San Onofre

Nuclear Generating Station

Units 2 and 3

LATE CENOZOIC STRATIGRAPHY

CAPISTRANO EMBAYMENT COASTAL AREA,

ORANGE COUNTY, CALIFORNIA

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A EDISON COMPANY

LECTRIC COMPANY

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& Assoc., Inc.
P.O. Box 3066
Newport Beach, California 92663

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CAPISTRANO EMBAYMENT COASTAL AREA,

ORANGE COUNTY, CALIFORNIA

for

SOUTHERN CALIFORNIA EDISON COMPANY

&

SAN DIEGO GAS & ELECTRIC COMPANY

by

Roy J. Shlemon

Roy J. Shlemon & Assoc., Inc.
P.O. Box 3066
Newport Beach, California 92663

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INTRODUCTION

Purpose

This study is commissioned by the Southern California Edison Company (SCE) to analyze the regional geology north and northwest of the San Onofre Nuclear Generation Station (SONGS). Of particular interest is determining the probable last time of displacement of faults known to offset Tertiary sediments in the coastal part of the Capistrano Embayment between SONGS on the south and Dana Point on the north (Fig. 1). These faults, informally designated Dana Point, "Vaciadero," and "Carr" are interpreted by West (1975, 1979), to displace the Tertiary Monterey and possibly the lower part of the overlying Capistrano Formation.

A fundamental question is whether or not fault movement continued into late Quaternary time. This can be answered by identifying the presence, extent, and possible deformation of late Cenozoic stratigraphic markers in the Capistrano Embayment coastal area. Accordingly, the major objectives of this study are:

(1) To determine the presence and extent of late Cenozoic stratigraphic markers in the coastal portion of the Capistrano Embayment;

(2) To ascertain the age of these markers (a) by synthesizing literature pertaining to direct dating, namely, amino-acid stereochemistry and radiometric assay, and (b) by indirect or relative dating of marine deposits by faunal association, and (c) by correlating fluvial terrace sediments and geomorphic surfaces with glacio-eustatic sea level changes; and

(3) To assess, within the resolution of field measurement, possible displacement of the Capistrano Embayment markers by the Dana Point Fault, "Vaciadero Fault", and "Carr Fault" as mapped by West (1975, 1979).

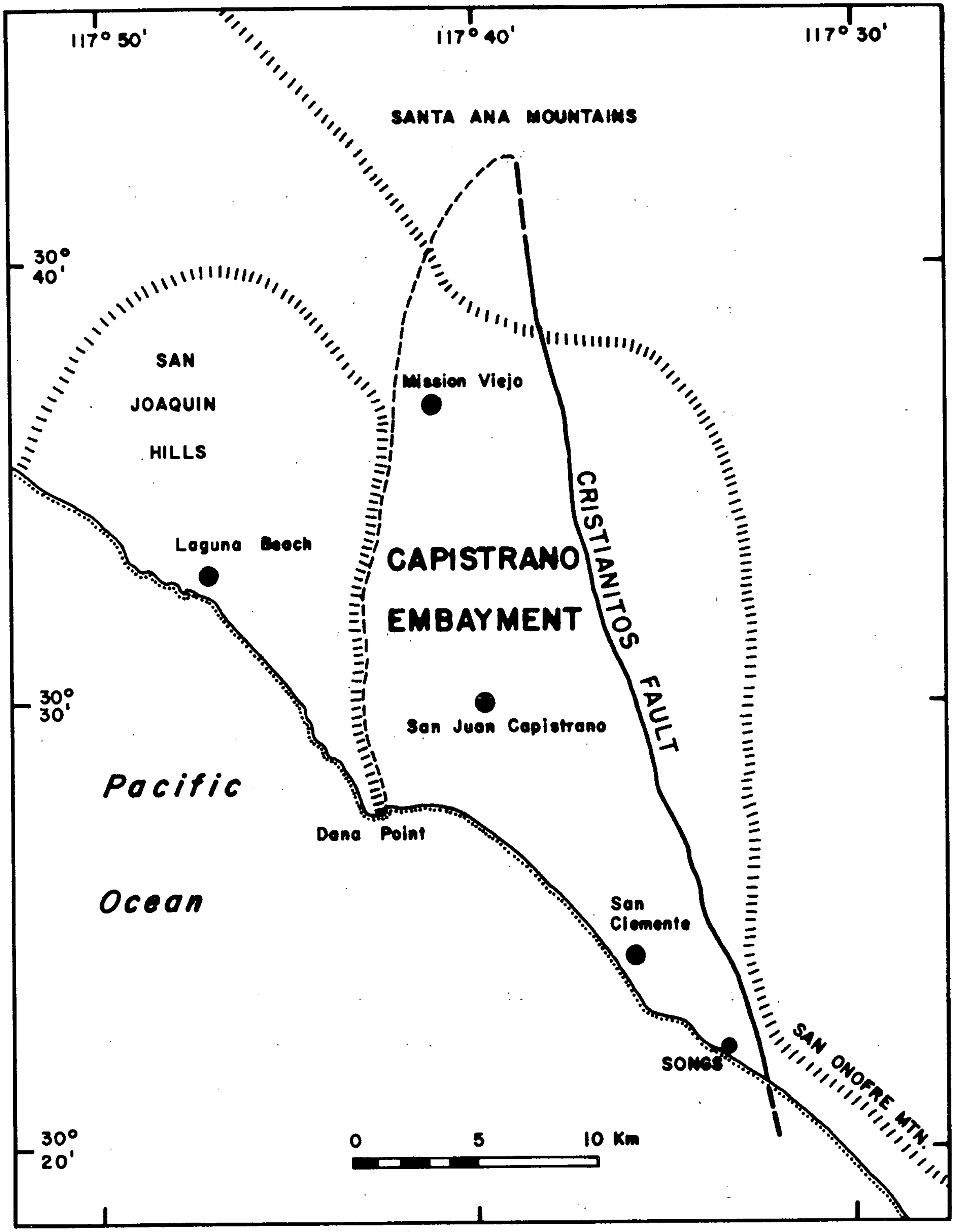


FIGURE 1 - Location map of the Capistrano Embayment. (after Ehlig, 1979).

Summary of Conclusions

(1) Late Cenozoic markers useful to date last movement of faults in the coastal part of the Capistrano Embayment are the (a) Tertiary Capistrano Formation (upper part), (b) 125,000 year old Terrace 1 platform and its shoreline-angle elevations, (c) 60,000 - 70,000 year old fluvial fill terrace deposits bordering San Juan, San Mateo and San Onofre creeks, (d) 17,000 - 20,000 year old buried channels underlying the San Juan, San Mateo, and San Onofre Creek floodplains, and (e) the post-125,000 year old buried paleosols within piedmont fan and debris flow deposits mantling the Terrace 1 platform.

(2) The Terrace 1 platform has been tilted up to the north between SONGS and Dana Point in late Quaternary time.

(3) The Dana Point Fault displaces the Tertiary Capistrano Formation, but not the 125,000 year old Terrace 1 platform deposits.

(4) The "Vaciadero Fault" and "Carr Fault" do not displace the probable upper Capistrano Formation nor, accordingly, the overlying Quaternary marine terrace and continental deposits.

(5) Last faulting in the coastal portion of the Capistrano Embayment, between Dana Point and SONGS, occurred before about 125,000 years ago.

Acknowledgements

In addition to literature synthesis and field observations, this study benefited greatly from personal communication with others who have mapped in the Capistrano Embayment. Particularly beneficial were the comments of J. West (consulting geologist, Fullerton, California) and P. Ehlig (California State University, Los Angeles). Logistical support was furnished in part by the Southern California Edison Company. Greatly appreciated is the assistance of J. L. McNey, SCE Senior Engineering Geologist.

Previous Investigations

The geology of the Capistrano Embayment has been described in detail by Vedder and others (1957, 1975), Ingle (1962, 1971), and most recently by Ehlig (1977, 1979). These studies have dealt mainly with Capistrano Embayment structural evolution and sedimentary history. Detailed mapping (scales 1:24,000 and 1:48,000) also appear in several reports of the California Division of Mines and Geology (cf., Blanc and Cleveland, 1968; Cleveland, 1975; Edgington, 1974; Fife, 1974; Miller and Tan, 1976; Morton, 1974; and Morton and others, 1973, 1974). These maps and accompanying text describe well the Tertiary section, but in lesser detail the Quaternary fluvial and marine terrace deposits. Late Quaternary stratigraphic sequences and rates of deformation between Camp Pendleton, south of SONGS (Fig. 1), and Laguna Beach are given by Schlemon (1978a, 1978b, 1979).

Scope of Investigation

The data and interpretations presented in this study devolve from two main sources:

(1) Assessment of published literature and unpublished consultants' reports pertaining to the extent and age of late Cenozoic sediments in the coastal portion of the Capistrano Embayment; and

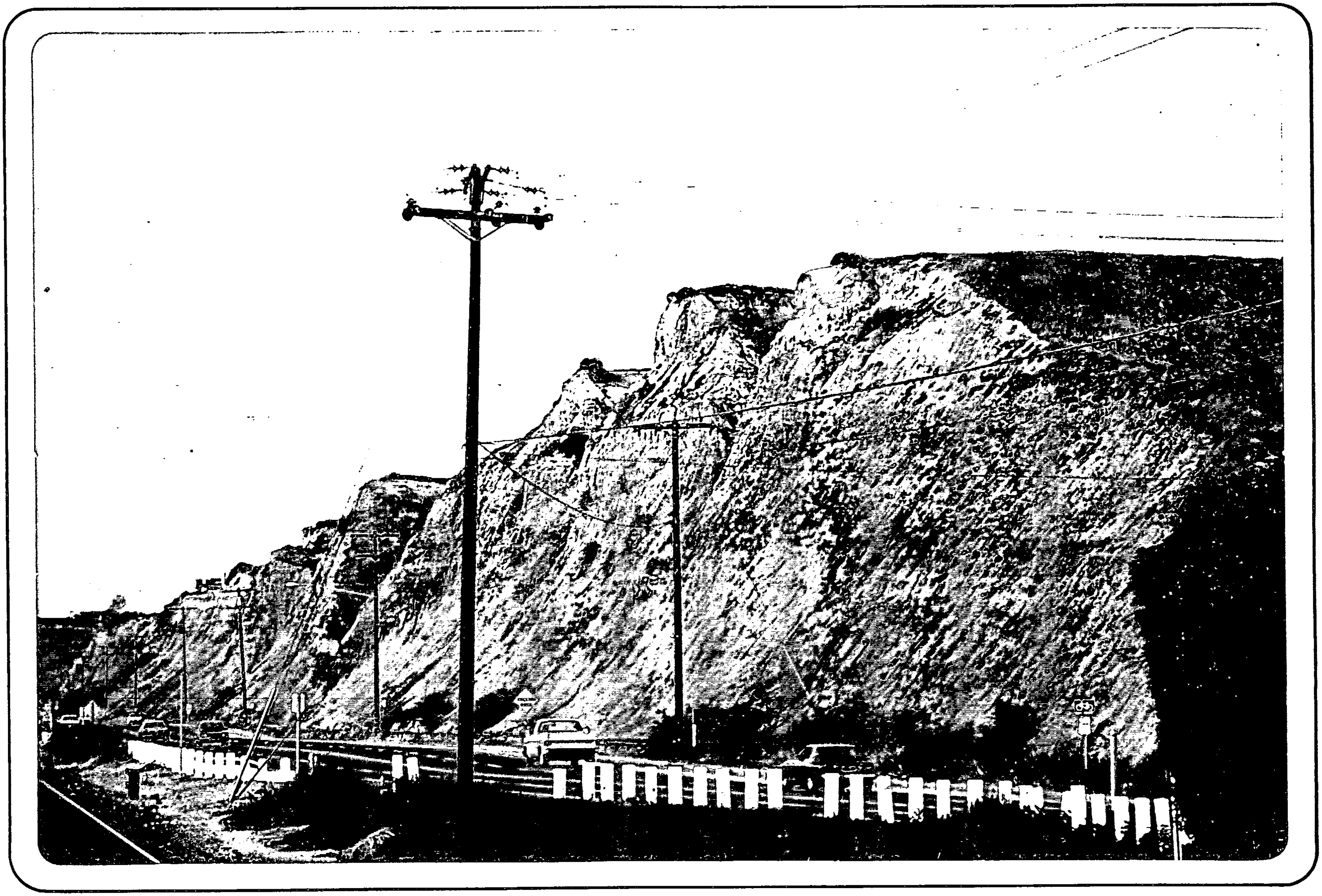


Fig. 2 - Gently dipping but undisplaced Tertiary Capistrano Formation, north side Pacific Coast Highway; north San Clemente area (Poche, Fig. 3). The Terrace 1 platform and overlying marine and continental sediments crop out near top of bluff.

CENOZOIC MARKERS FOR ASSESSING AGE OF FAULTING

Tertiary Sediments

The Capistrano Embayment originated as a submarine trough about 10 million years ago (mya), and has received sediments from upper Miocene through lower Pliocene time. According to the mapping of Vedder and others (1975), and as summarized by Ehlig (1979), the Tertiary Monterey Formation ranges in age from about 10 to 14 million years. The top of the overlying Capistrano Formation, laid down at a depth of about 900 metre (m) some 10 to 4 mya, has been slowly uplifted from original bathyal environments to an elevation about 200 m above sea level near the present coast.

Both the Monterey and Capistrano formations crop out in coastal bluffs and in many stream and arroyo cuts between SONGS and Dana Point. As shown in Fig. 2, these Tertiary sediments are only slightly deformed with dips generally less than 15 degrees. Except at Dana Point where the Dana Point Fault of West (1975, 1979; Fig. 3, 4, juxtaposes the San Onofre Breccia and Capistrano Formation (Morton and others, 1973), no other through going faults are known to displace coastal sediments of Tertiary age.

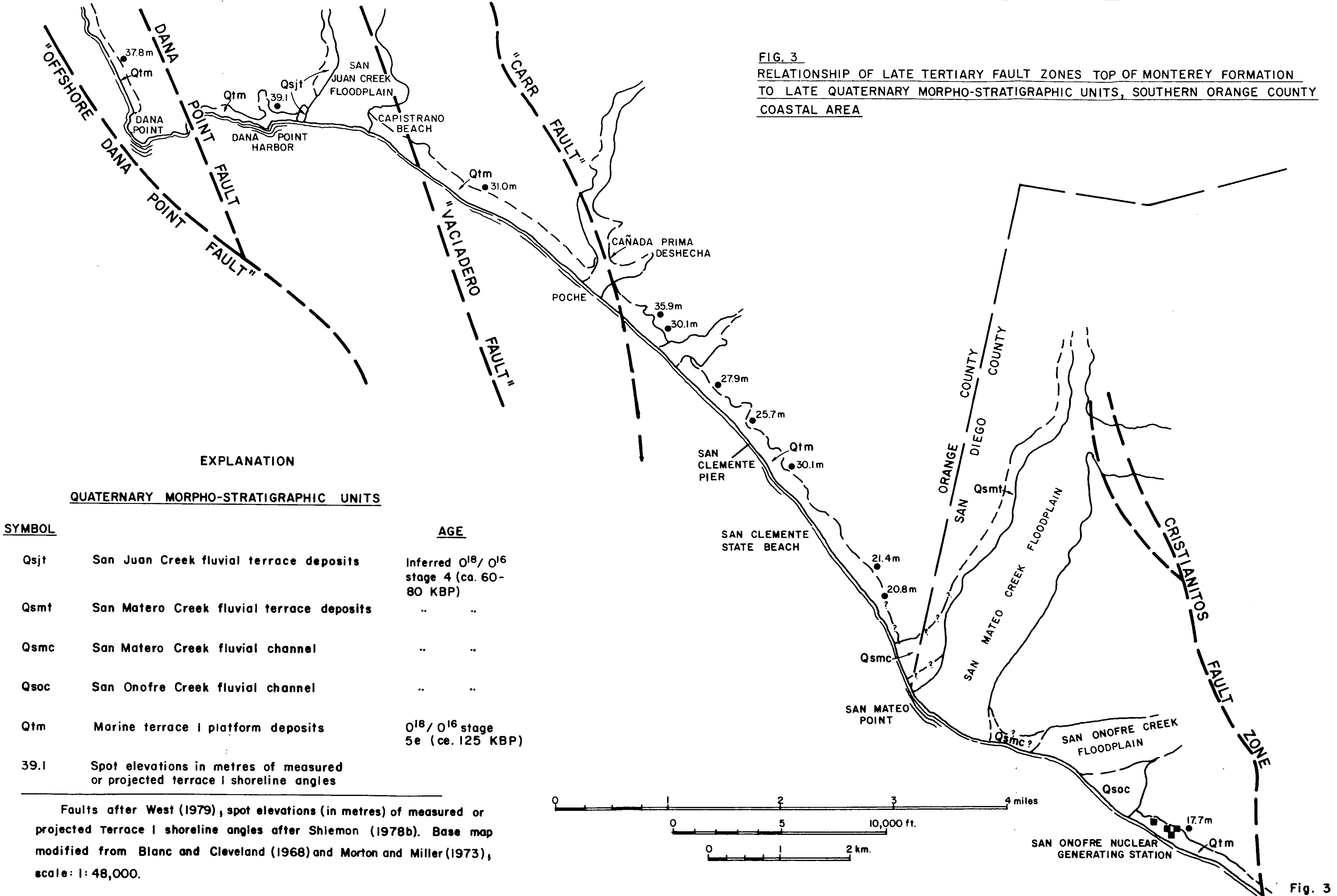
Clear offset of the Tertiary section is best observed about one kilometre (km) south of SONGS 2&3 in sea cliffs where the Cristianitos Fault (Fig. 3) adjoins the Monterey shale and the San Mateo sandstone (member of the Capistrano Formation; Ehlig, 1977, 1979). Last movement of the Cristianitos Fault, however, occurred more than about 125,000 years ago (Shleman, 1978a).

Late Quaternary Fluvial and Marine Terrace Deposits

Several late Quaternary stratigraphic markers are present, both locally and

(2) Specific field checks of coastal bluffs and related exposures that trend across projections of Dana Point Fault, "Vaciadero Fault," and "Carr Fault" as mapped by West (1975, 1979).

FIG. 3
RELATIONSHIP OF LATE TERTIARY FAULT ZONES TOP OF MONTEREY FORMATION TO LATE QUATERNARY MORPHO-STRATIGRAPHIC UNITS, SOUTHERN ORANGE COUNTY COASTAL AREA



EXPLANATION

QUATERNARY MORPHO-STRATIGRAPHIC UNITS

SYMBOL		AGE
Qsjt	San Juan Creek fluvial terrace deposits	Inferred O^{18}/O^{16} stage 4 (ca. 60-80 KBP)
Qsmt	San Matero Creek fluvial terrace deposits	.. ..
Qsmc	San Matero Creek fluvial channel	.. ..
Qsoc	San Onofre Creek fluvial channel	.. ..
Qtm	Marine terrace I platform deposits	O^{18}/O^{16} stage 5e (ce. 125 KBP)
39.1	Spot elevations in metres of measured or projected terrace I shoreline angles	

Faults after West (1979), spot elevations (in metres) of measured or projected Terrace I shoreline angles after Shlemon (1978b). Base map modified from Blanc and Cleveland (1968) and Morton and Miller (1973), scale: 1: 48,000.

Fig. 3

regionally, to date the probable last movement of the Dana Point Fault and "Vaciadero Fault" and "Carr" Fault". The most extensive is a wave-cut platform and overlying marine sediments of the first emergent terrace (Terrace 1), traced almot continuously for 25 km between Camp Pendleton and Dana Point (Shlemon, 1978b, 1979). Younger Quaternary markers are less extensive, mainly local fluvial terrace and buried channel deposits of San Juan, San Mateo and San Onofre creeks (Fig. 3).

Terrace 1 Platform and Shoreline Angle Elevations

The Terrace 1 platform was cut during a glacio-eustatic high-stand of sea level about 125,000 years ago (marine oxygen-isotope stage 5e; Shlemon, 1978a, 1978b). The shoreline angle elevation of this platform was originally 6 to 10 m above above the present, but now rises northward from about 17 m near SONGS to 39 m at Dana Point (Unit Qtm, Fig. 3; Shlemon, 1978b).

The platform is exposed continuously in sea cliffs south of SONGS but less so northward toward Dana Point. Exposures are sufficient, however, to project the platform across bluffs now urbanized or where breached by younger streams, particularly San Juan, San Mateo and San Onofre creeks (Figs. 3 and 4).

From measurement of shoreline-angle elevations, deformation of the "late Sangomonian" Terrace 1 platform (up-to-the-north tilt) ranges from approximately 9 cm/1,000 years near SONGS to 26 cm/1,000 years at Dana Point, apparently related to continuing tectonism in the San Joaquin Hills and Laguna Beach area (Fig. 1; Shlemon, 1978b, 1979).

Fluvial Terrace Deposits

Fluvial terrace deposits flanking major coastal streams in the Capistrano Embayment (San Juan, San Mateo and San Onofre creeks, Fig. 3, 5, 5a) also record late Quaternary climatic and related glacio-eustatic sea level change. San Juan and Mateo creeks are bordered by at least one fluvial fill traceable inland at least several km (Fugro, 1975a; Shlemon, 1978a). At San Mateo Creek, in particular, the fluvial terrace is identified seaward to the vicinity of Interstate Highway 5 where it is buried by younger colluvial and debris-flow deposits, but exposed again as a buried channel in bluffs on the north side of San Mateo Point (Unit Qc4, Fig. 5).

No radiometric dates are yet available for these fluvial terraces. However, they bear moderately- to strongly-developed soils indicating a pedogenic age in excess of about 40,000 years (Shlemon, 1978a, Shlemon and Hamilton, 1978). Further, as shown in Figure 5, they are younger than the stage 5e marine platform and, analogous to other gravel-filled channels underlying present floodplains, were likely graded to a glacio-eustatic low stand of sea level some 60,000 to 70,000 years ago (isotope stage 4; "early Wisconsinan"). As deduced from world-wide sea level curves (Shackleton and Opdyke, 1973), the stage 4 low stand was about 80 m below the present and thus both San Juan and San Mateo Creek terrace gravels once extended to a base several km offshore the present coast. Similar to the Terrace 1 platform, these channel gravels have probably been uplifted a few metres by regional tilting within the last 60,000 to 70,000 years.

Fig. 4 - Terrace 1 (First Emergent) platform gravels (near top of bluff) overlying Capistrano Formation near Dana Point. Dana Point Fault, juxtaposing San Onofre Breccia and Capistrano Formation, passes underneath large building (beyond gazebo), top center of photograph.

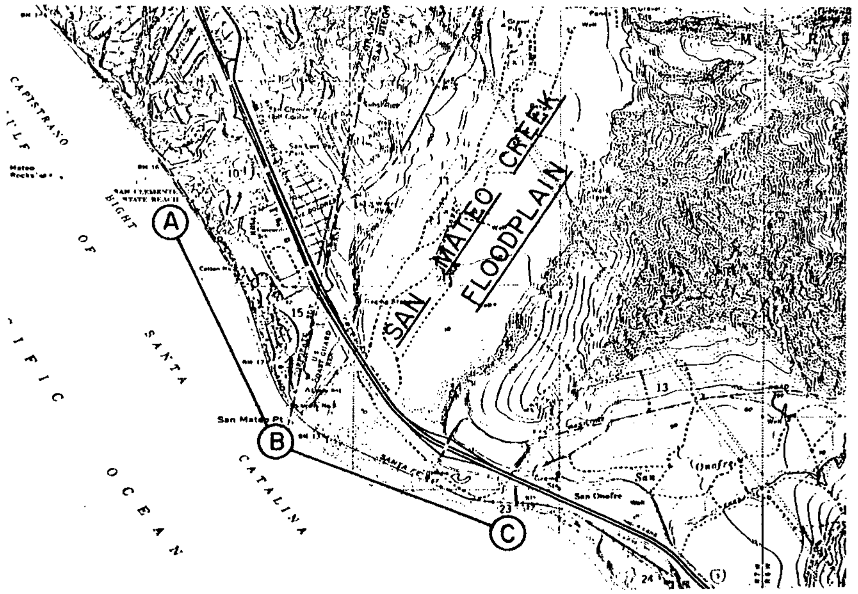
Channel gravels in similar stratigraphic position have likewise incised the Terrace 1 platform south of San Onofre Creek (Unit Qsoc, Fig. 3), and now form the bluffs between SONGS and the San Onofre Creek floodplain (Figs. 3, 5, 5a, and 6). Stratigraphic relationships in this area are particularly instructive, for well exposed here are sediments and soils recording each major late Quaternary climatic/glacio-eustatic sea level change.

As illustrated in Fig. 5a, the 125,000-year old Terrace 1 platform marine gravels and sands, about 2 m thick (Unit Qt5e, Fig. 5), crop out almost continuously in sea cliffs (base elevation 16.8 m) between SONGS and the Cristianitos Fault. From SONGS northward to San Onofre Creek, however, these marine gravels have been incised by younger fluvial gravels laid down by San Onofre Creek (Unit Qc4) during isotope stage 4, some 60,000-70,000 years ago. The San Onofre Creek gravels are especially well exposed in excavations immediately north of SONGS where the base occurs at an elevation of about 13 m (Fig. 5a). The fluvial gravels, recognized in an earlier study (Fugro, 1975b), are distinguished from older (stage 5e) marine deposits mainly by: (1) their thickness, increasing from about 4 m at SONGS Unit 1 to 12 m at the San Onofre Creek source area; (2) smaller size; namely, about 17-18 cm diameter compared with 30-32 cm for the marine gravels; (3) crude imbricate structure; (4) interbedded, poorly-sorted fluvial fine sand and silt lenses; (5) presence of estuarine fossils (Fugro, 1975b, p. 8); and (6) lower elevation and greater contact relief with the underlying Tertiary formation.

The San Onofre Creek-Cristianitos Fault coastal section records yet another diagnostic stratigraphic unit apparently previously unrecognized: a moderately- to strongly-developed buried paleosol formed on San Onofre Creek stage 4 gravels and overbank deposits (Fig. 5a). This buried soil, typified by a strong-brown (7.5YR 5/6), 1.5 m-thick $B2_t$-B3 horizon with strong, coarse blocky structure and many, yellowish-red (5YR 5/6), moderately-thick clay films (cutans) on ped faces, crops out near the top of sea cliffs and in San Onofre State Beach access roads northwest of SONGS Unit 1 (Fig.5a). Intrinsically, the buried soil formed during an epoch of non-deposition (relative landscape stability). Its stratigraphic position between San Onofre Creek fluvial gravels of "glacial age" (stages 2 and 4) suggests formation mainly during stage 3 ("mid-Wisconsinan") about 35,000 to 50,000 years ago (Fig. 5a).

In brief, the gravels cropping out along the southern Capistrano Embayment coastal area have several origins; some are stage 5e marine deposits; others are younger, laid down and reworked in fluvial channels during the stage 4 low stand of sea level. Separating the various gravels may be formidable at any given locality; and thus require reconstructing late Quaternary landscape evolution by analyses of water well logs, of buried and relict paleosols, and of facies changes within coastal gravel sequences (Shlemon, 1978a).

LOCATION OF SECTION



LEGEND

Quaternary Stratigraphic Units

Symbol	Description	Age (approx. years before present)
Qclu	Modern/Holocene gravel channel deposits (upper); San Mateo/San Onofre Creek flood plain.	~ 0 - 5,000
Qcl1	Post-glacial estuarine sediments (Flandrian transgression) ($0^{18}/0^{16}$ stage 1)	~ 5,000 - 17,000
Qc2	Buried channel gravels, San Mateo Creek ($0^{18}/0^{16}$ stage 2)	~ 17,000 - 20,000
Qc4	Fluvial terrace gravel deposits, San Mateo/ San Onofre Creeks; buried near coast ($0^{18}/0^{16}$ stage 4)	~ 60,000 - 70,000
Qnm	Post-stage 5e non-marine (continental) piedmont fan and debris flow deposits with intercalated buried soils	~ 5,000 - 125,000
Qt5e	Regressional marine gravels and sands; fossiliferous; overlying first marine platform ($0^{18}/0^{16}$ stage 5e)	~120 - 125,000
Tc	Capistrano Formation	Tertiary

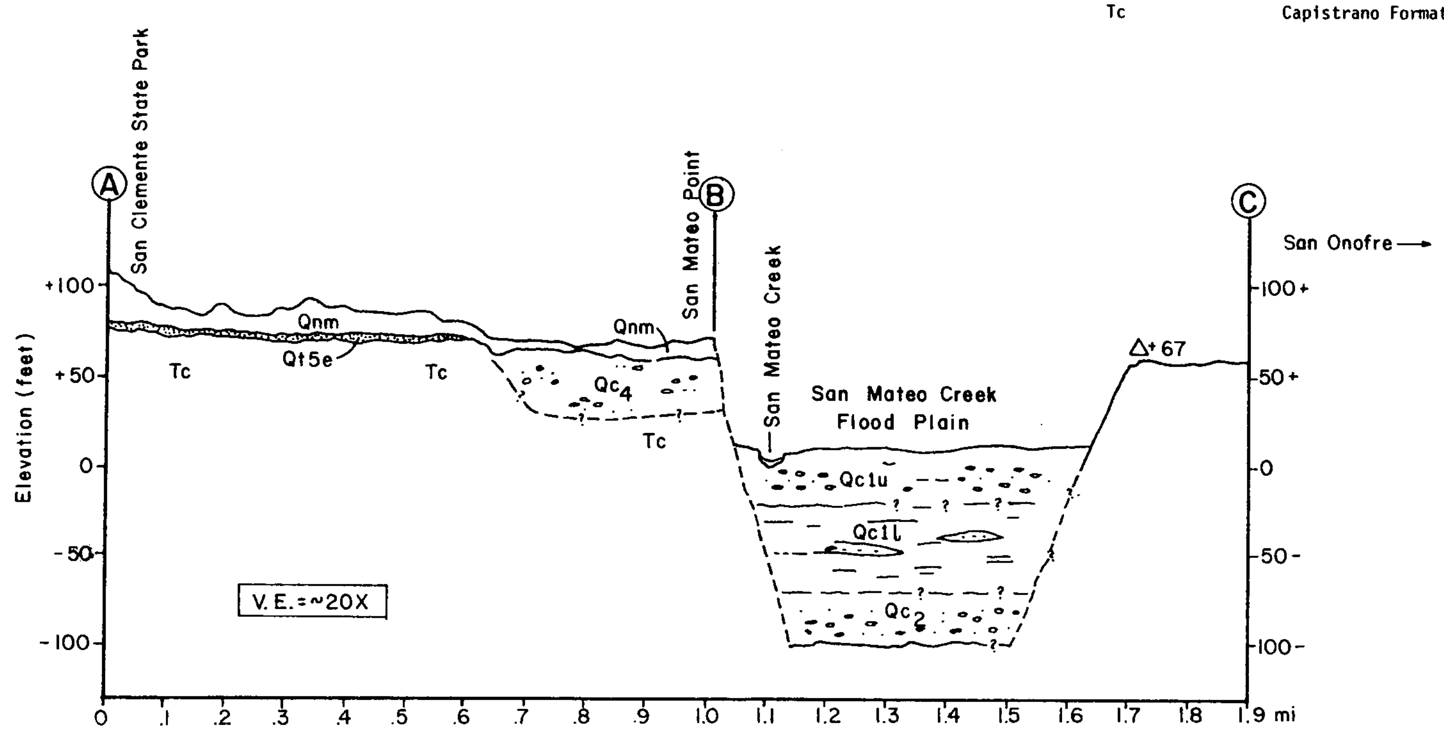


Fig. 5 LATE QUATERNARY CHANNEL, FLUVIAL AND MARINE TERRACE DEPOSITS, SAN MATEO AND SAN ONOFRE CREEK AREA, ORANGE AND SAN DIEGO COUNTIES, CALIFORNIA

Fig. 5

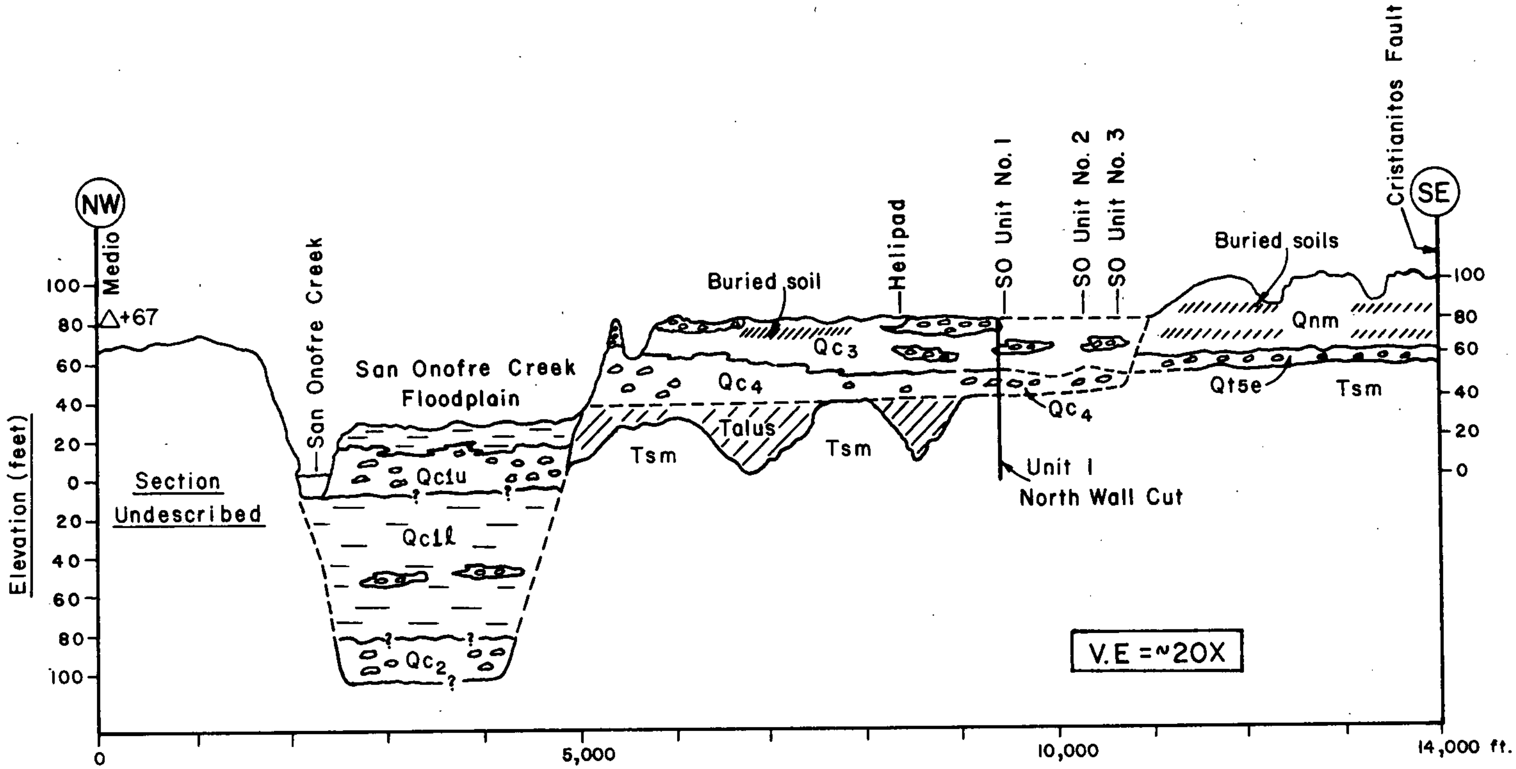


Fig. 5a - Relationship of late Quaternary channel, fluvial and marine terrace deposits, San Onofre Creek - Cristianitos Fault. See Fig. 5 for legend; Tsm = San Mateo Formation. Units Qc3 (ca. 35,000 - 55,000 years BP) and Qc4 exposed in sea cliffs (San Onofre State Beach), railroad cuts, and SONGS Unit 1 excavation (north wall).

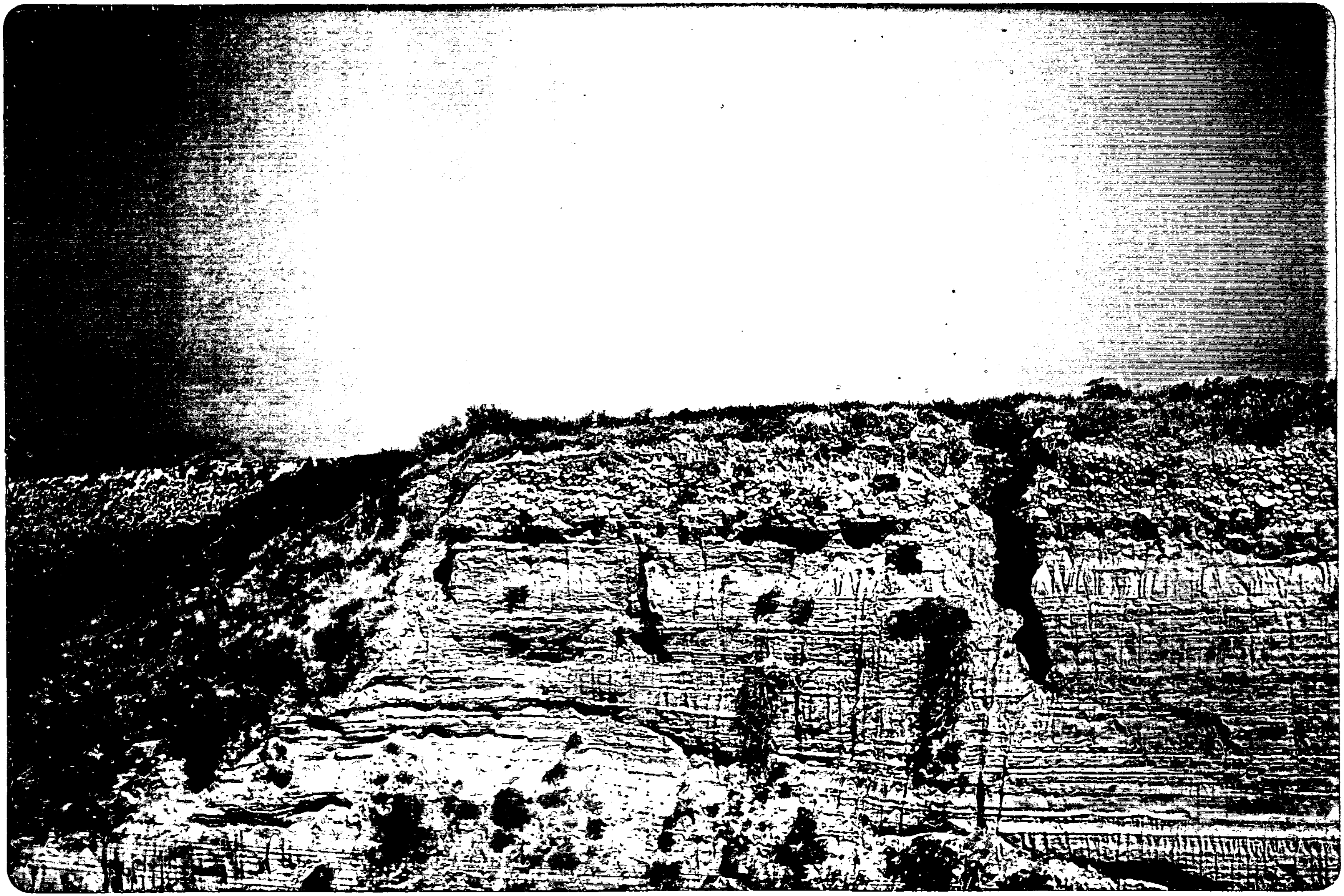


Fig. 6 - Fluvial terrace deposits (isotope stage 4) incised through marine gravels (stage 5), unconformably overlying Tertiary Capistrano Formation between San Onofre and San Mateo creeks.

Buried Channel Deposits

The last major glacio-eustatic low stand of sea level, approximately 17,000 to 20,000 years ago (oxygen isotope stage 2), is recorded beneath the flood plain of San Juan, San Mateo and San Onofre creeks by buried, gravel-filled channels (Fig. 3; Unit Qc2, Figs. 5, 5a). The base of these channels, identified in numerous water well logs, is approximately -30 to -35 m beneath the present coast. The gravels (braided stream deposits) are comparable in stratigraphic position and depth to many others along the southern California coast laid down by ancestral channels of the Los Angeles, San Gabriel, Santa Ana and Santa Margarita rivers (Poland and Piper, 1956; Poland and others, 1959; Shlemon, 1978a).

Post-Stage 5e Buried Paleosols

In addition to late Quaternary depositional units, coastal bluffs in the Capistrano Embayment are typified by non-marine (continental) piedmont fan and debris flows, many separated by buried paleosols. These sediments, overlying stage 5e marine and stage 4 fluvial terrace deposits, are approximately 20 m thick in the San Onofre area. They contain at least six intercalated buried paleosols (Haplic Natrixeralfs), each of which formed within about 5,000 to 8,000 years (Shlemon, 1978a; Shlemon and Hamilton, 1978). These paleosols, though local in extent, are thus excellent stratigraphic markers to determine sediment age and hence time of last movement of faults projected into the area.

North of SONGS the thickness of the continental deposits and frequency of buried paleosols decreases. Nevertheless, particularly in the San Clemente

State Beach area, at least three buried paleosols are present (Shlemon, 1978b, p.18). As exposed in road and trail cuts, none of these post-stage 5e soils has been observed displaced.

RELATIONSHIP OF LATE CENOZOIC FAULTS AND STRATIGRAPHIC MARKERS

The late Cenozoic markers in the coastal part of the Capistrano Embayment best record vertical displacement of faults. The most continuous of these markers are the Tertiary Capistrano Formation, exposed in sea cliffs and cuts of the Pacific Coast Highway, and the late Quaternary Terrace 1 platform.

Of the faults described by West (1975, 1979), only the Dana Point clearly offsets Tertiary sediments. The "Vaciadero" and "Carr" Faults; (inferred at depth), have no surface expression in coastal exposures, particularly those specifically examined for a distance of approximately 500 m on either side of fault projection. And, as spelled out in sections following, these faults do not displace the Terrace 1 platform (Fig. 3).

Dana Point Fault

The Dana Point Fault, displacing the Tertiary San Onofre Breccia and Capistrano Formation, is exposed in bluffs between Dana Point and the Dana Point Harbor (Figs. 3 and 4). Previous mapping (Vedder and others, 1957, 1975; Edgington, 1974) shows that the Fault does not displace overlying Quaternary colluvium. This is borne out by Terrace 1 shoreline angle elevations of about 38 and 39 m north and south, respectively, of Dana Point (Fig. 3) indicating no measureable displacement within at least the last 125,000 years.

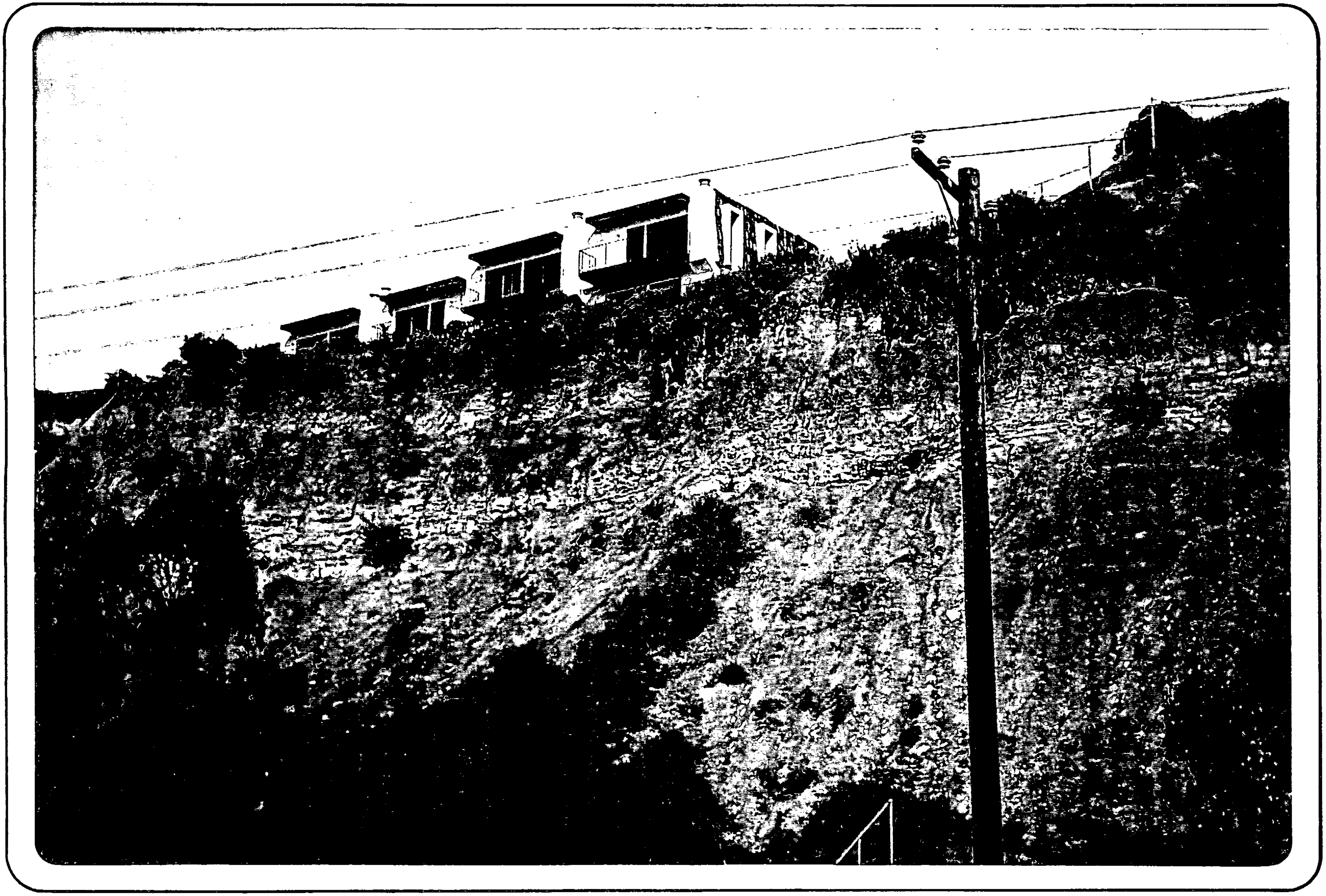


Fig. 7 - Capistrano Formation undisplaced across seaward projection of Vaciadero Fault, Capistrano Beach. Terrace 1 platform and marine sediments discontinuously traceable in foundation cuts near top of bluffs.

"Vaciadero Fault"

The inferred Vaciadero Fault trend southeastward across the Capistrano Embayment intersecting the coast at Capistrano Beach (Figs. 1 and 3). Here, the Terrace 1 platform is only discontinuously exposed in coastal bluffs but, based on projected shoreline elevations, is not offset (Shlemon, 1978b, p.16).

More significantly, the underlying Capistrano Formation in this area contains distinctive, readily traceable sand-shale interbeds. As exposed in cuts along the Pacific Coast Highway (Fig. 7), these markers are gently warped, but not displaced. Thus the upper Capistrano Formation, as well as overlying Quaternary markers, are not offset by the Vaciadero Fault. This is consistent with West's interpretation of subsurface data (1979, structure section C-B).

"Carr Fault"

Similar to other Tertiary faults in the Capistrano Embayment, the inferred Carr Fault trends southeastward crossing the coast in the northern part of San Clemente (Poche area, Fig. 3). A measured Terrace 1 shoreline angle elevation, immediately south of this locality, is a few metres higher than that expected by projection (Fig. 3; Shlemon, 1978b, p.16, 32). However, field checks and helicopter overflights indicate that the "high" shoreline elevation pertains to an older and higher platform. Thus, within the resolution of field measurement, any movement of the Carr Fault would have occurred more than about 125,000 years.

Perhaps a more significant stratigraphic marker is the essentially continuous and unbroken Capistrano Formation in highway cuts at this locality. As mapped by Vedder and others (1957, 1975), Edgington (1974), and as shown in Fig. 2, the Capistrano Formation is gently warped but traceable undisplaced across the coastal projection of the Carr Fault. Therefore last movement of the fault in this area must have occurred before "upper Capistrano time."

SUMMARY AND CONCLUSIONS

Three faults, named Dana Point, "Vaciadero" and "Carr" are reported by West (1975, 1979) to project across the Capistrano Embayment coastal area between Dana Point in the north and San Onofre on the south. The time and magnitude of last displacement (vertical) of these faults is ascertained by identifying and dating late Tertiary and Quaternary stratigraphic markers.

The most important Tertiary marker is the Capistrano Formation, laid down at bathyal depths between about 4 to 10 million years ago. In the coastal portion of the Capistrano Embayment, the Formation has since been uplifted and gently warped. It is displaced by the Dana Point Fault, but is unbroken where crossed by projections of the "Vaciadero Fault" and "Carr Fault".

Late Quaternary stratigraphic markers are: (1) the Terrace 1 platform, dated by radiometric assay and faunal association as pertaining to marine isotope stage 5e ("late Sangamon") and formed about 125,000 years ago; (2) fluvial terrace deposits bordering San Juan, San Mateo and San Onofre creeks, dated by depositional environment and stratigraphic position as probably laid down during isotope stage 4 ("early Wisconsinan"), some 60,000 to 70,000 years ago; (3) gravel-filled channels of San Juan, San Mateo and San Onofre creeks underlying the present floodplains, deposited during the last glacio-eustatic low stand of sea level ("late Wisconsinan") about 17,000 to 20,000 years; and (4) post-stage 5e buried paleosols within piedmont fan and debris flow deposits found mainly overlying the Terrace 1 platform.

The shoreline-angle elevation of Terrace 1 rises from SONGS to Dana Point indicative of up-to-the-north tilting in late Quaternary time. Though not directly traceable across the Dana Point Fault, shoreline-angle elevations are comparable on either side, supporting previous mapping and interpretations that last displacement occurred more than about 125,000 years ago.

Projection of the Terrace 1 shoreline across the Vaciadero and Carr Faults likewise suggests that, within the resolution of field measurement, no late Quaternary displacement has occurred. This interpretation is also supported by attitude of the immediately underlying Capistrano Formation which, although gently folded, is not offset.

In sum, the Dana Point, Vaciadero and Carr Faults, as projected seaward by West (1975, 1979), do not visibly offset the Terrace 1 stratigraphic marker. Therefore last displacement occurred before at least 125,000 years ago.

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