk	240±40	-	160±35	-
	NP-S-5	Mollusk	240±40	-	130±30	-
	NP-S-6	Mollusk	137±10	-	114±18	-
	NP-S-7	Mollusk	82±5	96±15	72±15	94±17
	NP-S-8	Mollusk	69±4	53±4	65	-
Laguna* Beach	LB-S-1	Mollusk	44±3	35±3	41	-
	LB-S-2	Mollusk	72±4	65±6	-	69±10
Dana* Point	DP-S-1	Mollusk	146±14	-	112±12	-
San* Clemente	SC-S-1	Mollusk	178±16	-	77±20	-
San Diego (Mission Bay)	SD-S-1	Mollusk	154±12	-	131±20	-
San Nicolas Island	SNI-S-1	Mollusk	177±17	-	128±25	-

---

* Same sample localities as listed by Southern California Edison (1970, Sec. 2.9, p. 5).

Table 3

Sangamon-Age Terrace
Age Data from Ku and Kern (1974)

Location	Locality Number	Fossil	Th^{230}/U^{234} Age ($x10^3$ yr.)
Point Loma	2577	coral	109±6
	2577	coral	131±8
	2577	coral	124±7
	2577	mollusk	84±6
	2523	mollusk	120±10
	2523	mollusk	100±6
Pacific Beach	1845	mollusk	93±3

Table 4

Sangamon-Age Terrace
Age Data from Valentine and Veeh (1969)

Location	Sample	Fossil	Th^{230}/U^{234} Age (x10^3 yr.)
San Nicolas Island	SN-1	coral	≥ 120
	SN-13	coral	120 ± 20

Table 5

Sangamon-Age Terrace
Age Data from Veeh and Valentine (1967)

Location	Fossil	Th^{230}/U^{238} Age ($x10^3$ yr.)
Cayucos	coral	130±30[1]
	chiton	140±30[2]

---

[1] Recalculated by Ku and Kern (1974) at 124 ± 27.

[2] Recalculated by Ku and Kern (1974) at 97 ± 24.

Table 6

Sangamon-Age Terrace
Age Data from Fanale and Schaeffer (1965)

Location	Sample	Fossil	U/HE Age ($x10^3$ yr.)
First Terrace at Palos Verdes Hills	853A	Mollusk	200
	YC-1	Mollusk	105±30
	853C	Mollusk	130±20
	SS-1	Mollusk	115±20
	RS-1	Mollusk	115±20
	GS-1	Mollusk	95±15
	855D	Mollusk	130±20

Table 7

Sangamon-Age Terrace
Age Data from Bradley and Addicott (1968)

Location	Sample	Fossil	Th^{230}/U^{238} Age ($\times 10^3$ yrs)
Santa Cruz	Cal F-1	Mollusk	88±14
	Cal F-2	Mollusk	68±10
	Cal F-3	Mollusk	76±8
	Cal F-4	Mollusk	16±2
	Cal F-5	Mollusk	100±7; 91±7

Table 8

Sangamon-Age Terrace
Age Data from Lajoie and others (1975b)

Location	Fossil	Amino-acid Age ($x10^3$ yrs)
Ano Nuevo	Pelecypod	140-150
Santa Cruz	Pelecypod	140-150
Cayucos	Pelecypod	140-150
Goleta	Pelecypod	50-70
Newport Beach	Pelecypod	140-150
San Nicolas Island	Pelecypod	140-150
Torrey Pines	Pelecypod	140-150

Table 9

Sangamon-Age Terrace
Age Data from Szabo and others (1970)

Location	Sample	Fossil	Open System Age (x10^3 yrs.)[1]	Closed System Age (x10^3 yrs.)[2]
Point Dume	M-1710-A	Mollusk	103±20	128±10[3]
First Terrace Palos Hills	PVH-S-1	Mollusk	86±15	104±8 [3]
	PVH-S-2	Mollusk	95±15	104±8 [3]
Terrace "C" at Malibu	CC-S-1	Mollusk	115±15	139±10[3]
Newport Beach	NB-S-3	Mollusk	-	74±7

---

[1] Calculated from Th^{230}/U^{234} and Pa^{231}/U^{235}.

[2] Calculated from Th^{230}/U^{234} activity ratios.

[3] Same data as Table 1.

Table 10

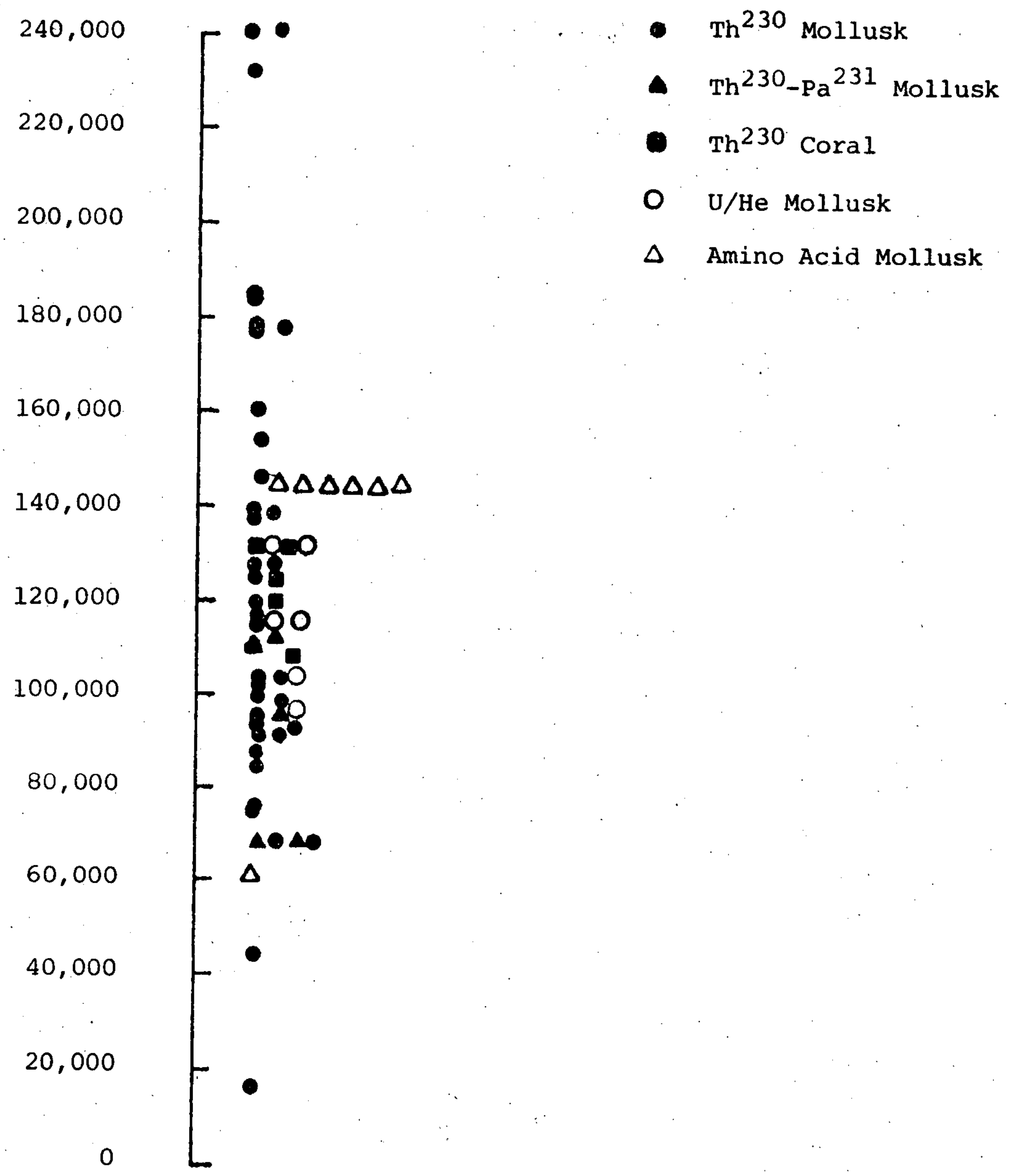
Sangamon-Age Terrace
Radiometric Dates of Absolute Value

Location	Ages (yrs.)	Reference
Th^{230}/Pa^{231} Mollusk Ages		
Palos Verdes	110,000±15,000	Szabo and Rosholt (1969)
Point Dume	112,000±15,000	Szabo and Rosholt (1969)
Newport Beach	69,000±7,000	Szabo and Vedder (1971)
Newport Beach	94,000±17,000	Szabo and Vedder (1971)
Laguna Beach	69,000±10,000	Szabo and Vedder (1971)
Th^{230} Coral Ages		
Point Loma	109,000±6,000	Ku and Kern (1974)
Point Loma	124,000±7,000	Ku and Kern (1974)
Point Loma	131,000±8,000	Ku and Kern (1974)
San Nicolas Island	120,000±20,000	Valentine and Veeh (1969)
Cayucos	130,000±30,000	Veeh and Valentine (1967)

TABLE 11

Plot of Radiometric Data
For the Sangamon-Age Terrace

AGES (yrs.)	TYPE OF AGE DATE



NOTE: Average Th^{230}-Pa^{231} closed system ages are plotted. Open system Th^{230} ages are not plotted.

Vll. REWORKING OF FOSSILS

Although few, if any, of the dated fossils were obtained from undistrubed growth positions, communications with two of the original investigators and recent field investigations confirm that dated fossils are the same age as the deposit.

The mollusks collected by Vedder (Table 2) were rarely in the growth position, but the lack of mixing of assemblages indicates non-reworking (J. G. Vedder, U.S. Geological Survey, 1975, oral communication.).

The corals collected by Valentine (Tables 4 and 5) were not in growth positions, but the abundance of species of corals and mollusks leaves little doubt that the reworking was only from wave action in the surf zone (J. W. Valentine, University of California, Davis, 1975, oral communication).

Field investigation of two of the fossil localities, DP-S-1 and SC-S-1 (Table 2), supports the conclusion that reworking from older deposits is improbable. Examination of a selected group of shells suggests that reworking has been due only to wave action:

- Fossils are abundant and evidence of assemblage mixing is lacking.
- Most shells reflect a similar state of preservation.
- Most fossils are thick-shelled and well adapted to survive wave action. They still maintain delicate interior shell features, and, occasionally articulation.

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1X. GLOSSARY OF TERMS

abrasion platform - See "terrace."

bench - See "terrace."

estuary - Brackish, back-water environment at mouth of stream where stream empties into ocean. This condition presently exists and has periodically existed in the past as interglacial sea levels rose and marine waters flooded the mouths of the deeply incised streams.

eustatic - Change in sea level relative to land derived from fluctuation of the ocean, as opposed to tectonic fluctuation. Glacio-eustatic: sea level fluctuation due to climatically controlled glacial and interglacial episodes.

fill terrace - See "terrace."

Illinoian age - Glacial period preceding Sangamon Interglacial period approximately 150,000 (?) years ago.

platform - See "terrace."

Sangamon age - Interglacial period from about 75, 000 to 125,000 years ago, immediately preceding last glacial period.

shoreline angle - Break in slope at rear, landward edge of marine terrace where the flat surface of the terrace (tread) meets the sea bluff (riser).

strath - See "terrace."

terrace - Elevated landform exhibiting flat, gently sloping upper surface and representing former level of fluvial, marine, or lacustrine activity; elevation of landform, due to lowering of altitude of abrasional or depositional level. Underlying terrace deposits may or may not be present. Form is also referred to as a "bench" or "platform."

Types of Terraces

abrasion - Marine (or lacustrine) terrace formed through prolonged wave action and erosion followed by lowering of sea level (or lake) relative to land. Actual beveled bedrock surface is generally overlain by mantle of terrace deposits.

fill - Fluvial (locally, marine or lacustrine) terrace formed through filling of a previously scoured channel; subsequent stream incision results in this channel fill forming elevated terrace.

strath - Fluvial terrace formed by abrasional beveling of bedrock; little or no associated deposit. Also includes terraces cut on older fluvial fill deposits. Term is infrequently applied to abrasion or wave-cut platform.

wave-cut - Same as "abrasion."

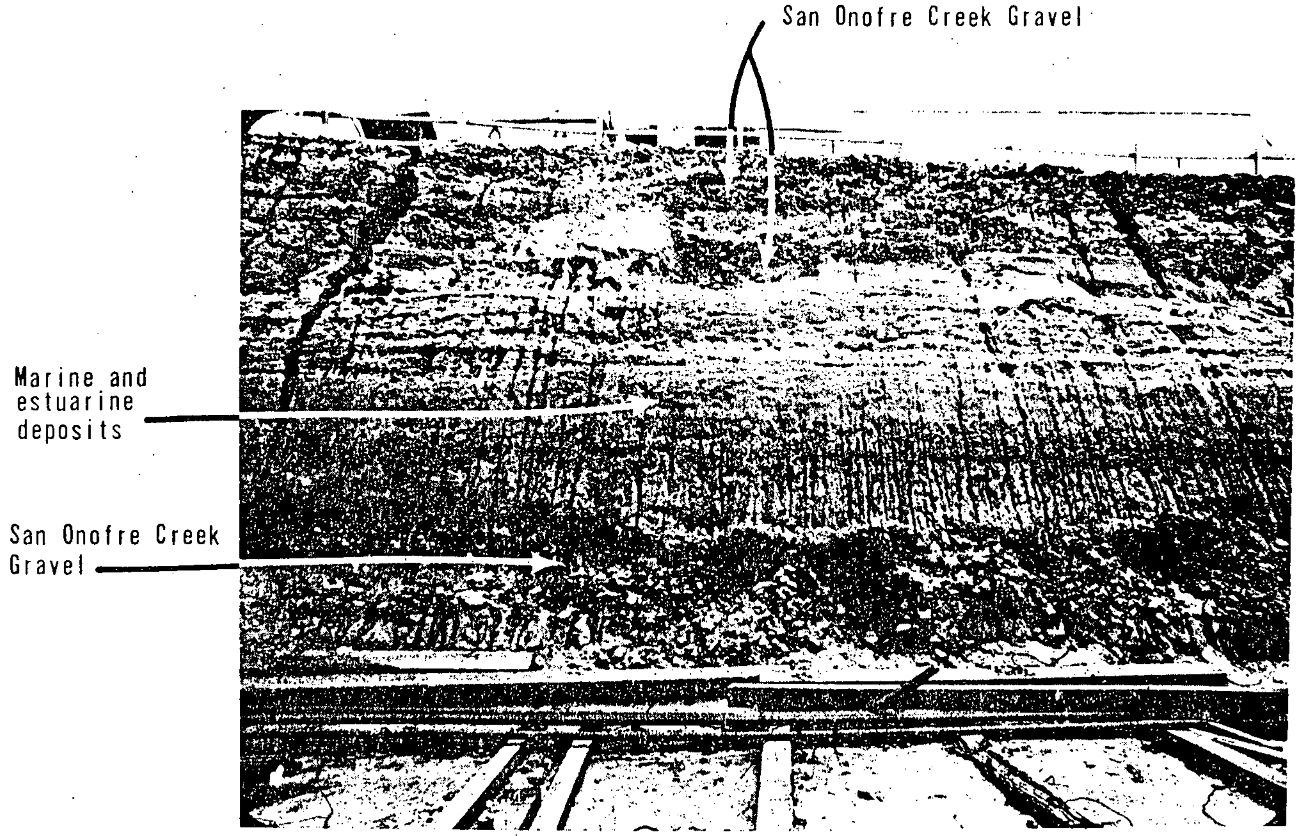
transverse gradient - Gradient, or slope, or terrace surface, perpendicular to course of stream (or wave) flow at time of terrace formation.

tread - Upper, flat, gently sloping surface of a terrace; bounded at head and toe by terrace scarps or "risers."

wave-cut platform - See "terrace."

Wisconsin age - Last major glacial period from about 10,000 to 75,000 years ago.

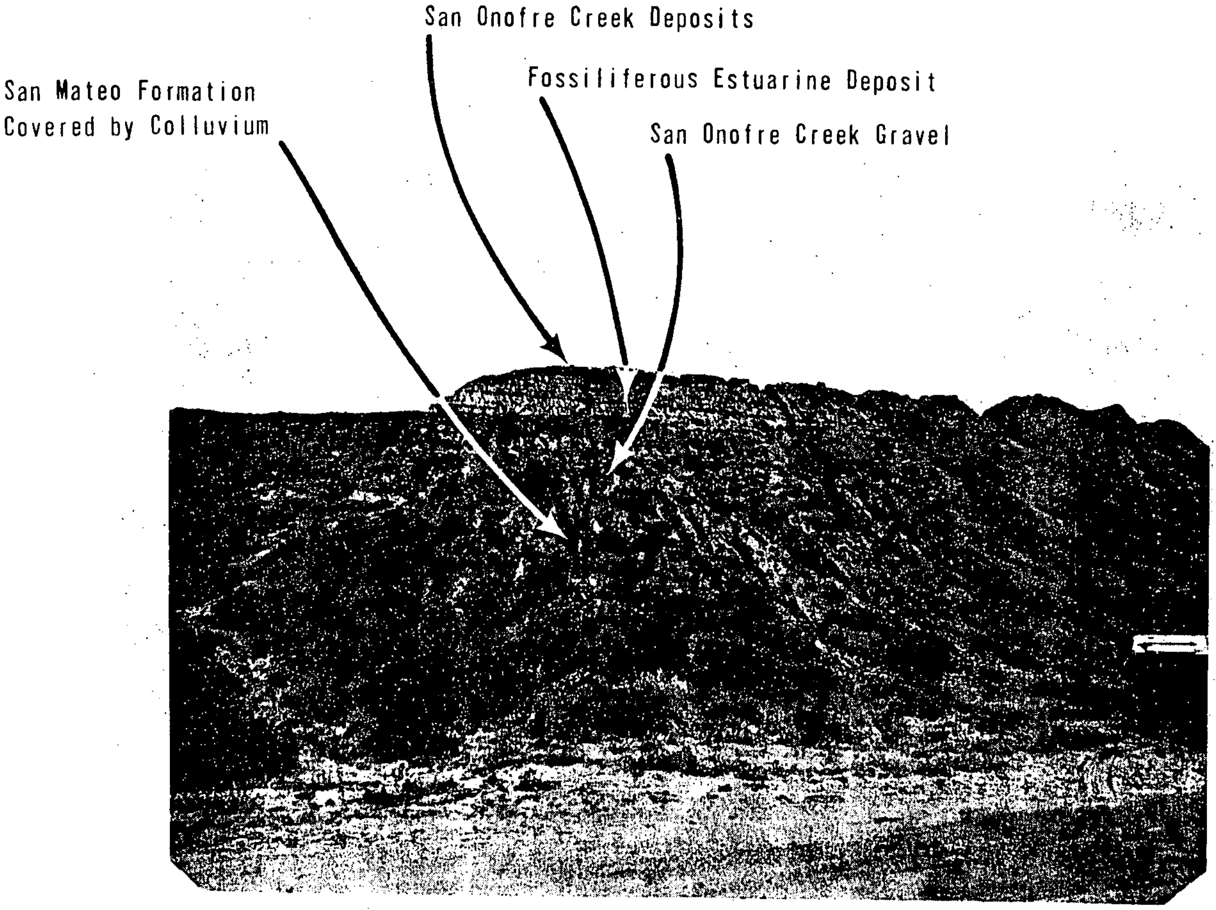
Yarmouth age - Interglacial period preceding Illinoian glacial period approximately 200,000 (?) years ago.



Exposure on plant east wall of SONGS excavation showing marine and estuarine-type desposits interbedded with San Onofre Creek gravel.

EXPOSURE ON EAST WALL OF EXPOSURE
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY
FUGRO, INC. Long Beach, California

Project No 74-069-02
Date JULY 23, 1975
COMPILED BY JB
PREPARED BY A. Smith
CHECKED BY M.K. ANDELIN
APPROVED BY
DRAWING NO 1



Exposure at mouth of San Onofre Creek showing estuarine-type deposit interbedded with San Onofre Creek gravel. Height of exposure approximately 75 feet.

EXPOSURE MOUTH OF SAN ONOFRE CREEK
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY
FUGRO, INC. Long Beach California

Project No 74-069-02
Date JULY 23, 1975
COMPILED BY JB
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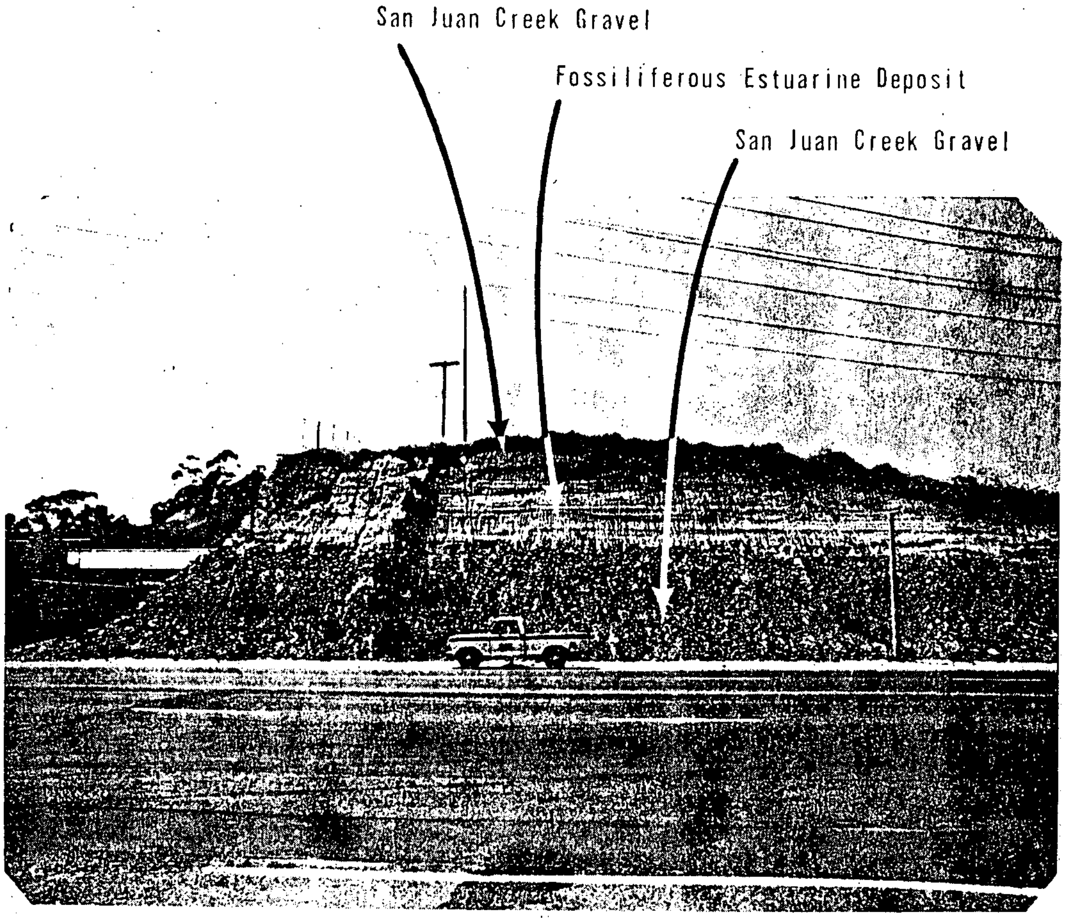
DRAWING NO. 2



Exposure at mouth of San Juan Creek at Dana Point showing estuarine-type deposit interbedded with San Juan Creek gravel.

EXPOSURE, MOUTH OF SAN JUAN CREEK
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY
FUGRO, INC. Long Beach California

Project No 74-069-02
Date JULY 23, 1975
COMPILED BY JB
PREPARED BY A. Smith
CHECKED BY M R ANDELIN
APPROVED BY
DRAWING NO.
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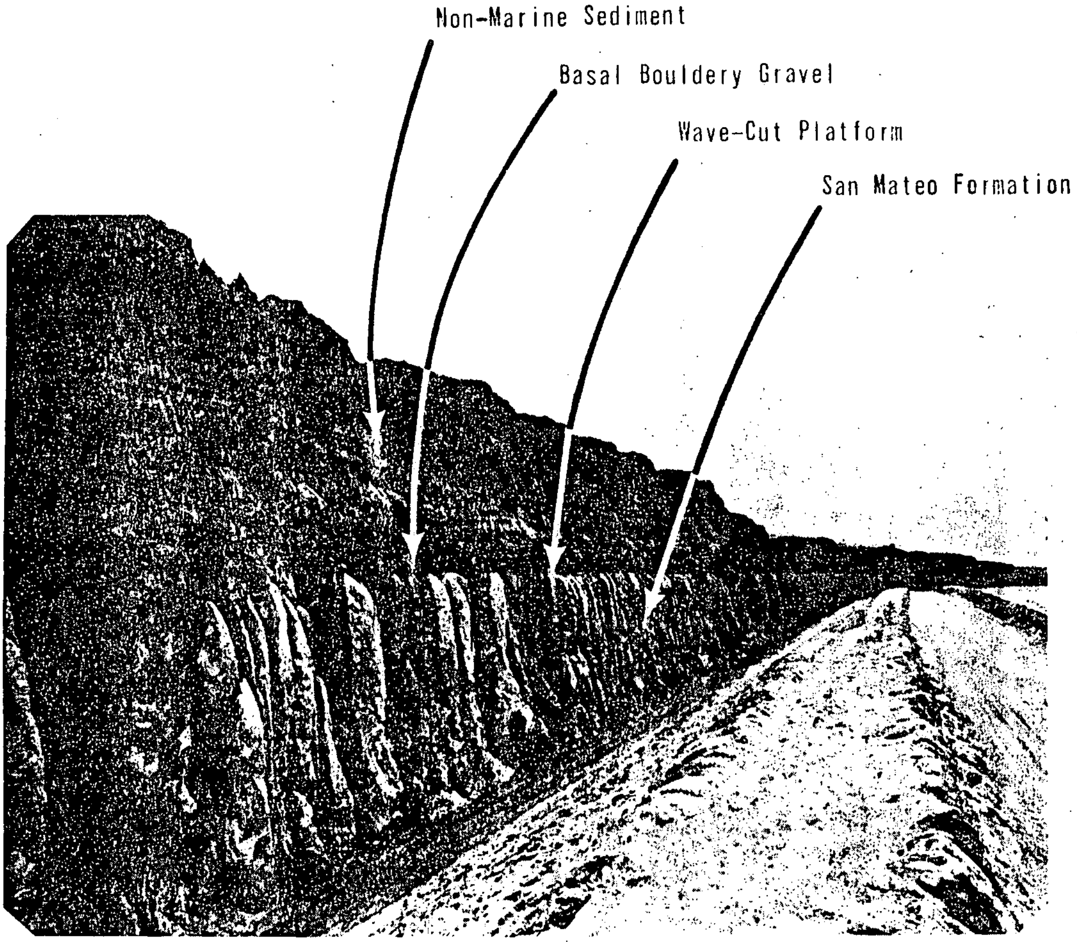
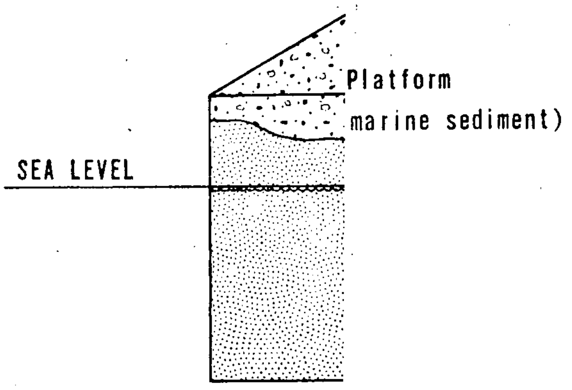


Looking southeast from SONGS along Qt_1 terrace. Basal bouldery gravel (Marine deposit) mantles Qt_1 wave-cut platform at an elevation of approximately 50 feet above sea level (seen at far right).

WAVE CUT PLATFORM SOUTH OF SONGS
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY
FUGRO, INC. Long Beach California

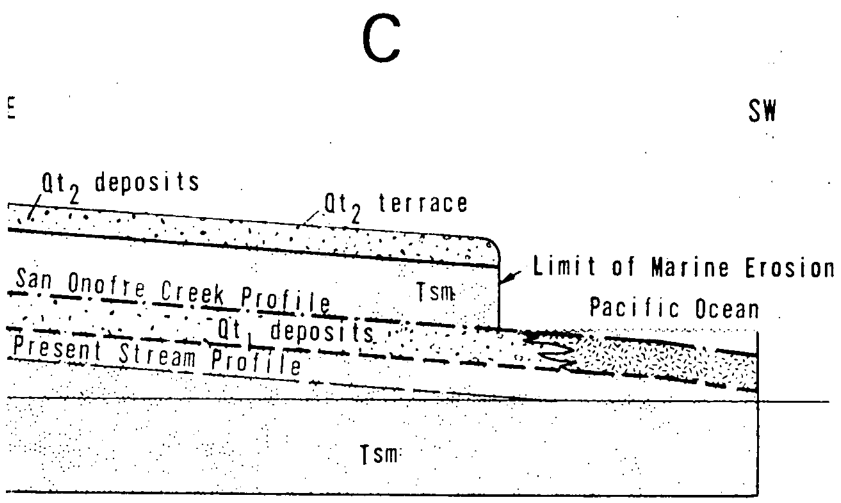
Project No 74-069-02
Date JULY 23, 1975
COMPILED BY JB
PREPARED BY A. Smith
CHECKED BY M.R. ANDELIN
APPROVED BY C. Shaw
DRAWING NO. 4



San Onofre Stream Deposits;
interfingered with marine deposits
at mouth of creek

San Mateo Formation

IAGRAM. MOUTH OF SAN ONOFRE CREEK	Project No 74-069-02	
OFRE NUCLEAR GENERATING STATION	Date JULY 23. 1975	
UNITS 2 and 3	COMPILED BY J. Bell	FIGURE NO.
HERN CALIFORNIA EDISON COMPANY	PREPARED BY Jew F.	1
RO, INC. Long Beach California	CHECKED BY M R Ande	
	APPROVED BY	



AGGRADATIONAL STREAM PHASE (Qt$_1$)
AND HIGH SEA LEVEL
~ 120,000 yrs. b.p.

⁘ San Onofre Creek Deposits

▨ Marine Deposits

☐ Tsm – San Mateo Fm.

NOTE: Units are projected onto a single vertical plane; topography is diagrammatic
Vertical scale approximately 1" = 100'
No horizontal scale implied

DIAGRAMMATIC (COMPOSITE) CROSS SECTIONS
SAN ONOFRE CREEK

SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY

FUGRO, INC. Long Beach California

Project No 74-069-02
Date JULY 23 1975
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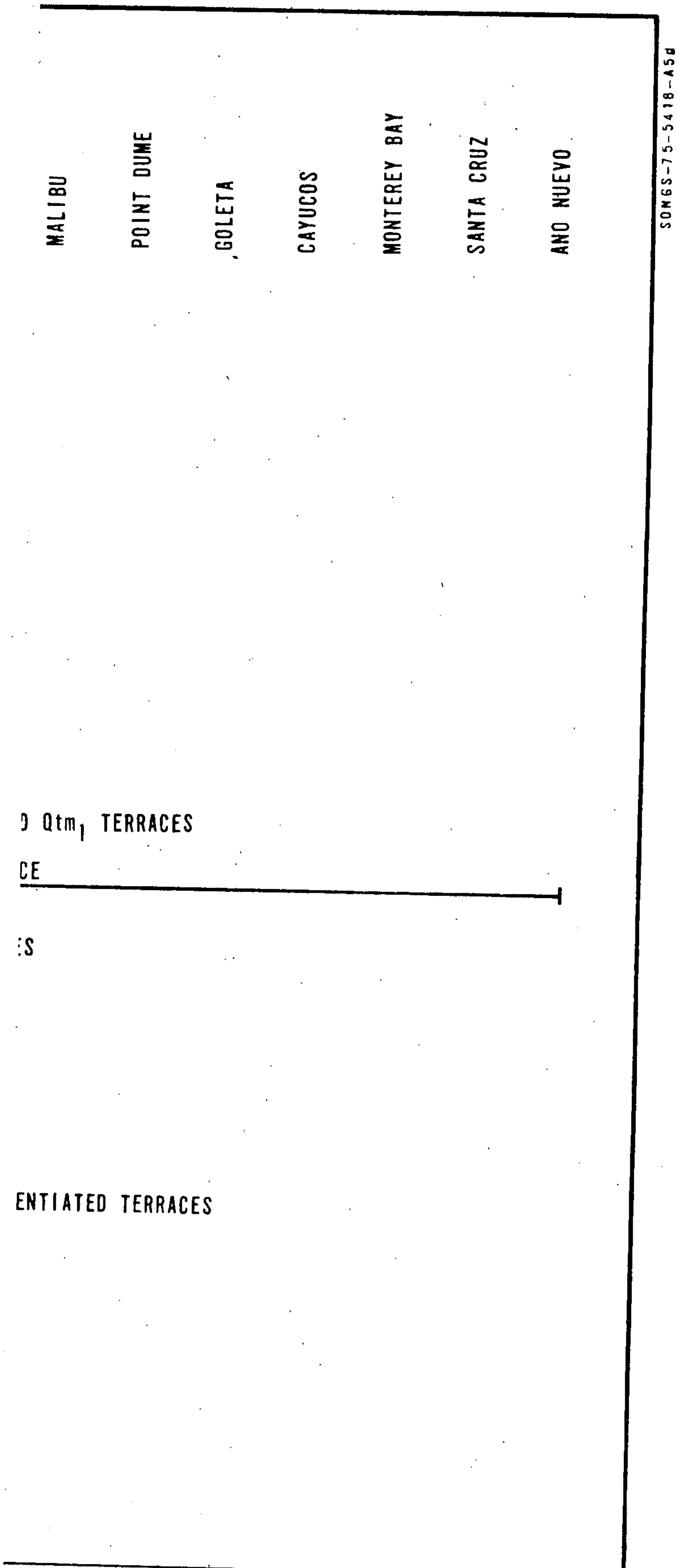
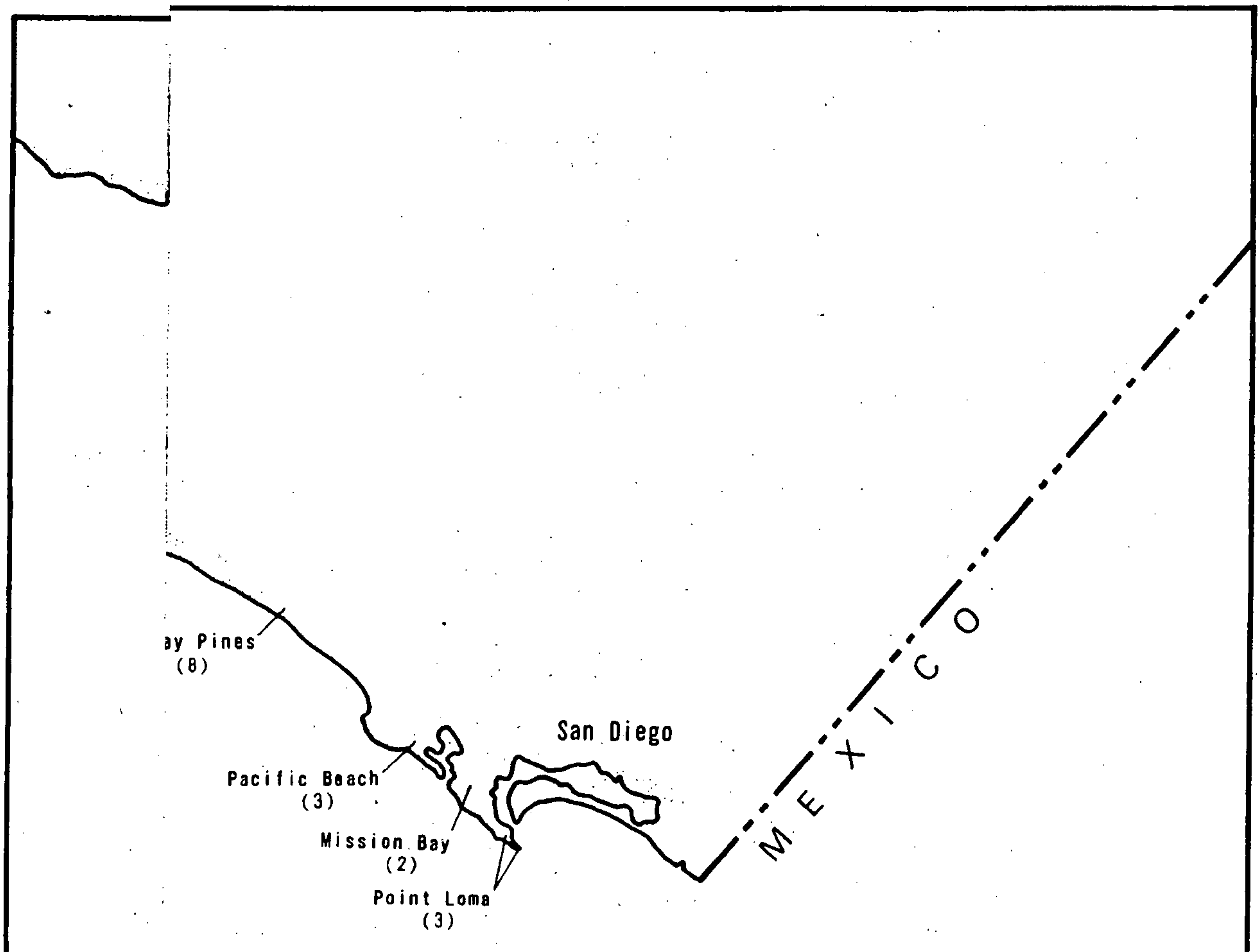
FIGURE NO. 2



MAPPING OF THE SANGAMON TERRACE
ONG THE CALIFORNIA COAST
RE NUCLEAR GENERATING STATION
UNITS 2 and 3
RN CALIFORNIA EDISON COMPANY
RO, INC. Long Beach California

Project No. 74-069-02	
Date JULY 23, 1975	
OMPILED BY J. Bell	FIGURE NO.
PREPARED BY Tug F.	3
CHECKED BY	
APPROVED BY	



NOTE: Number in parentheses indicates table containing data

RADIOMETRIC DATA SITES ALONG
THE CALIFORNIA COAST

SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 and 3
SOUTHERN CALIFORNIA EDISON COMPANY

FUGRO, INC. Long Beach California

Project No 74-069-02
Date JULY 23, 1975
COMPILED BY J. Bell
PREPARED BY
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FIGURE NO.
4

SONGS 75 5420 A4a

ENCLOSURE 2

GEOMORPHIC ANALYSIS OF TERRACES IN SAN JUAN AND BELL CANYONS, ORANGE COUNTY, CALIFORNIA

Prepared for:

SOUTHERN CALIFORNIA EDISON
P.O. BOX 800
Rosemead, California 91770

By:

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

Project No. 74-069-01

September 15, 1975

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Figure No. A-1A   Terraces of the San Juan-Bell Canyon Areas

Figure No. A-1B   Terraces of the San Juan-Bell Canyon Areas

Figure No. A-2   Reconstructed Terrace Profiles, San Juan and Bell Canyons

SCOPE OF STUDY

A detailed geomorphic analysis of stream terraces in San Juan Creek and Bell Canyon and marine terraces at Dana Point was initiated in order to determine recency of movement within the Cristianitos fault zone. Although none of the branches of the Cristianitos fault zone is believed to displace overlying Quaternary stream deposits (Edgington, 1974; Fife, 1974; Morton, 1974; and Morton and others, 1974), absolute ages of these undisturbed Quaternary deposits have been uncertain. Therefore, the scope of this geomorphic study was two-fold:

- To determine, if possible, absolute ages of the Quaternary stream deposits overlying the Cristianitos fault zone by correlating stream terraces with dateable marine terraces.
- To demonstrate the absence or existence of deformation of the stream terrace profiles extending through the Cristianitos fault zone.

The Cristianitos fault zone extends north from the San Onofre bluffs to Santiago Creek traversing several major stream drainages which contain will preserved terrace remnants. Levet (1940) and Oates (1960) attributed these stream terraces to uplift of the Santa Ana Mountain block in the headwater regions of the streams. A review of other current literature suggests that the stream terraces can be related to the series of eustatically-derived marine-cut benches found at elevations of 75 to 600 feet or more along this part of the coast (Edgington, 1974; Morton and Miller, 1973; Palmer, 1967; and Vedder and others, 1957).

If ages can be established through terrace correlation for successive stream levels crossing the Cristianitos fault zone, recency of movement as well as recurrence intervals might be determined. Although the fault zone has not been found to displace Quaternary stream deposits, differential movement could have occurred through general warping. Putnam (1942) found such a relationship along the Ventura River where the Ventura stream terraces exhibit a convex profile downstream owing to general uplift in the central part of the stream profile. An absence of such warping, however, can be demonstrated by identifying consistent downstream terrace altitudes, such as was done by Palmer (1967) along the Santa Ana River.

The San Juan Creek area was selected for investigation for the following reasons:

- Several levels of stream terraces are well preserved and easily identifiable in San Juan Creek.
- Several levels of marine terraces are well preserved and easily identifiable at the mouth of San Juan Creek at Dana Point.
- The marine and stream terraces have been partially differentiated and mapped by previous investigators.

- Dateable material is available in the marine terrace deposits near Dana Point.
- Most of the area is easily accessible.

PREVIOUS INVESTIGATIONS

Stream terraces within San Juan and Bell Canyons were originally recognized by Levet (1940) and later mapped in detail by Oates (1960). More recent work by the California Division of Mines and Geology and the U.S. Geological Survey has provided additional maps and data on the stream and marine terraces (Edgington, 1974; Morton, 1968, 1970, 1974; Morton and Miller, 1973; Morton and others, 1974; Neblett, 1966; and Vedder and others, 1957).

The marine terraces at Dana Point have been previously studied, and the data have been published by Vedder and others (1957), Edgington (1974), Morton and Miller (1973), and Palmer (1967). Much of the field data, however, remain as unpublished information of D. L. Fife of the California Division of Mines and Geology and J. G. Vedder of the U.S. Geological Survey.

A radiocarbon date of greater than 32,600 years (Southern California Edison, 1970, Appendix 2A) was obtained on carbonaceous material from a Trabuco Canyon terrace deposit that is correlative with a similar stream terrace deposit (Qt_4) in San Juan Creek (Oates, 1960). Closed-system and open-system uranium-thorium dates of 146,000 ± 14,000 years and 112,000 ± 12,000 years, respectively, were obtained by Szabo and Vedder (1971) on mollusk shells from the first emergent terrace (Qtm_1) at Dana Point. A compilation of all radiometric data for the first emergent terrace indicates however, that the age of the terrace is approximately 120,000 years (Fugro, 1975).

DESCRIPTION OF UNITS

The terraces that were differentiated for this study are shown on Figures A-1A and A-1B.

San Juan Creek originates in the Santa Ana Mountains, flows in a general southwesterly direction, joins with Trabuco Creek at San Juan Capistrano and debouches into the Pacific Ocean at Dana Point. San Juan Creek is a consequent stream that is apparently uncontrolled by any underlying geologic structure. Several of its tributary streams, however, are subsequent streams that have contributed to a rectangular or trellis network within the San Juan Creek drainage. Bell Canyon, Cañada Gobernadora, and Cañada Chiquita flow remarkably straight to the south where they are right-angle tributaries to San Juan Creek. Their straightness and parallelism is probably due to some underlying geologic structural control. The courses are aligned with the strike of the underlying sedimentary beds and may be influenced by lithologic differences within the underlying units.

San Juan Canyon and Bell Canyon display four to six levels of paired and unpaired, fill terraces overlying Cretaceous and Tertiary bedrock. The terraces are developed on the Cretaceous Williams Formation, and the Tertiary Silverado, Santiago, Topanga, San Onofre, Monterey, and Capistrano formations. The terraces range in altitude from approximately 25 feet to as much as 400 feet above the present stream level (Figures A-1A and A-1B). The best developed terrace level (Qt_4) is about 60 percent perserved; the Qt_3 level is about 30 percent preserved; the Qt_2 level is about 10 percent preserved; and the other terrace levels are less than 10 percent preserved. The youngest and lowest terrace (Qt_5) is included on Figures A-1A and A-1B, but it is not included on the profile or in the following discussion. It is found at elevations of 20 feet or less above the present stream level and may be part of the recent floodplain (Holocene age). It is also poorly preserved because it has been destroyed in many areas by man-made activities.

Although some of the best preserved remnants are found on the east side of San Juan Creek upstream from the confluence with Bell Canyon, the terrace remnants in Bell Canyon were used in the profile reconstruction because they are more numerous and more laterally extensive.

The degree of preservation of individual terrace remnants is variable, but, in general, the lower levels (Qt_3, Qt_4) possess the best preserved remnants. The older and higher remnants are more dissected and less extensive than the lower ones. Terrace levels Qt_3 and Qt_4 are the dominant levels. They are generally flat-crested and commonly exhibit gently sloping surfaces. The slope of their tread is largely colluvial cover generated from the adjacent slopes. The remaining levels above Qt_3 are more dissected and more undulatory.

All of the stream terraces are fill type terraces with as much as 50 to 60 feet of alluvium comprising the fill. Each level consists of a separate deposit capping a bedrock bench.

No discernable difference was found in the lithologic composition of the terrace deposits. All levels contain a bouldery gravel (igneous and metamorphic boulders as much as 3 to 4 feet in diameter) within a red-brown sandy matrix. The alluvium is poorly sorted, crudely stratified, sub-angular to sub-rounded, and moderately to well consolidated. The gravel is locally covered by 5 to 10 feet of overbank silt, containing remnant B_2 and B_3 soil horizons, and colluvial silt.

The marine terraces (Qtm_1, Qtm_2, Qtm_3, Qtm_4, Qtm_5) near Dana Point are wave-cut benches, overlain by marine and non-marine deposits, occurring at elevations of approximately 100-150, 200-280, 300-320, 340-380 and 380-440 feet above sea level. The shoreline angle elevations of the lower two terraces (Qtm_1, Qtm_2) are 150 and 280 feet, respectively. These marine benches were formed by prolonged wave erosion of the bedrock and therefore truncate the underlying faulted and tilted Capistrano Formation. The lower terraces (Qtm_1, Qtm_2, Qtm_3) are flat to steeply seaward-sloping benches, whereas the higher terraces (Qtm_4, Qtm_5) are moderately well dissected and cap only the high ridge crests.

The lower three marine terraces (Qtm_1, Qtm_2, Qtm_3) contain ten feet or more of marine sand and silt and gravelly sand interfingered with a variable thickness of stream deposits. The marine sand is gray, crudely stratified, moderately consolidated, and fossiliferous, containing a basal bouldery gravel about one foot thick. The silt is a red-brown, non-stratified, moderately consolidated, fossiliferous estuarine deposit. The stream terrace deposits are similar to those found in San Juan Creek. At the mouth of San Juan Creek along Del Obispo Road, stream deposits interfinger with a red-brown fossiliferous sandy silt that is an estuarine deposit (Fugro, 1975, Plate 3).

PROCEDURE

In order to accurately reconstruct terrace profiles across the Cristianitos fault zone downstream to the coastal terraces, it was necessary to determine terrace elevations more precisely than the 20-foot contour intervals on the 7 1/2 minute topographic maps would allow. From the confluence of Bell and San Juan Canyons downstream to the coast, terrace elevations were determined using Orange County Flood Control District topograpic maps of San Juan Creek (2 and 5-foot contour intervals; Orange County Flood Control

District, 1970), and by using a Swedish Paulin barometric altimeter. The altimeter was readable to 2-foot intervals, and measurements were made according to procedures outlined in Hodgson (1970). Base station readings were generally taken at least every hour at established U.S. Geological Survey benchmarks. Readings were temperature corrected and adjusted for diurnal and non-periodic barometric pressure changes. These barometric corrections were double-checked against recorded barometric pressure readings taken at El Toro Marine Weather Station about 10 to 15 miles from San Juan Creek.

Terraces were mapped using published maps and aerial photographs on a scale of 1" = 2000'. Previously mapped terrace deposits were field checked, and it was determined that accurate terrace elevations could be established only by using surfaces that were clearly identifiable on the aerial photographs. Some of the areas previously mapped as terrace materials either contained no recognizable deposits or the deposits occurred without any recognizable surface.

Terraces from the junction of Bell and San Juan Canyons downstream to the coast were field checked and elevations were determined either from Orange County Flood Control District maps or from the barometric altimeter. Points of spot elevation were established in the field by judging which portions of the individual surfaces were the most representative. Colluvial cover, transverse gradient, surface undulation, and man-made alteration were taken into account.

The terraces in Bell Canyon were inaccessible, and elevations were obtained from a 7 1/2 minute topographic map with a contour interval of 20 feet.

A profile line was drawn down the approximate center of Bell and San Juan Creeks (Figures A-1A and A-1B). Terrace locations and elevations were plotted parallel to the stream profile line (Figure A-2).

RESULTS

Summary

The mapped terraces (Figures A-1A and A-1B) and the reconstructed terrace profiles (Figure A-2) in San Juan and Bell Canyons indicate:

- Four major (Qt_1, Qt_2, Qt_3, Qt_4) and three minor (Qt_{2-3}, Qt_{3-4}, Qt_5) terrace levels are present.
- Two terrace profiles (Qt_3, Qt_4) extend undisturbed across the Cristianitos and Mission Viejo fault zones. The higher terraces are not preserved across the fault zones and therefore could not be correlated.
- Two intermediate terrace levels (Qt_{2-3}, Qt_{3-4}) exist through the Mission Viejo fault zone.
- The two dominant terrace levels (Qt_3, Qt_4) correlate to two prominent marine terraces (Qtm_1, Qtm_2) at Dana Point.
- The two dominant terrace levels (Qt_3, Qt_4) rise in

altitude above the present stream level within about 2 miles of the coast.

Discussion

The identifiable stream terrace levels in Bell and San Juan Canyons occur at approximately the following altitudes above the present stream level:

Qt_1	300-400 feet
Qt_2	200-220 feet
Qt_{2-3}	160-180 feet
Qt_3	140-150 feet
Qt_{3-4}	100-110 feet
Qt_4	60 feet
Qt_5	25 feet

The identifiable marine terrace levels at Dana Point occur at approximately the following elevations:

Qtm_1	100-150 feet
Qtm_2	200-280 feet
Qtm_3	300-320 feet
Qtm_4	340-380 feet
Qtm_5	380-440 feet

Only two of the terrace profiles (Qt_3, Qt_4) are continuous along the entire length of the study.

The two upper terrace levels (Qt_1, Qt_2) are preserved only in the upper reaches of the drainage system. Downstream from the confluence of Cañada Gobernadora, no levels above Qt_3 are recognizable, probably owing to a greater degree of dissection in this area. The highest level (Qt_1) is present only as fragmentary exposures at varying altitudes and cannot be used to reconstruct a profile.

At least two intermediate levels (Qt_{2-3}, Qt_{3-4}) are present where the Mission Viejo fault zone crosses San Juan Creek, and these remnants can be used to reconstruct profiles of only about one mile in length. These levels are not recognized anywhere else along the stream system, including the area where the Mission Viejo fault zone cuts across Bell Canyon. The intermediate levels suggest post-terrace movement on the Mission Viejo fault, but they are most probably minor levels formed during a downcutting phase of the stream. This non-tectonic origin is supported by the continuity of both the Qt_4 and Qt_3 levels through the zone.

It was found during the field investigation that Morton (1974) erroneously labeled the terraces upstream from the confluence of San Juan and Bell Canyons. The levels Qt_3 and Qt_2 mapped by Morton should be labeled Qt_4 and Qt_3, respectively. (Morton's unit designations are the same as those used in this report.) They then agree with Oates (1960) and can be correctly plotted on the profile (Figure A-2).

The reconstructed lower terrace profiles (Qt_3, Qt_4) are continuous and undisturbed across the Cristianitos fault zone. Terrace remnants are physically preserved on either side of the fault zone, and the continuity of the projected terrace profiles indicates that no discernible faulting, warping, or tilting has occurred in the vicinity of the fault. The profiles remain parallel to the present stream level throughout the length of the traverse until within about two miles of the coast. At the confluence of Trabuco and San Juan Creeks, the dominant terrace level (Qt_4) begins to rise in altitude above the present stream level from 60 feet to over 100 feet. An apparent rise, as reflected in the altitude of the last downstream Qt_4 remnant (Figure A-2), is due to the preservation of only the higher portions of the terrace. Downstream from the confluence of San Juan and Trabuco Creeks, the terrace remnant has been eroded back so that generally only the higher portions of the transverse tread gradient remain.

The Qt_3 level rises from 140 feet above the present level to over 200 feet. The last downstream Qt_3 remnant (Figure A-2) occurs at a slightly lower altitude than the adjacent Qtm_2 marine bench. This may be due to the stripping of the upper fine-grained part of the terrace deposit.

The two lower terrace levels (Qt_3, Qt_4) can be reasonably correlated with the two lower marine terrace levels, (Qtm_1, Qtm_2) at Dana Point on the basis of projection of profiles (Figure A-2) and mapping (Figure A-1A). The non-marine terrace profiles can be projected to the corresponding marine benches at the mouth of the stream, and the stream terraces can be traced laterally downstream into the marine terraces. This lateral continuity is supported by a similar marine and non-marine terrace correlation in San Onofre Creek (Fugro, 1975). No other marine benches exist within the range of these lower stream terraces.

The higher stream terraces (Qt_2, Qt_1) are not well enough preserved to allow reconstruction to the coast, but they are probably related to the higher marine levels (Qtm_3, Qtm_4, Qtm_5).

Slight warping of the Qt_4 stream terrace near San Juan Capistrano is suggested by the anomalously high elevation of the lower marine platform (Qtm_1) at Dana Point. The Qtm_1 bench has a shoreline angle elevation of approximately 150 feet at Dana Point and appears to range up to an elevation of 180 feet north of Dana Point along Pacific Coast Highway. This same marine terrace can be traced continuously to the south where at San Onofre Nuclear Generating Station the abrasion platform is approximately 55 feet above sea level.

The multiple marine platforms in the Dana Point area are all apparently warped over the anticlinal structure of the San Joaquin Hills (J. G. Vedder, U.S. Geological Survey; D.L. Fife, California Division of Mines and Geology, 1975, oral communication). The marine terraces rise in elevation south along the coast from Laguna Beach, reach a peak in the Dana Point area, and descend toward San Clemente.

The age of the lowest emergent marine platform at Dana Point (Qtm_1) and at SONGS (Qt_1) is Sangamon (Fugro, 1975). The generally accepted world-wide elevation of the Sangamon-age high sea level stand is approximately 30 feet (Flint, 1971), as determined in tectonically stable areas. This suggests that the Qtm_1 terrace has been subjected to regional uplift or hydro-isotatic warping such as the Nestor Terrace at San Diego has undergone (Ku and Kern, 1974).

The absolute age of the first marine terrace (Qtm_1) has been shown to be approximately 120,000 years (Fugro, 1975). This marine terrace can be correlated with similar terraces along the California coast that have been radiometrically dated.

A correlation of the Qt_4 level with the Qtm_1 level (Figure A-2) indicates that the Qt_4 terrace is 120,000 years old. This age is supported by the remnant B_2 and B_3 soil horizons which indicate a Sangamon age or older. The Qt_3 stream terrace is graded to the Qtm_2 marine level, but this marine level has not as yet been absolutely dated. It is, however, perhaps, on the order of 200,000 years old since the emergent, eustatically-derived benches were apparently formed at approximately 100,000 year intervals, as interpreted from oxygen isotope data (K. R. Lajoie, U.S. Geological Survey, 1975, oral communication). This age is supported by a mollusk sample from the Qtm_2 level at Newport Beach that yielded a uranium-thorium closed-system age of 350,000± 80,000 years and an open-system age of 192,000 ±

40,000 years (Szabo and Vedder, 1971).

CONCLUSIONS

- Two dominant stream terrace levels (Qt_3, Qt_4) can be traced down San Juan and Bell Canyons. The profiles are continuous and undisturbed through the Cristianitos fault zone. No discernible warping, tilting, or faulting of levels Qt_3 or Qt_4 has occurred and no intermediate terrace levels are present through the zone.
- Stream terrace levels Qt_4 and Qt_3 are graded to marine terrace levels Qtm_1 and Qtm_2, respectively. However, both terrace systems are apparently warped in the Dana Point area (about 12 miles from the site) where the marine terraces are arched over the San Joaquin Hills anticlinal structure.
- Terrace levels Qt_4 and Qtm_1 are of Sangamon age---approximately 120,000 years old---based on recent compilations of geomorphic and age data (Fugro, 1975). No discernable tectonic movement has therefore occurred through the Cristianitos fault zone in the last 120,000 years.

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GLOSSARY OF TERMS

abrasion platform - See "terrace".

bench - See "terrace".

consequent stream - Stream that develops across terrain in response only to trend and relief of terrain.

diurnal - Daily; i.e., daily fluctuation.

esturary - Brackish, back-water environment at mouth of stream where stream empties into ocean. This condition presently exists and has periodically existed in the past as interglacial sea levels rose and marine waters flooded the mouths of the deeply incised streams.

eustatic - Change in sea level relative to land derived from fluctuation of the ocean, as opposed to tectonic fluctuation.

fill terrace - See "terrace".

platform - See "terrace".

Sangamon age - Interglacial period from about 75,000 to 125,000 years ago, immediately preceeding last glacial period.

shoreline angle - Break in slope at rear, landward edge of marine terrace where the flat surface of the terrace (tread) meets the sea bluff (riser).

strath - See "terrace".

subsequent stream - Stream that develops its course in response to underlying geologic structure in bedrock;

transverse gradient - Gradient, or slope, of terrace surface, perpendicular to course of stream (or wave) flow at time of terrace formation.

tread - Upper, flat, gently sloping surface of a terrace; bounded at head and toe by terrace scarps or "risers".

wave-cut platform - See "terrace".

NATION

ary stream terraces; flat-crested with
sloping and gently undulatory surfaces.
ing deposits consist of red-brown, poorly
subangular to subrounded, moderately to
nsolidated bouldery gravel.

nate heights of stream terraces above
stream level:

300-400 Feet

200-220 Feet

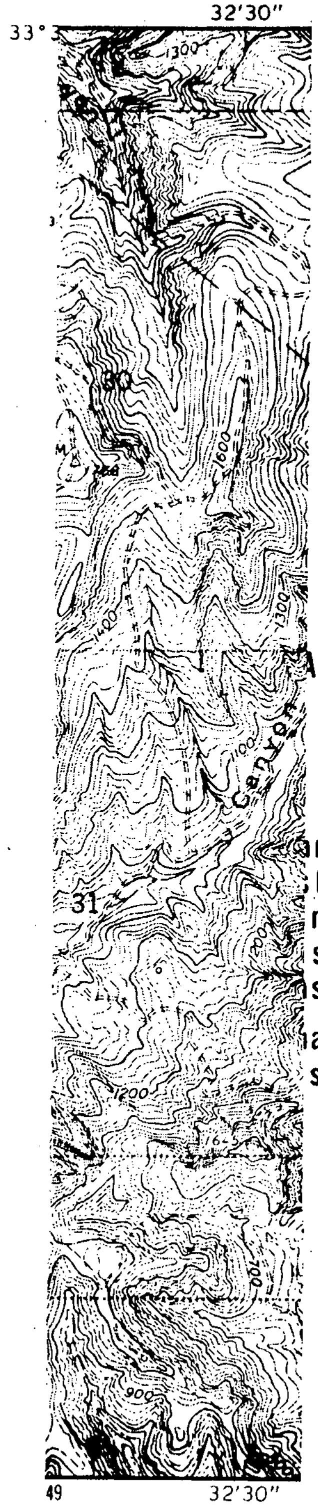
160-180 Feet

FUGRO

TERRACES OF THE
SAN JUAN-BELL CANYON AREAS

FIGURE NO.:
A-1A

JECT SAN ONOFRE NUCLEAR SITE SDG&E 74-069-01



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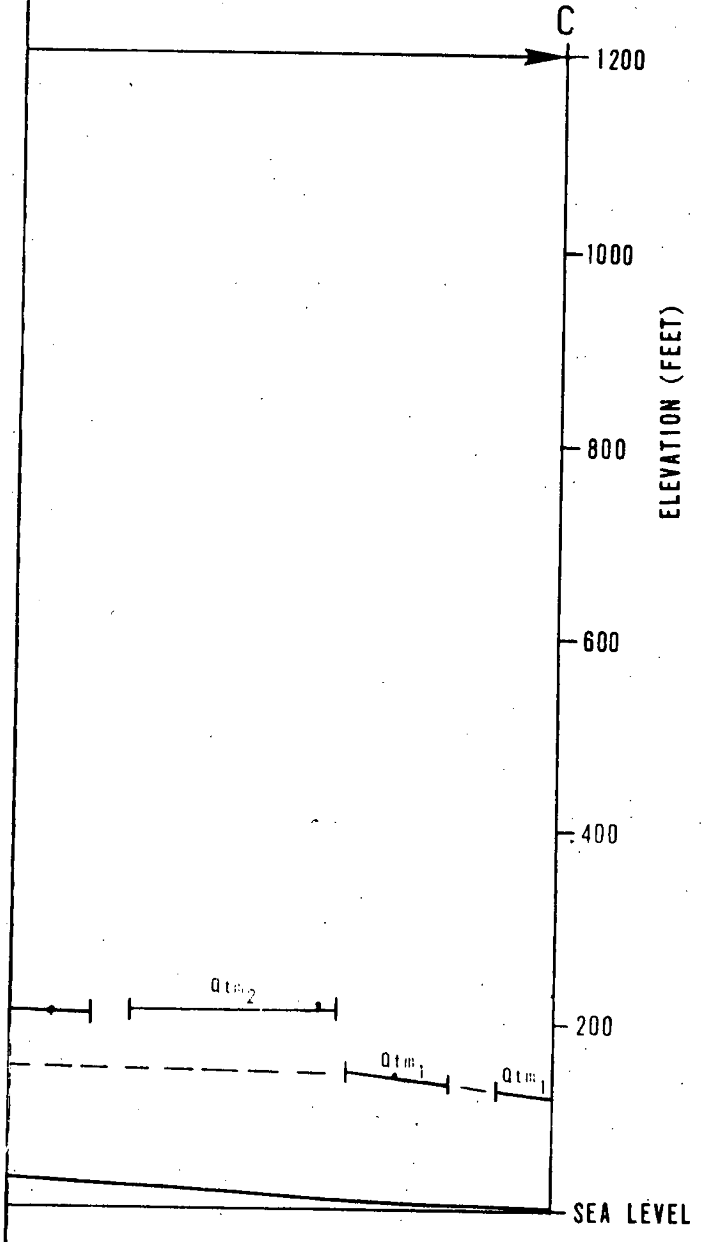
FUGRO

. TERRACES OF THE
SAN JUAN–BELL CANYON AREAS

FIGURE NO.:
A–1B

ECT SAN ONOFRE NUCLEAR SITE   SDG&E 74–069–01



D BY J. Bell 5/18/75
ED BY AL SMITH 5-19-75
D BY J. Bell 5/20/75
ED BY PDavis 6-5-75

RECONSTRUCTED TERRACE PROFILES
SAN JUAN AND BELL CANYONS

PROJECT SAN ONOFRE NUCLEAR SITE SDG&E 74-069-01

FUGRO

FIGURE NO.: A-2