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SAN ONOFRE
NUCLEAR GENERATING STATION
UNITS 2 AND 3

LATE QUATERNARY RATES OF DEFORMATION LAGUNA BEACH-SAN ONOFRE STATE BEACH ORANGE AND SAN DIEGO COUNTIES, CALIFORNIA

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LAGUNA BEACH - SAN ONOFRE STATE BEACH

ORANGE AND SAN DIEGO COUNTIES, CALIFORNIA

for

Southern California Edison Company

and

San Diego Gas & Electric Company

by

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INTRODUCTION

Purpose

This study is one of several commissioned by the Southern California Edison Company (SCE) and San Diego Gas & Electric Company (SDG&E) to analyze the regional geology north and northwest of San Onofre Nuclear Generating Stations, Units 2 & 3. Of particular interest is locating possible late Quaternary structural displacements or a "hinge line" of uplift northward across the Capistrano Embayment and toward the San Joaquin Hills. This specific study deals with the late Quaternary evolution of the coastal area, mainly delimiting the continuity and elevation of the first marine terrace contact (wave-cut platform; or Terrace 1 of Shlemon, 1978) from approximately the Target Canyon area of Camp Pendleton on the south to Laguna Beach on the north (Fig. 1).

The major purposes of this study are:

(1) To determine late Quaternary (last 125,000 years) rates of deformation along the coast for a distance of approximately 17 km from San Onofre Units 2 & 3 to Dana Point; and by reconnaissance another 15 km northwestward to Laguna Beach; and

(2) To compare these rates of deformation with published data for other coastal areas in southern California; and thereby assess the relative tectonic stability of the San Onofre area.

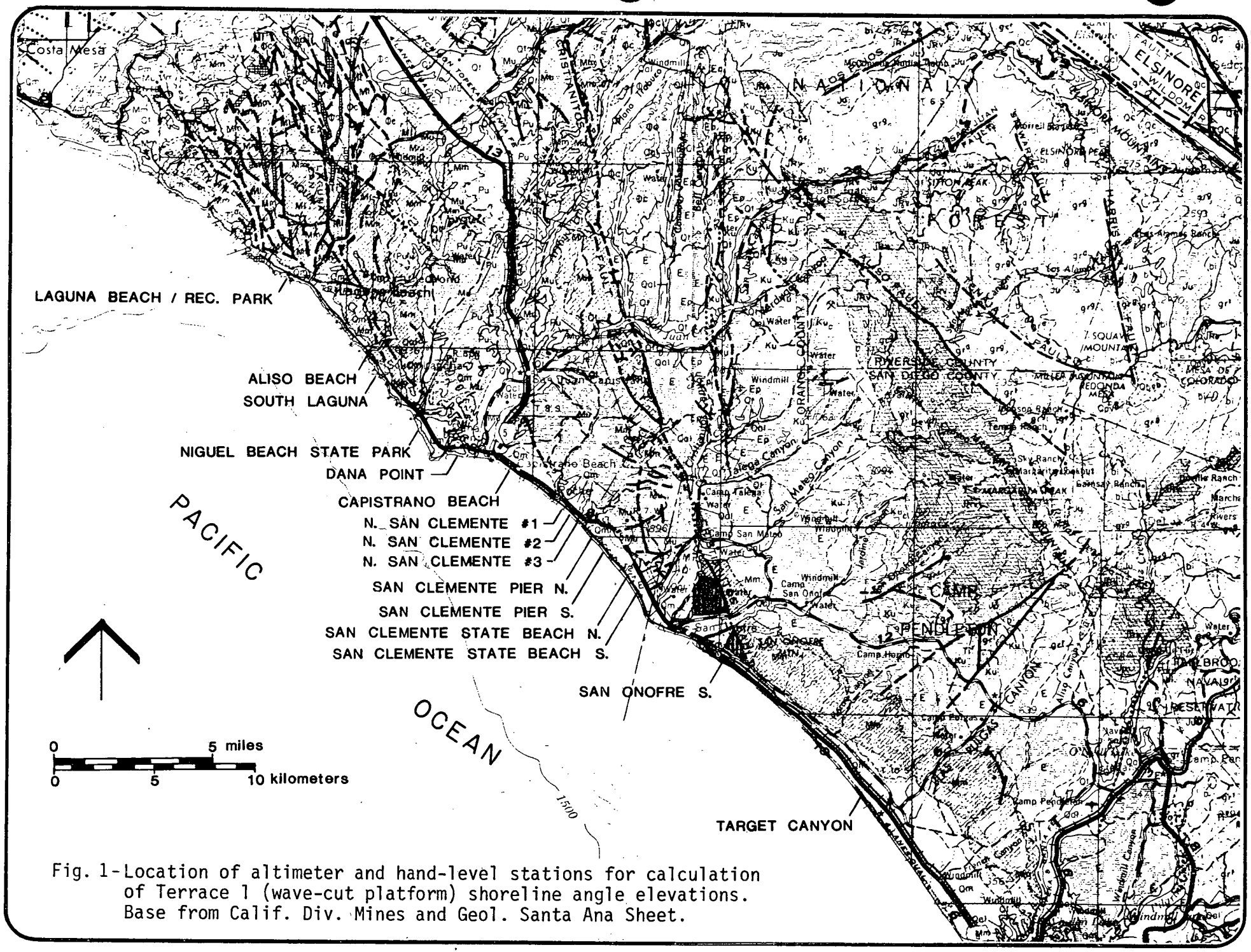


Fig. 1-Location of altimeter and hand-level stations for calculation of Terrace 1 (wave-cut platform) shoreline angle elevations. Base from Calif. Div. Mines and Geol. Santa Ana Sheet.

Previous Investigations

The geological setting and most recent syntheses of San Onofre Units 2 & 3 area geology have been spelled out in the San Onofre Units 2 & 3 Final Safety Analysis Report (FSAR). Other SCE and SDG&E commissioned geotechnical investigations have emphasized various aspects of late Quaternary stratigraphy, geomorphology, and coastal evolution in order to date the last movement of faults (e.g., Fugro, 1975a, 1975b, Shlemon, 1977). The present study extends northward the late Quaternary chronology developed for the Camp Pendleton - San Onofre State Beach area (Shlemon, 1978a).

Several regional geological maps identify late Quaternary coastal sediments north of the San Onofre area; particularly the wave-cut platform of Terrace 1 and its overlying marine and continental sediments. From a regional standpoint, most comprehensive is the mapping of Vedder and others (1957, 1975) where several discontinuous flights of marine terraces and related deposits are recognized between San Clemente on the south and Newport Beach on the north (Fig. 1).

Marine terrace deposits in the study area have also been mapped by the California Division of Mines and Geology; mainly in the San Clemente area (Blanc and Cleveland, 1968), at San Juan Capistrano (Morton and others, 1974), and in the Dana Point region (Edgington, 1974). Additionally, several theses briefly refer to the location and age of late Quaternary sediments between San Onofre Units 2 & 3 and Laguna Beach (Ball, 1961; Bartow, 1964; Duggan, 1961; Neblett, 1966; Palmer, 1967).

An abundance of U-series and amino-acid dates are now available to date Terrace 1 deposits ("first emergent terrace") in Southern California. Those particularly pertaining to the study area have been reviewed by Fugro (1975a), Shlemon (1977, 1978a), Szabo and Vedder (1971), and Wehmiller and others (1977).

Scope and Investigative Procedures

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

(1) Assessment of published literature and unpublished consultants' reports pertaining to mapping and radiometric and relative dating of geological units, geomorphic surfaces; and of glacioeustatic sea level fluctuations as they bear upon the late Quaternary evolution of the San Onofre north area; and

(2) Field measurements, observations and description, particularly of the Terrace 1 basal contact and overlying sediments where exposed in sea cliffs, and road and gully cuts north of San Onofre Units 2 & 3.

Following helicopter and ground reconnaissance, some 15 Terrace 1 shoreline angle localities between San Onofre and Laguna Beach were identified and elevations determined by altimeter survey and instrumental hand-levelling. Additionally, rates of late Quaternary uplift were recalculated for the Target Canyon area of Camp Pendleton (cf. Shlemon,

1978a), approximately 12 km south of San Onofre Units 2 & 3. Finally, all literature pertaining to long-term average uplift rates for the Southern California coast was compiled in order to assess the late Quaternary tectonic stability of the San Onofre area.

Acknowledgements

In addition to literature synthesis and collection of new field data, this study also benefited greatly from personal communication graciously provided by others working in the immediate area, or with techniques directly applicable to dating late Quaternary coastal sequences. In particular, K. R. Lajoie and G. O. Kennedy, U.S. Geological Survey, Menlo Park, reviewed various U-series dating techniques, provided interpretation of sediment age based on amino-acid dating and faunal assemblage, and generally reviewed concepts regarding the tectonic stability of the Orange and San Diego County coastal region.

Logistical support was furnished in part by the Southern California Edison Company. In particular, J. L. McNey arranged for helicopter reconnaissance, and P. Hamilton assisted in field work in the immediate vicinity of San Onofre Units 2 & 3.

TERRACE 1 SHORELINE ANGLE ELEVATIONS

Throughout much of Southern California and along most other cliffed coasts of the world, present mean sea level is represented geomorphologically by a distinct break in slope or an "angle" at the base of coastal bluffs. This is the average point where land and water meet (Fig. 2). This shoreline angle often varies a metre or two from place to place, even on modern coasts, owing to local differences of tidal range, direction and force of wind, height of breakers, slope of shore, and other local effects engendered by topographic differences and erosional resistance of bedrock. The modern shoreline angle may not be identifiable at every locality, for often it is ephemeral, frequently covered by locally-derived colluvial or eolian deposits. Therefore, identifying the precise elevation of ancient shorelines is likewise difficult. Nevertheless, even an estimated paleo-shoreline angle elevation provides a first approximation of possible regional deformation, especially if the old shore can be traced with some continuity in sea cliffs, and can be dated, either directly by radiometric techniques, or indirectly by association with late Quaternary glacioeustatic sea level fluctuations.

Two aspects of elevated shoreline angle elevations are particularly relevant to determine changes in regional deformation or the possible presence of faults: (1) application as datable stratigraphic markers; and (2) use to calculate rates of regional uplift and/or tilt.

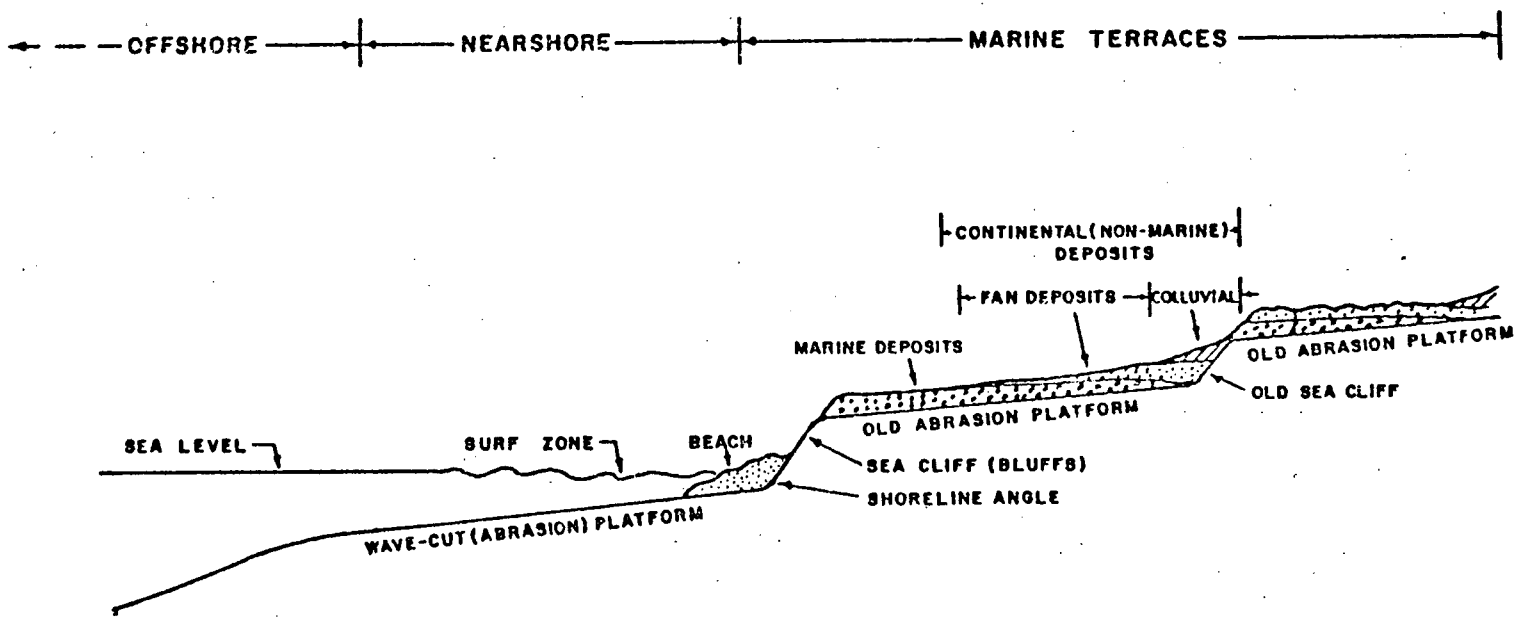


Fig. 2 - Diagrammatic cross-section and geomorphological terminology pertaining to raised terraces, Laguna Beach - San Onofre State Beach, California.

Shorelines as Stratigraphic Markers

The first marine terrace platform (Terrace 1) along the southern California coast is considered by most Quaternary geologists to be an excellent stratigraphic marker. First, it is well dated. Many radiometric dates indicate that the wave-cut platform was probably bevelled by a transgressing sea during "late Sangamon" time (marine oxygen isotope stage 5e) about 120,000 - 125,000 years ago (see, for example, representative sea level curves of Bloom and others, 1974; and Shackleton and Opdyke, 1973). An abundance of local uranium-series, amino-acid and faunal assemblage data likewise support a stage 5e age for the regressive marine deposits directly overlying the platform along the Southern California coast in general and at San Onofre in particular (summarized in Fugro, 1975a; Shlemon, 1977, 1978a; and Wehmiller and others, 1977).

And second, with few exceptions, over 50 percent of the Terrace 1 marine sediment - bedrock contact is exposed almost continuously in sea cliffs between Target Canyon (Camp Pendleton) on the south and Dana Point on the north. Further, the basal marine contact, usually marked by well-rounded gravels, is an excellent stratigraphic marker useful to demonstrate continuity and absence of vertical displacement along faults projected toward the coast. As described in sections following, the Terrace 1 platform is a particularly striking planar feature in sea cliffs between San Onofre Units 2 & 3 and the Target Canyon Area (Fig. 3). Northward, toward Dana Point, though locally

covered by colluvium or vegetation and "breached" by floodplains of San Onofre, San Mateo and San Juan Creeks, the contact is sufficiently well preserved such that horizontal projection limits vertical movement potentially ascribable to late Quaternary faulting.

Shorelines as Indicators of Regional Deformation

In addition to being datable stratigraphic markers, many old shorelines are useful to assess possible late Quaternary regional deformation, particularly rates of uplift, and of longitudinal or seaward tilt.

A general regional uplift rate is approximated by comparing a raised shoreline angle elevation with that of the sea at time of its formation. This procedure is especially applicable for Terrace 1, generally the lowest, most extensively preserved, and best dated shoreline along the California coast. In addition, if two or more elevations are obtainable inland along a line normal to the ancient coast, it is possible to determine if there has been any seaward tilting of the old platform since abandonment in late Quaternary time. And finally, based on several shoreline angle elevations, a few km apart, it is also possible to compute an average longitudinal tilt rate for the coastal area. This latter technique, applied to the study area, makes it now possible to determine more precisely the "hinge line" of coastal uplift in the Dana Point - Niguel Beach area, some 17-20 km northwest of San Onofre Units 2 & 3 (Fig. 1).

Fig. 3 - Planar contact of marine and continental sediments overlying Terrace 1 platform, cut on Tertiary Monterey Formation. View southeastward from San Onofre Units 2 & 3.

Accuracy of Shoreline-Angle Elevations

Discovering a clear exposure of a raised shoreline angle is indeed fortuitous. Inherently, because of its location at the base of an ancient cliff, an old shoreline is usually covered by a few to several metres of colluvium and overlying continental deposits. Rarely, therefore, can the elevation be determined directly by instrumental survey. Normally it is necessary to approximate the shoreline angle by first, determining the elevation of the marine terrace-bedrock contact at a sea cliff or gully exposure; second, assuming or measuring a seaward gradient of the platform, based on elevation differences of two or more localities inland along the contact; and third, projecting this gradient to a topographic break in slope, generally indicative of the base of an old sea cliff.

The Terrace 1 shoreline in Orange and San Diego Counties generally dips seaward about 1 degree, comparable to measured slopes of the modern offshore platform (Bradley, 1958; Bradley and Griggs, 1976; Buffington and Moore, 1963). This low gradient is visible in the almost continuous exposures at Target Canyon (Shlemon, 1978) and at Dana Point (this study) some 17 and 12 km north and south, respectively, of San Onofre Units 2 & 3 (Fig. 1).

The Dana Point "calibration area" is particularly instructive, for the Terrace 1 contact is superbly exposed, both in sea cliffs above the Dana Point Harbor, and inland some 600 m adjacent to the shoreline angle (Fig. 4). The difference in elevation between these two points is about 1 m, yielding a seaward gradient of less than 1/2 degree.

Fig. 4 - Terrace 1 platform exposed in excavation (lower right) at top of bluffs overlooking Dana Point Harbor. Terrace 1 shoreline angle approximated by "break in slope" inland (northward) along Street of the Golden Lantern, Dana Point.

In contrast to Dana Point, an apparent maximum seaward "tilt" of about 1-1/2 degrees occurs at the north San Clemente #1 locality (Fig. 1), based on difference in elevation of the platform as exposed in sea cliffs and in a gully inland some 335 m near the shoreline angle.

Given the accuracy of projecting shoreline angles, three field measurements techniques were used to determine Terrace 1 elevations between San Onofre and Laguna Beach: (i) direct reading of a Paulin micro-surveying altimeter with scale calibrated to 2-ft. (0.6 m) intervals; and set to local benchmarks every 2-3 hours in order to correct for variations in diurnal barometric pressure; (ii) hand-levelling with a "Locke level" starting at a known elevation, usually present sea level or local benchmarks; and (iii) broadly verifying altimeter and hand-levelling elevations by comparison with U.S. Geological Survey topographic maps (20-foot interval).

The accuracy of the Terrace 1 elevation, where clearly exposed in sea cliffs and based on altimeter and hand-levelling, is probably well within one metre. In addition, at most localities the basal gravel-bedrock relief is also less than about one metre. Less precise, however, is the shoreline angle elevation where based on projection inland more than about 50 m from sea cliffs or gully exposures. A 1 degree difference from assumed or measured platform gradient may yield a 2-3 m error in elevation when projected inland about 300 m. In sum, therefore, the calculated shoreline angle elevations for the 14 localities between San Onofre and Laguna Beach must be considered approximations; and the

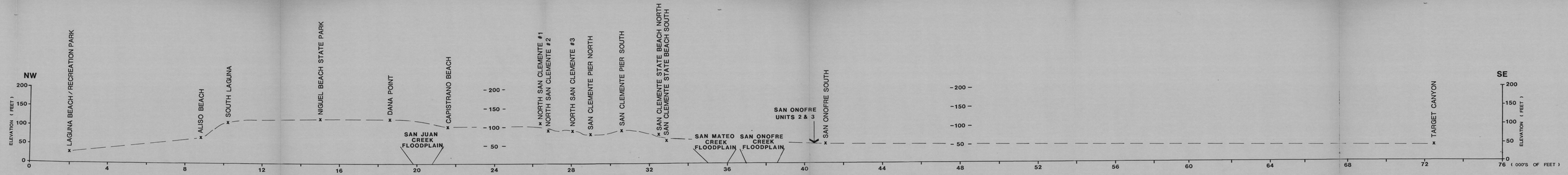
elevations, at a maximum, may be about ± 2 m from those indicated in this study. However, it is the trend of shoreline angle elevations along a given coast that is meaningful, especially to compute a long-term (ca. 125,000 years), average rate of uplift and/or tilt.

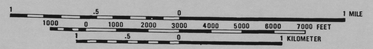
TERRACE 1 AS A STRATIGRAPHIC MARKER

The contact of Terrace 1 basal marine gravels and sands overlying bedrock is perhaps one of the most widespread late Quaternary terrestrial stratigraphic markers in Southern California. As shown on Figs. 3 and 5, the contact is almost planar and continuous in sea cliffs for some 12 km southward from San Onofre Units 2 & 3 to the Target Canyon area (Fig. 1). This contact is readily discernible in outcrop except where breached by narrow, steep-walled coastal arroyos or "displaced" by large, rotated landslide blocks (San Onofre Units 2 & 3 FSAR).

The widest gap in Terrace 1 continuity occurs between San Onofre Units 2 & 3 and the southern part of San Clemente State Beach (Fig. 5). Here, Tertiary sediments and late Quaternary marine and continental deposits have either been eroded or were never laid down in this approximately 2.5 km gap, now filled by channels and floodplains of San Onofre and San Mateo Creeks. To the north, from San Mateo Point to San Clemente State Beach (Fig. 1), the coastal bluffs are dissected so that the Terrace 1 contact is not exposed, but could likely be encountered approximately 3-5 m below the surface some 0.3 - 0.4 km inland. Presently, however, this area is in "private estate" and therefore inaccessible for detailed field check.

Northward from San Clemente State Beach 3-4 km to locality "north San Clemente #3" (Table 1; Figs. 1 and 5), the Terrace 1 - bedrock contact is exposed discontinuously in sea cliffs, coastal gullies and access trails to the beach. The contact is particularly well displayed





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HORIZONTAL DISTANCE ALONG COAST "SMOOTHED" BETWEEN CONTROL POINTS
SEE TEXT FOR LOCATIONS OF MEASURED TERRACE CONTACTS AND PROJECTED SHORELINE ANGLE

QUALITY OF EXPOSURES

CONTINUOUS IN SEA CLIFFS.

DISCONTINUOUS IN CLIFFS AND IN ROADS AND GULLY CUTS.

PROJECTED SHORELINE ANGLE ELEVATIONS - TERRACE 1 PLATFORM (~125,000 B.P.)
LAGUNA BEACH - TARGET CANYON (CAMP PENDLETON)
ORANGE AND SAN DIEGO COUNTIES, CALIFORNIA

Figure 5

at San Clemente State Beach (Fig. 6) where several exposures clearly reveal well-rounded basal marine gravels and 5-8 m of overlying marine sands and silts, some of which are fossiliferous and bear both Protothaca and Saxidomus, genera useful for amino-acid dating (K.R. Lajoie, personal communication).

In the northern part of San Clemente, the Terrace 1 - bedrock contact rises to an elevation of about 25-26 m (Fig. 5). It is thus almost at the top of the present coastal bluffs and therefore locally concealed by construction fill and new vegetation. Yet here, too, access trails and steps to the beach frequently expose the contact, and locally its overlying fossil-bearing marine sands (Table 1; Fig. 7).

Between north San Clemente and the east side of San Juan Creek (Figs. 1 and 5) the Terrace 1 contact is exposed for 1-1/2 - 2 km almost continuously near the top of bluffs adjacent to the coast highway (El Camino Real). The contact here is especially prominent, distinguished by seeps, contrasting vegetation, and basal marine gravels.

The Terrace 1 contact is breached by the approximately 0.6 km wide floodplain of San Juan Creek (Fig. 5). However, immediately north at Dana Point is the most extensive exposure of Terrace 1 between San Onofre Units 2 & 3 and Laguna Beach. Here, in an excavation at the top of bluffs overlooking the Dana Point Harbor (accessible from Street of the Golden Lantern; Table 1), the contact is clearly and continuously exposed for almost 1 km (Fig. 8). At this locality the platform is overlain almost exclusively by regressive marine sands. However, inland (northward)

Fig. 6 - Exposures of Terrace 1 platform, basal marine gravels and sands, and overlying continental sediments with intercalated buried paleosols; access trail to beach, San Clemente State Beach.

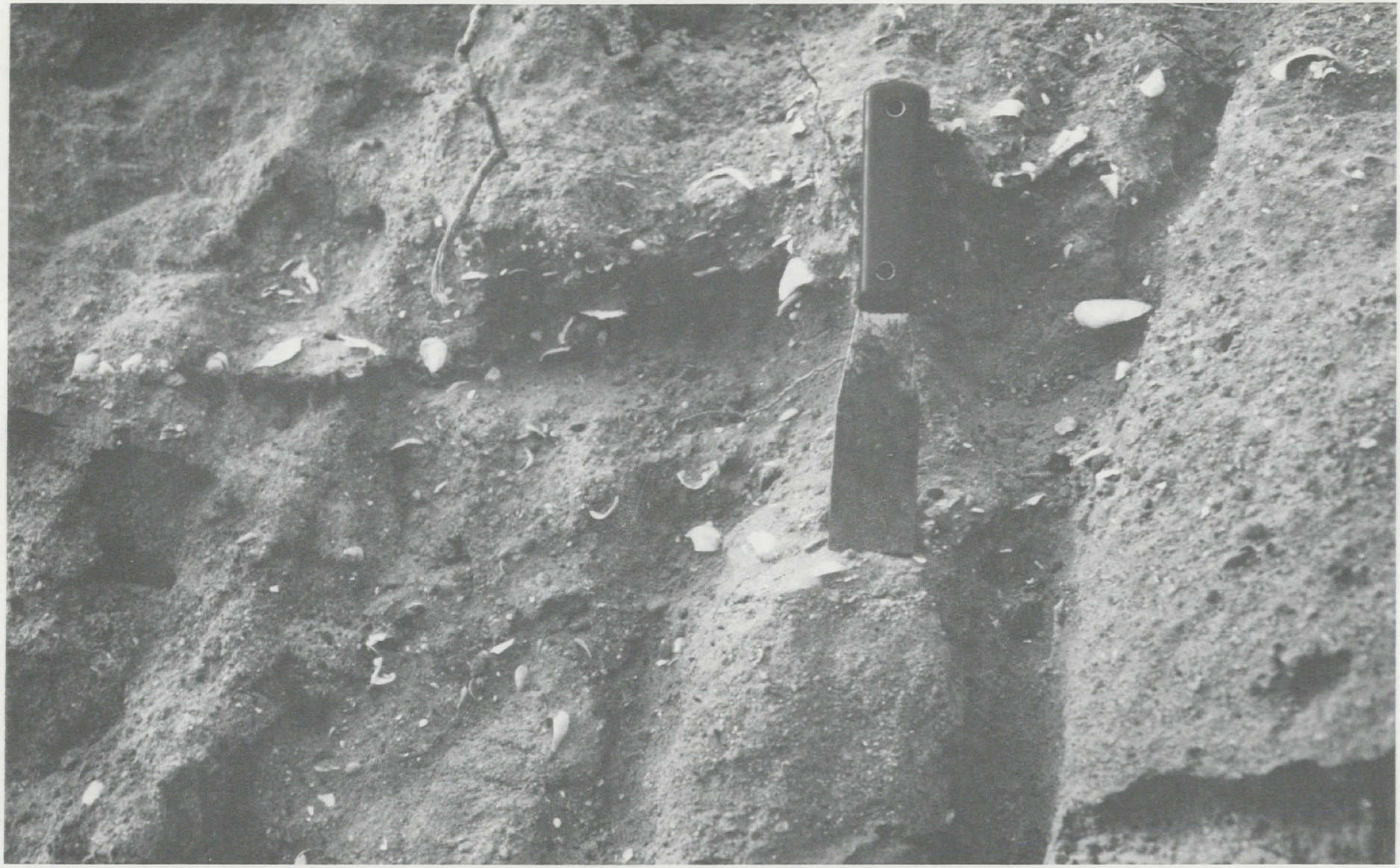

Fig. 7 - Fossil shells in basal marine sands 3-4 m above Terrace 1 platform, Exposures adjacent to stairs and access trail to beach. Locality: North San Clemente # 3 (Fig. 1; Table 1).

Fig. 8 - Basal Terrace 1 gravels overlying Capistrano Formation in 700-800 m continuous cut at top of bluffs, Dana Point (see also Fig. 4).

Table 1

Terrace 1 - Measured Shoreline Angle Localities, Target Canyon - Laguna Beach

Locality	USGS Quadrangle	T & R	Projected Distance to Shoreline Angle (m)	Notes
Target Canyon	Las Pulgas Canyon	SE 1/4, sec. 14, T. 10 S., R.6 W.	800	Continuous exposures 0.4 km from seacliff to approx. freeway culvert; Instrumentally surveyed (Shlemon, 1978, p. 109)
San Onofre South	San Onofre Bluffs	SE 1/4, NW 1/4, sec. 30, T. 9 N., R. 6 W.	335	Sea cliff and coastal arroyo exposures; approx. 0.4 km SE SO Units 2 & 3
San Clemente State Beach South	San Clemente	NW 1/4, SW 1/4, sec. 10, T. 9 S., R. 7 W.	305	Sea cliff and beach access road to Life Station #1, San Clemente State Beach (Fig. 6).
San Clemente State Beach North	San Clemente	NW 1/4, SE 1/4, sec.10, T. 9 S., R. 7 W.	30	Sea cliff and beach access road exposures from north side of main parking lot, San Clemente State Beach, approx. 300 m SE of Avenida Calafia.
San Clemente Pier South	San Clemente	NW 1/4, SE 1/4, sec. 4, T. 9 S., R. 7 W.	225	Roadcut exposures, City of San Clemente; Boca del Canon, corner of La Rambla; discontinuous exposure in sea cliffs.
San Clemente Pier North	San Clemente	NW 1/4, NW 1/4, sec. 4, T. 9 S., R. 7 W.	85	Seacliff exposures and discontinuous roadcuts; Arenoso Lane and Via Mecha, approx. 400 m N. of San Clemente Pier.

Locality	USGS Quadrangle	T & R	Projected Distance to Shoreline Angle (m)	Notes
North San Clemente #3	Dana Point	NW 1/4, SE 1/4, sec. 32, T. 8 S., R. 7 W.	290	Exposures adjacent to stairs to beach, seaward from 1408 Buena Vista Drive, near Dije Ct; fossil locality. (Fig. 7)
North San Clemente #2	Dana Point	SE 1/4, NW 1/4, sec. 32, T. 8 S., R. 7 W.	185	Exposure in cuts adjacent to tanks and sewage disposal ponds, approx. 200 m. inland from coastal bluffs.
North San Clemente #1	Dana Point	NW 1/4, NW 1/4, sec. 32, T. 8 S., R. 7 W.	30	Seacliff exposures near top of bluffs east of El Camino Real, and discontinuous exposures with basal gravel-marked contact in gullies approx. 335 m inland.
Capistrano Beach	Dana Point	NE 1/4, SW 1/4, proj. sec. 24, T. 8 S., R. 8 W.	75	Roadcut exposure in Palisades Dr., near top of bluff and "look-out point", City of San Clemente.
Dana Point	Dana Point	SW 1/4, NE 1/4, sec. 22, T. 8 S, R. 8 W.		Excavation near top of bluff over-looking Dana Point Harbor; approx. 5 m east of Street of the Golden Lantern; contact continuous approx 700-800 m (Figs. 4 & 8)
	Dana Point	NE 1/4, NE 1/4, sec. 22, T. 8 S., R. 8 W	90	Roadcuts, Street of the Copper Lantern, fossil locality. Shore line angle elevation approximate by "break in slope" at La Cresta Drive (Fig. 9)
Niguel Beach State Park	Dana Point	NW 1/4, SW 1/4, sec. 13, T. 8 S., R. 8 W.	15	Seacliff exposure, basal marine gravels "plastered" against San Onofre Breccia; overlain by ca. 20 m marine sand; contact laterally covered by colluvium.

Locality	USGS Quadrangle	T & R	Projected Distance to Shoreline Angle (m)	Notes
South Laguna	San Juan Capistrano	SW 1/4, SW 1/4, sec. 5, T. 8 S., R. 8 W.	7 - 8	Roadcuts near Pacific Coast Highway (PCH) and 5th Ave., South Laguna; contact discontinuous, local colluvial cover.
Aliso Beach	Laguna Beach	NE 1/4, proj. sec. 1, T. 8 S., R. 8 W.	3 - 5	Exposure east of PCH in trail cuts, south of Aliso Creek, adjacent to GTE Building.
Laguna Beach/ Recreation Park	Laguna Beach	SE 1/4, SW 1.4, proj. sec. 23, T. 7 S., R. 9 W.	225	Recreation Point, Heisler Park; contact ca. 1 m below BM "32-ft" at coastal point.

some 600 m near the shoreline angle (Fig. 9), the contact is covered by a veneer of prograded continental deposits bearing a weakly-developed soil. In brief, from about San Juan Creek to the Dana Point "sea stack", almost continuous exposure reveals remarkable continuity and no discernible offset of the Terrace 1 - bedrock contact.

North of Dana Point, an area examined in reconnaissance, there are no known extensive exposures of the Terrace 1 contact. However, close scrutiny of sand-mantled slopes at Niguel State Beach (Fig. 1) reveals the contact, albeit discontinuous, at an elevation only slightly lower than the shoreline angle at Dana Point (Fig. 5).

From Niguel Beach to Laguna Beach (Figs. 1 and 5) the Terrace 1 contact is only intermittently exposed, mainly in cuts of the Pacific Coast Highway in South Laguna, in bluffs flanking Aliso Creek, and in sea cliffs at the Recreation Park area of Laguna Beach. Undoubtedly the terrace contact is exposed elsewhere in this region, primarily in ephemeral foundation excavations, but certainty of shoreline angle elevation is less than south of Dana Point. Indeed, it is possible that basal marine gravels, perhaps both younger and older than Terrace 1 in the Laguna Beach are separated only a few metres vertically. However, multiple terraces are difficult to discern because a well established urban cover now masks much of the area.

In summary, from Target Canyon at Camp Pendleton to Dana Point, some 30 km "airline" distant, the Terrace 1 contact is exposed almost continuously in about 50 percent of the area; somewhat discontinuously in sea

cliffs for another 35 - 40 percent; and either concealed or eroded over the remaining 10 - 15 percent. Nowhere in the study area, within the resolution of field mapping, has the Terrace 1 contact been observed displaced.

Fig. 9 - Basal marine gravels and sands containing fossil shells immediately overlying Terrace 1 - bedrock contact near shoreline angle; Street of the Copper Lantern, Dana Point.

LATE QUATERNARY RATES OF DEFORMATION

The shoreline angle elevations of Terrace 1, deduced from the 15 localities between Target Canyon and Laguna Beach, permit approximation of late Quaternary rates of deformation. Three components of deformation may be evaluated from the data obtained: (1) regional up-to-the-northwest (longitudinal) tilt between Target Canyon and Dana Point; (2) possible seaward tilt in the north San Clemente area; and (3) average uplift of the region over the last 125,000 years. These rates may be compared with others along the Southern California coast to evaluate the relative tectonic stability of the San Onofre Units 2 & 3 area, and apparent coastal deformation associated with late Quaternary uplift of the San Joaquin Hills.

Stage 5e Sea Level

The absolute elevation of sea level some 125,000 years ago (marine oxygen isotope stage 5e) is still conjectural. Estimates range from approximately +6 m to somewhat in excess of +10 m (see, for example: Bloom and others, 1974; Chappell, 1974; Kern, 1977; Ku and Kern, 1974; Ku and others, 1974; Shackleton and Opdyke, 1973; Steinen and others 1973; and Wehmiller and others, 1977). Most workers do agree, however, that sea level was indeed higher than the present (Shackleton and Opdyke, 1973), related to glacio-eustatic rise associated with the last major interglaciation ("late Sangamon").

Although the stage 5e sea level (Terrace 1) has yet to be determined precisely, it is instructive to plot shoreline-angle elevations in order to compare regional changes in late Quaternary deformation. For the Target Canyon - Laguna Beach area, a general uplift rate, for Terrace 1, expressed as cm/1000 years, is tabulated for stage 5e sea levels at both +6 and +10 m (Table 2).

Longitudinal Tilt

Late Quaternary uplift north of San Onofre Units 2 & 3, across the Capistrano Embayment and toward the San Joaquin Hills, has been known for many years (Edgington, 1974; Morton and others, 1974; Szabo and Vedder, 1971; Vedder and others, 1957, 1975). This up-to-the-northwest tilt appears to be continuing as suggested by historic levelling (Wood and Elliott, 1977). Of particular interest is the average long-term rate of "longitudinal" tilt; and this can be approximated by change in shoreline-angle elevations of Terrace 1 between Target Canyon and Laguna Beach.

As shown on Table 2 and in Figure 5, projected shoreline-angle elevations of Terrace 1 gradually increase from about 13 m at Target Canyon to almost 40 m at Dana Point. Northward, although fewer data are thus far available, there appears to be a rapid lowering of shoreline toward Laguna Beach, decreasing to a projected 9.3 m at Recreation Park (Fig. 5).

However, because Terrace 1 elevation control is sparse in this area

Table 2

Average Uplift Rate of Terrace 1 for the Last 125,000 Years (Stage 5e level) Between Laguna Beach (North) and Target Canyon, Camp Pendleton (South)

Locality	Measured or Projected Shoreline Angle Elevation (ft)	(m)	Uplift Rate (cm/1000 years) Original Shoreline Elevation +6 m	+10 m
Target Canyon/Camp Pendleton	42	13.0	6	2
San Onofre South	57	17.7	9	6
San Clemente State Beach South	66-68	20.8	12	9
San Clemente State Beach North	68-70	21.4	12	9
San Clemente Pier South	97	30.1	19	16
San Clemente Pier North	83	25.7	16	13
North San Clemente #3	90	27.9	18	14
North San Clemente #2	97	30.1	19	16
North San Clemente #1	116	35.9	24	21
Capistrano Beach	100	31.0	20	17
Dana Point	125-126	39.1	26	23
Niguel Beach State Park	122	37.8	25	22
South Laguna	112-114	35.0	23	20
Aliso Beach	72-74	22.6	13	10
Laguna Beach Recreation Park	30	9.3	3	-1

See text for descriptions of measured locality and projection of gradient for shoreline-angle elevation

it is quite conceivable that the Laguna Beach/Recreation Point contact is not that of stage 5e (ca. 125,000 years BP), but perhaps stage 5a (ca. 80,000 years BP), or even stage 3 (ca. 35,000 - 45,000 years BP), indicative of an uplift rate greater than that shown in Table 2.

North of Laguna Beach, near Emerald Bay and at Corona del Mar, reconnaissance altimeter survey suggests that the Terrace 1 shoreline-angle elevation increases to about 16 m; and rises to a reported 25 m some 6 km farther north at Newport Beach (Wehmiller and others, 1977, Table 13).

Slight warping or gentle folding of the Terrace 1 contact is suggested by a 3-4 m "spread" of shoreline-angle elevations in the north San Clemente area (Fig. 5). Alternatively, however, this slight deversity of elevation may be indicative of field measurement error, or possibly of projecting a platform gradient higher than that of the Target Canyon and Dana Point "calibration" areas (Table 2). However, a "smoothed" curve, from San Onofre to Laguna Beach, indicates the presence of uplift and slight warping along the southern flanks of the San Joaquin Hills, apparently reaching a maximum in the Dana Point - Niguel State Beach area (Fig. 5). North of Niguel Beach, there may be additional minor warping of the Terrace 1 platform.

In brief, as measured from the shoreline curve (Fig. 5), the average up-to-the-north longitudinal tilt rate of Terrace 1 between San Onofre and Dana Point, a 17 km distance, is approximately 17 cm/1000 years. (Based on a +6 m stage 5e sea level.) In comparison,

a tilt rate for the flanks of the San Joaquin Hills between Dana Point and Laguna Beach, a 13 km distance, is about 24 cm/1000 years. These rates correspond well with the general area and magnitude of Terrace 1 deformation reported earlier by Szabo and Vedder (1971, p.284).

Seaward Tilt

Most classic flights of marine terraces in Southern California have been identified by expression on topographic maps (Alexander, 1953; Bradley, 1957; Palmer, 1967; Woodring and others, 1946). In this regard, the older terraces appear to dip shoreward at increasingly higher angles suggestive of general uplift and seaward tilt. But this may be more apparent than real, for the older and higher terraces are typically underlain by colluvial and mud-flow deposits, many with intercalated buried soils. In reality, therefore, terrace slope often bears little relationship to gradient of the underlying buried wave-cut platform. And thus true tectonic tilt seaward can be ascertained only where there are sufficient exposures normal to the coast to permit hand- or instrument-levelling.

Seaward tilt of the Terrace 1 platform is less than 1 degree, as measured in the well-exposed Target Canyon and Dana Point calibration localities. A maximum tilt of slightly less than 2 degrees occurs in the north San Clemente area. These seaward gradients are comparable to those of modern offshore platforms; and thus, within the resolution of

measurement, indicate little or no seaward tilting of the Terrace 1 platform in about the last 125,000 years.

A slightly higher than average gradient of the Terrace 1 platform at the north San Clemente #1 locality (Fig. 1 and 5) points out the possibility that projection may have been made to a topographic break some 2-3 m higher than the correct shoreline-angle. This is the only locality, outside of Camp Pendleton, where urbanization is yet incomplete, and construction has not destroyed subtle "breaks in slopes", most nondiscernible on 20ft contour interval maps.

In particular, a low terrace, some 2-3 m higher than Terrace 1, occurs discontinuously about 350 m inland at the north San Clemente #1 locality (Table 1). The precise age of this apparently older geomorphic surface is unknown, although plausibly it may have originated during a relatively high stand of sea level about 140,000 years ago, identified in many oceanic areas by radiometrically-dated raised reef deposits (Bloom and others, 1974, p. 203). A buried shoreline angle of similar elevation, relative to Terrace 1, has recently been identified in the Pt. Conception area (Dames and Moore, 1978) and was assigned a tentative age of about 195,000 years (Shlemon, 1978b, p. A-31), based on assumed association with a high stand of sea level during marine isotope stage 7 (Shackleton and Opdyke, 1973).

In review, the slightly higher than "average" elevation of the Terrace 1 shoreline angle at north San Clemente may reflect tectonic uplift and very minor seaward tilt. Alternatively, however, at this and adjacent localities, the shoreline angle may have been projected to

a slightly older shoreline, and the elevations shown in Table 2 are conservative, possibly 2-3 m too high.

Regional Rates of Uplift

Longitudinal and seaward tilt of the Terrace 1 marker in the San Onofre north area are components of regional late Quaternary uplift. Rates of uplift have been plotted for the study area from Target Canyon to Laguna Beach (Table 2); and for comparison with other localities in coastal Southern California (Table 3).

Long-term average uplift rates, expressed in cm/1000 years, calculated for both a postulated +6 and +10 m stage 5e sea level, show that the Target Canyon area of Camp Pendleton has undergone probably no more than about 6 cm/1000 years of uplift during the last 125,000 years. This rate increases to approximately 9 cm/1000 years northward at San Onofre Units 2 & 3, and to a maximum of 26 cm/1000 years at Dana Point (Table 2).

Comparison of the Dana Point-San Clemente-San Onofre uplift rates (based on a +6 m sea level at stage 5e) with 14 other localities along the Southern California coast (Table 3) indicates that deformation is occurring most rapidly along the south side of the Transverse Ranges, an area of regional compression (Wehmiller and others, 1978). High uplift rates, in the order of 500-800 cm/1000 years, have also been reported from the Baldwin Hills, based mainly on radiocarbon dating of marine shells (Bandy and Marincovich, 1973). More recently, however

Table 3

Comparison of Late Quaternary Uplift Rates
Southern California Coast *

Reference	Area	Length of Record (Thousands of Years)	Approximate Uplift Rate (cm/1000 Years)
Wehmiller et al., (1978, p. 513)	Ventura/Pitas Point	40-50	620
Wehmiller et al., (1978, p. 513)	Ventura/Pitas Point	2.5	640
Wehmiller et al., (1978, p. 513)	Ventura	80	200
Wehmiller et al., (1977, table 13)	Santa Barbara, Goleta	30-50	140
Wehmiller et al., (1977, table 13)	Cayucos	135	13
Wehmiller et al., (1977, table 13)	San Pedro (First Terrace)	120-140	18
Wehmiller et al., (1977, table 13)	Newport Beach (First Terrace)	120-140	15
Wehmiller et al., (1977, table 13)	San Diego/Pt. Loma	120	16
Wehmiller et al., (1977, table 13)	San Diego/Pt. Loma	70-90	23
Birkeland (1972 p. 441)	Malibu Coast	105	30-45
Bandy & Marincovich (1973 p. 653)	Baldwin Hills, L.A. Basin	36	500-800
Woodward & Marcus (1976, p. 128)	Rancho La Brea, L.A. Basin	100	40-50
Ku & Kern (1974 p. 1715)	San Diego Coast	120	11-14
Kern (1977 p 1563)	San Diego Coast	120	16-20
(This Report)	Dana Point	125	26
(This Report)	San Clemente	125	12-19
(This Report)	San Onofre	125	9

* San Onofre-Dana Point uplift rates calculated from sea level assumed at +6 m, ca. 125 kya.

Woodward and Marcus (1976) have criticized the Baldwin Hills data and point out that late Quaternary uplift at nearby Rancho La Brea is in the order of 40-50 cm/1000 years. Whether the Baldwin Hills and Rancho La Brea areas owe their apparent differential uplift to movement along the Newport-Inglewood or related faults remains yet enigmatic.

The San Diego-Point Loma area appears to have long-term average uplift rates in the order of some 11-20 cm/1000 years (Table 3). Northward, near San Onofre Units 2 & 3, the long term uplift rate decreases to about 9 cm/1000 years, about one-half that at San Diego, a third of that at Dana Point, and almost two orders of magnitude less than that reported for the Baldwin Hills.

In the study area, Terrace 1 is an excellent stratigraphic marker, to approximate shoreline-angles of Terrace 1 and to compare late Quaternary uplift rates on a regional basis. In this regard, the San Onofre area certainly appears to have been one of the most tectonically stable coastal areas in Southern California for at least the last 125,000 years.

SUMMARY AND CONCLUSIONS

Late Quaternary rates of deformation (regional uplift, longitudinal and seaward tilt) can be approximated for coastal areas by shoreline-angle elevations of dated terraces. The first (lowest) wave-cut platform and overlying marine terrace and continental deposits in the Camp Pendleton - San Onofre State Beach area (Terrace 1) is an excellent stratigraphic marker, for it can be traced northwestward along the coast in sea cliffs and adjacent arroyo and roadcuts some 17 km from San Onofre Units 2 & 3 to Dana Point, and an additional 15 km by reconnaissance to Laguna Beach.

Terrace 1 regressive marine deposits are dated radiometrically and by faunal assemblage as approximately 125,000 years old (marine oxygen-isotope stage 5e). These deposits and the underlying terrace - bedrock contact are exposed almost continuously for 12 km from Target Canyon on the south to San Onofre Units 2 & 3 on the north. Further north, exposures are readily discernible but discontinuous between San Clemente State Beach and Capistrano Beach; and between Dana Point and Laguna Beach. The contact (stratigraphic marker) is missing where coastal cliffs are "breached", mainly by channels and floodplains of San Onofre, San Mateo and San Juan Creeks.

The shoreline angle of Terrace 1, calculated for 15 localities by projecting altimeter survey and hand-levelling elevations, rises from about 13 m at Target Canyon to a maximum 39 m at a "hinge zone" of uplift (folding) between about Dana Point and Niguel State Beach. Based on reconnaissance, shoreline-angle elevation decreases to almost 9 m at Laguna Beach; an apparent rapid change owing to late Quaternary deformation in the San Joaquin Hills, or, alternatively, to miscorrelation of terrace

contacts in the urban area of Laguna Beach. Within the resolution of survey, the Terrace 1 contact is not observed displaced between San Onofre Units 2 & 3 and Dana Point. However, some minor, non-discernible folding may be superimposed on the generally rising coastal zone.

Seaward gradient of the Terrace 1 - bedrock contact is approximately 1 degree, clearly visible at Target Canyon and Dana Point. This gradient is comparable to the modern offshore platform; and thus there appears to be little if any seaward tilt of Terrace 1 between at least Camp Pendleton and Dana Point.

Based on a conservative +6 m estimate for the stage 5e sea level, regional uplift rates between Target Canyon and Dana Point increase northward from about 6 to 26 cm/1000 years; and indicate longitudinal up-to-the-northwest tilt of the coast across the Capistrano Embayment and toward the San Joaquin Hills. In terms of local late Quaternary uplift, the 9 cm/1000 year rate at San Onofre Units 2 & 3 compares with approximately 11-16 cm/1000 years for the San Diego area, 40-50 and concievably 500-800 cm/1000 years for Rancho La Brea and the Baldwin Hills, respectively, and 620 cm/1000 years for the Ventura coast. Therefore, compared with late Quaternary uplift rates elsewhere, the San Onofre region must be viewed as being one of the most tectonically stable coastal areas in Southern California.

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