GEOLOGIC INVESTIGATIONS
of the
SAN DIEGO COASTAL PLAIN

EDITED by PATRICK L. ABBOTT and SHANNON O'DUNN

GEOLOGIC INVESTIGATIONS of the COASTAL PLAIN

SAN DIEGO COUNTY, CALIFORNIA

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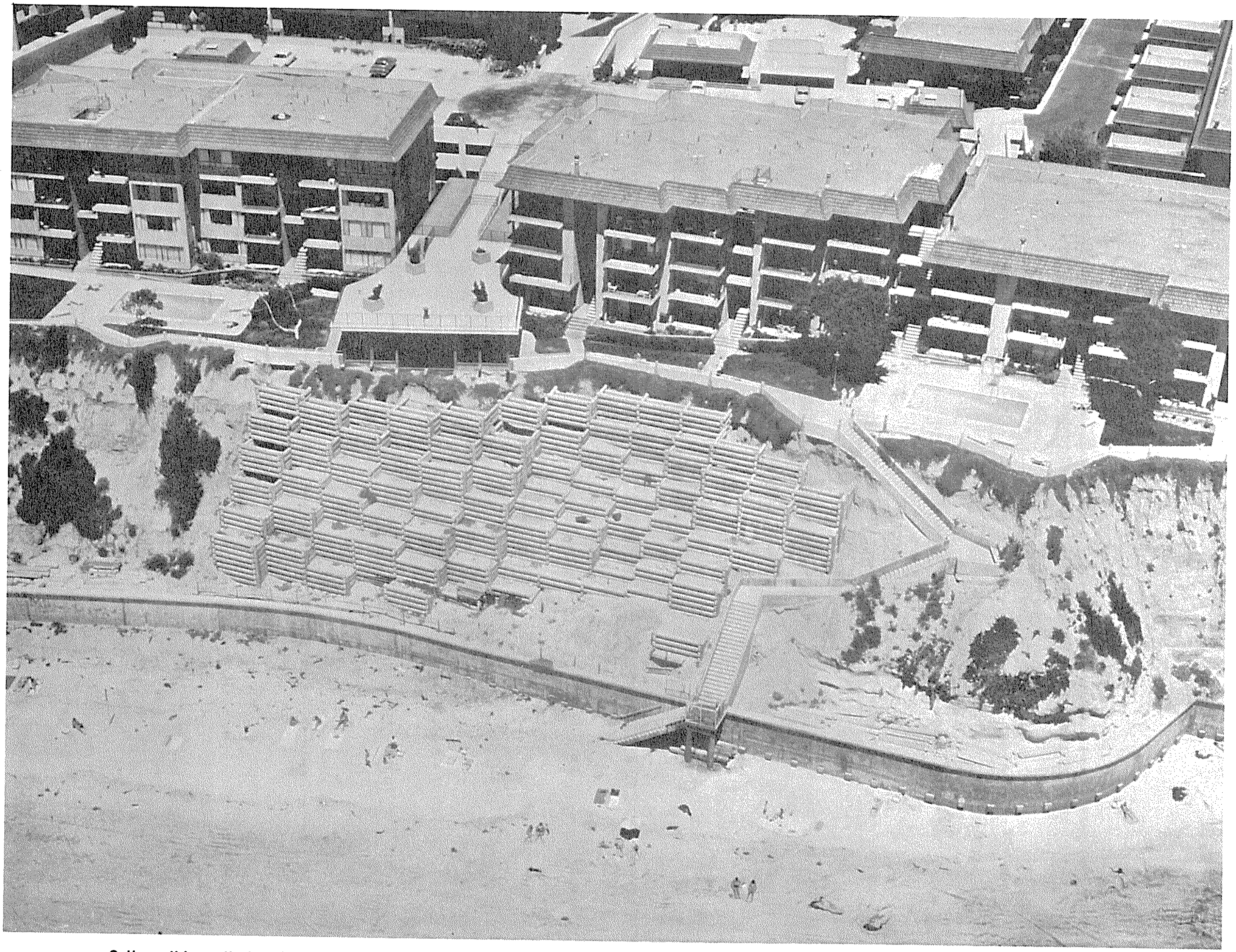

Crib wall installed on bluffs at Solana Beach to stop cliff failure. Photo by Woody Higdon of Photos by Woody, San Clemente, CA.

A NEWLY RECOGNIZED LATE PLEISTOCENE MARINE FAUNA

FROM THE CITY OF SAN DIEGO, SAN DIEGO COUNTY, CALIFORNIA

by

Thomas A. Deméré

San Diego Natural History Museum

ABSTRACT

The recent exposure of upper Pleistocene marine deposits in the downtown area of the city of San Diego, has led to the recognition of a distinctive and previously unknown older Pleistocene molluscan fauna. Museum collections made in the late 1800's and early 1900's from excavations in downtown San Diego, and from outcrops in Loma Portal and Logan Heights also contain elements of this new fauna, here designated as the Broadway Fauna. Although these fossils have been known for almost a century, they have been variously considered as representative of a peculiar facies of the Bay Point Formation or as Pliocene San Diego Formation correlatives. Several warm water taxa (*Turritella gonostoma*, *Argopecten abietis abbotti* and *Pecten vogdesi*) serve as local biostratigraphic indices for the recognition of the Broadway Fauna as they are unknown in younger deposits. In addition, amino-acid racemization of *Chione* shells has yielded an absolute date of 560,000 (±75,000) years B.P. for this fauna. Paleoenvironmental aspects of the Broadway Fauna suggest a warm water, littoral to sublittoral, mud and sand bottom environment within a protected marine embayment.

INTRODUCTION

Recent pipeline excavations in the downtown area of the city of San Diego, California, have exposed richly fossiliferous marine Pleistocene deposits. The majority of these deposits correlate both faunistically and temporally (amino-acid racemization) with previously recognized Pleistocene deposits in the San Diego area. However, one fossiliferous exposure near the intersection of Broadway and 2nd Avenue at a depth of 13 feet below street level represents a distinct older and previously unrecognized unit in the local Pleistocene. This deposit appears also to represent a base-point for the correlation of several additional deposits in the downtown and adjacent areas that in the past have been considered simply as peculiar Pleistocene facies or as Pliocene San Diego Formation correlatives.

It is the purpose of this paper to discuss these older deposits in terms of their temporal distinctiveness and to describe their various associated molluscan assemblages.

LOCALITIES

Fossil collections from 14 localities were examined during the course of this study. These collections are housed at the following institutions: the San Diego Natural History Museum (SDSNH); the California Academy of Sciences (CAS); and San Diego State University (SDSU). For the sake of this discussion, these localities have been grouped by geographic position, i.e., those from downtown San Diego, those from Loma Portal at the northeast end of Point Loma, and those from Greely Avenue in Logan Heights, East San Diego (Fig. 1).

DOWNTOWN LOCALITIES

In 1914, construction of the Southern Title Guarantee Company Building at 3rd Street near Broadway exposed a fossiliferous stratum at a depth of 18 feet below street level. A small collection of fossil mollusks was obtained from this stratum and donated to the San Diego Society of Natural History (SDSNH loc. 0706). In June of 1980, this same stratum was re-exposed in a pipeline trench at 2nd Street and Broadway. At that time a much larger bulk-collection was obtained (SDSNH loc. 3064) through the efforts of Ms. Dorain Mills of Woodward-Clyde Consultants. A third fossil assemblage from this stratum is in the collections of the California Academy of Sciences (CAS loc. 791) and was obtained in 1907 during construction of the "Union Building" along Broadway between 2nd and 3rd Streets.

In 1900, C. R. Orcutt published his "Catalog of fossils in the Orcutt collection," which appeared in two separate issues of his own journal,

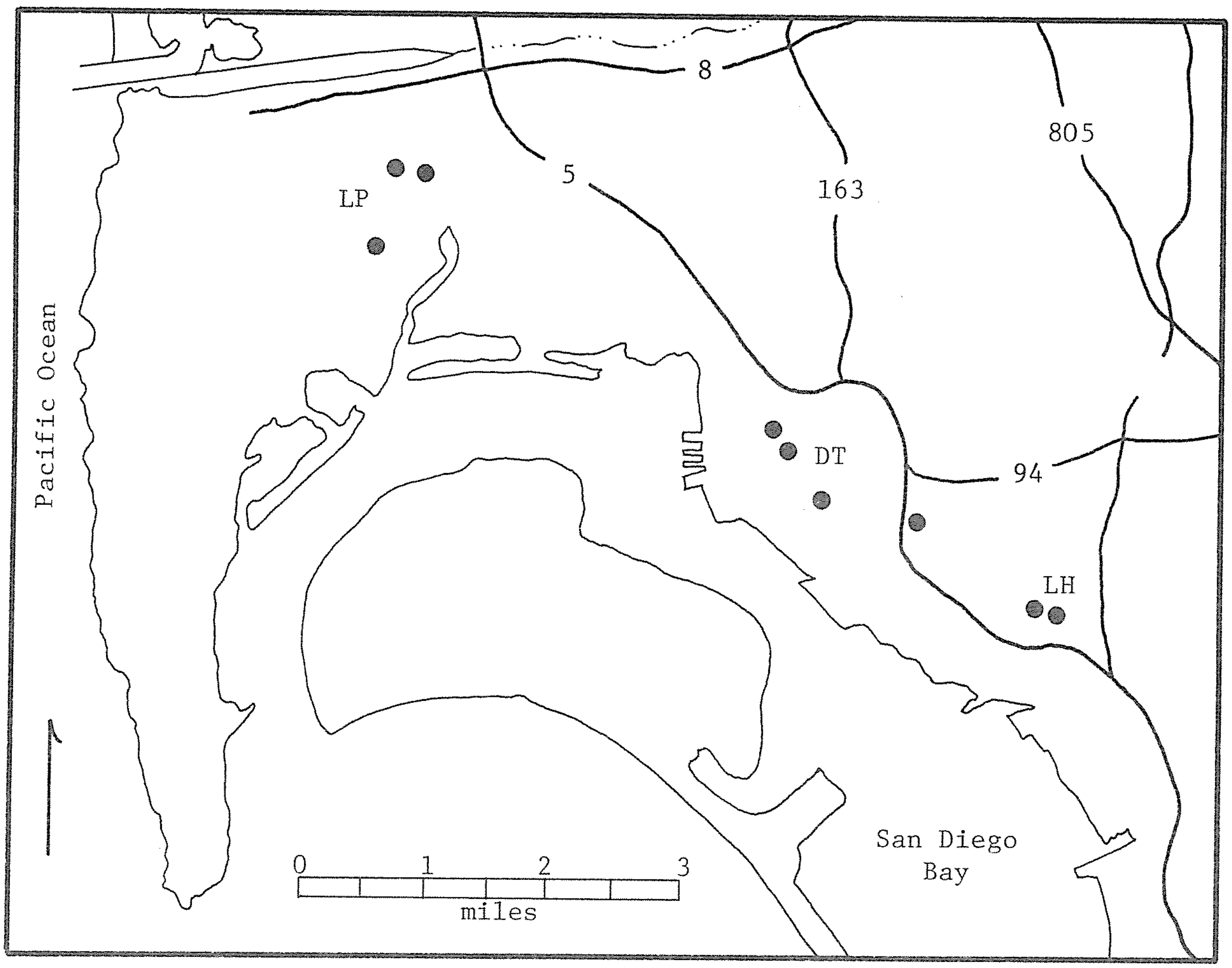

Figure 1 - Index map of the San Diego area showing location of fossil localities containing the Broadway Fauna. (DT = downtown localities, LP = Loma Portal localities; and LH = Logan Heights localities.)

The West American Scientist (Orcutt, 1900a, b). In this "catalog" are several references to San Diego fossils collected during street grading and sewer line trenching in the late 1800's. Two of these collections have at least partially survived the years since that time and are represented in the present collections of the San Diego Society of Natural History. These include a locality at 2nd Street near "A" Street collected on 16 April 1889 (SDSNH loc. 3132) and a locality at the corner of 8th Street and "H" Street (now Market Street) collected in 1888 (SDSNH loc. 3126). Of the Orcutt collections that have not survived is one recovered "from cistern dug at southeast corner 21st and 'J' Streets, San Diego, California, September 13, 1882, 10 feet below the surface" (Orcutt, 1900b, p. 36). However, a small collection of fossils presently housed at the California Academy of Sciences (CAS loc. 53976) appears to have come from this same locality. This fossil material was collected by the pioneer malacologist, Henry Hemphill, who was active in the San Diego area during the late 1800's. The data accompanying this collection read simply: "Pleistocene fossils, San Diego, California, from a cistern 10 feet below surface." It is suggested here that this cistern is the same as that mentioned by Orcutt. This correlation is supported by Orcutt's published faunal list which contains two characteristic molluscan species also found in the Hemphill collection (*Janira dentata* = *Pecten vogdesi* and *Chione succincta* = *Chione californiensis*). All of these downtwon localities have generally been considered as Pleistocene in age by previous workers, although none of these sites have ever received any detailed attention in the literature.

LOMA PORTAL LOCALITIES

In 1929, Stephens (p. 255) described a Pleistocene deposit at the northeast end of Point Loma (SDSNH loc. 0070) and included a brief discussion of the associated molluscan fauna. Stephens considered this deposit to be a protected facies correlative with Nestor terrace deposits along the west side of Point Loma. Stephens' original fossil material has since been lost but fortunately the late Dr. L. G. Hertlein had made a collection from this same locality that today is housed at the California Academy of Sciences (CAS loc. 1429). A similiar history applies to a deposit once exposed along Rosecrans Street near its intersection with Dumas and Curtis Streets. Stephens (1929, p. 252) had described fossils from this area (SDSNH loc. 0057) which have since been lost, but Hertlein's collection from the same area has survived (CAS loc. 1407).

In 1945, construction of the Frontier Housing Project at the north end of Point Loma exposed fossiliferous deposits from which only a small collection of fossils was salvaged (SDSNH loc. 0716). Hertlein and Grant (1972, p. 196) described the type of *Argopecten abietis abbotti* from this material and assigned the entire deposit to the Pliocene San Diego Formation. Just what criteria they based this correlation on is uncertain as there are no characteristic San Diego Formation fossils present in the collection from this deposit. In addition, there is no known occurrence of this distinctive Pliocene rock unit in this part of San Diego.

In 1956, Hertlein collected fossil material (CAS loc. 34791) from what he termed the "Midway Housing Project ... about 100 yards from the highway." From discussions with Dean Milow (personal communication) it is apparent that Hertlein was referring to the Frontier Housing Project and that his locality was very near to SDSNH loc. 0716.

Kern (1977, p. 1557) reported on a Pleistocene marine deposit from the Loma Portal area (SDSU loc. 2530) which he considered at the time of publication to be a Nestor terrace correlative. He has since revised this correlation based on amino-acid racemization of *Chione* shells and considers the deposit to represent an older Pleistocene unit (J.P. Kern, personal communication).

LOGAN HEIGHTS LOCALITIES

All of the Pleistocene deposits known from this region of San Diego occur in the general area of 32nd Street and Greely Avenue. Stephens (1929, p. 251) was the first to describe fossils from here (SDSNH loc. 0055) but again his material has been lost. However, Charles Sternberg made a small collection of fossils from this area during the 1920's (CAS loc. 1137). Hertlein and Grant (1972, p. 181) referred to fossils from this locality (*Pecten vogdesi*), which they considered to be Pliocene in age based on information supplied to them by George Kanakoff. It is not clear what criteria Kanakoff used to reach this conclusion since again no characteristic San Diego Formation fossils occur in collections from this locality. Kanakoff did, however, add that he considered a fossiliferous horizon overlying the "Pliocene" beds at this locality to be Pleistocene in age based on the common occurrence of *Chione*. I have visited this locality and examined fossils throughout the exposed section and it seems obvious that the entire deposit is Pleistocene, with the "Pliocene" fossils of Hertlein and Grant occurring in the same horizons as the Pleistocene indices recognized by Kanakoff. One of the curious aspects of this locality is the extreme induration of some of the fossiliferous horizons, some of which contain only shell molds. Perhaps it was this induration, which is unusual in the San Diego Pleistocene, that prompted Kanakoff to refer this locality to the Pliocene. It is interesting to note that Hertlein and Grant (1972, p. 182) considered the occurrence of *Pecten vogdesi* at CAS loc. 1137 to be a Pliocene record for that taxon, stating that "Except for its occurrence in the San Diego Formation, *Pecten vogdesi* has been reported from southern California only in beds of Pleistocene age." In light of data presented in this paper, *Pecten vogdesi* appears indeed to be restricted in southern California to Pleistocene deposits.

An additional collection was made from the Greely Avenue area in 1973 by J. P. Kern (SDSNH loc. 3020).

AGE AND CORRELATION

Historically, all San Diego Pleistocene molluscan faunas have been correlated with the Bay Point Formation of Hertlein and Grant (1939, p. 71-72), which they and subsequent workers (Addicott and Emerson, 1959, p. 24) in-turn have correlated with the regional type upper Pleistocene Palos Verdes Sand of Woodring *et al.* (1946). However, recent work by Kern (1977), Masters and Bada (1977), Wehmiller *et al.* (1977), and Karrow and Bada (1980) using amino-acid racemization have documented the existence of at least three temporally distinct upper Pleistocene marine deposits in the San Diego area. In terms of absolute ages they have distinguished deposits at 85,000 years B.P. (Bird Rock terrace), 120,000 years B.P. (Nestor terrace), and 220,000 years B.P. (unnamed). The deposits discussed in this paper represent a distinct older group than those previously known from San Diego. Amino-acid analysis of *Chione* shells from SDSNH loc. 3064 (downtown), and SDSHN loc. 3020

(Logan Heights) has given dates of 560,000 (±75,000) years B.P. for these deposits (E. Artim, personal communication). In addition, analysis of *Chione* from SDSU loc. 2530 (Loma Portal) has given a date of 500,000 to 600,000 years B.P. (J.P. Kern, personal communication).

In terms of biostratigraphic correlation these older deposits contain several distinctive index species that allow their separation from younger deposits on strictly faunal grounds. These index taxa include two living southern extralimital species, *Turritella gonostoma* and *Pecten vogdesi*, and an extinct but probable warm water taxon, *Argopecten abietis abbotti*. These taxa have to date been encountered only in San Diego collections from the three areas discussed here.

Warm water faunal elements also characterize the 220,000 years B.P. deposits and perhaps it could be argued that in the absence of absolute age control these two groups of deposits would appear to be merely different facies of a single interglacial event. However, in the downtown area alone we find both groups of deposits, each reflecting a protected bay environment or biotope and each containing a unique assemblage of molluscan species. This, coupled with the persistence of the older fauna into the Loma Portal and Logan Heights areas and the occurrence of the extinct *Argopecten* species, supports the idea that these deposits are indeed separated in time.

Because of this condition of at least four temporally distinct upper Pleistocene deposits in the San Diego area it seems best for the present to follow the suggestion of Kern (1977, p. 1560) and restrict use of the name Bay Point Formation to only strata at the type locality (Crown Point, 220,000 years B.P.) and to refer informally to these other deposits.

THE FAUNA

A total of 38 molluscan species (17 gastropods and 21 pelecypods) are reported from this older fauna here designated as the Broadway Fauna for its occurrence in trench exposures along Broadway in the city of San Diego (see Table I). It should be noted that of the 14 fossil collections examined for this study only two (SDSNH loc. 3064 and SDSU loc. 2530) represent faunal assemblages resulting from bulk-sampling methods. The remaining twelve collections are either remnants of older, once larger collections or represent the results of selective sampling techinques. The low species diversity evident in Table I is due to this remnant and/or selective sampling condition. The largest collection, SDSU loc. 2530 (Loma Portal) contains 29 species, 13 of which were found only at this locality. The smallest collection, SDSNH loc. 3132 (downtown), contains only a single species and represents a remnant of an older collection.

Of the 38 molluscan species reported in the Broadway Fauna only 6 can be said to be somewhat characteristic of the fauna in general. These include: *Turritella gonostoma*, *Argopecten abietis abbotti*, *Chione californiensis*, *Lucinisca nuttalli*, *Ostrea lurida*, and *Pecten vogdesi*. As discussed earlier, three of these taxa (*T. gonostoma*, *A. abietis abbotti*, and *P. vogdesi*) serve as local biostratigraphic indices for the recognition of this fauna. Because of their importance these taxa are figured in Plate I.

Interestingly, specimens of *Chione californiensis* from the downtown and Logan Heights localities display severe boring by sponges (see Plate I). This style of preservation is unusual and not found in younger San Diego Pleistocene faunas.

Table I - Faunal list of molluscan species reported from the Broadway Fauna. Counts were only made for fossils from SDSNH loc. 3064 and SDSU loc. 2530. For the remaining localities only relative frequencies were noted (A = abundant, C = common, F = frequent, and R = rare).

SPECIES	SDSNH 0706	SDSNH 3064	SDSNH 3126	SDSNH 3132	CAS 791	CAS 53976	SDSNH 0716	CAS 1407	CAS 1429	CAS 34791	SDSU 2530	SDSNH 3020	SDSNH 3133
Gastropoda													
Alabina tenuisculpta Carpenter, 1864	-	-	-	-	-	-	-	-	-	-	59	-	-
Bittium rugatum Carpenter, 1866	-	-	-	-	-	-	-	-	-	-	45	-	-
Caecum californicum Dall, 1885	-	2	-	-	-	-	-	-	-	-	12	-	-
Cerithidea californica (Haldeman) 1840	-	2	-	-	-	-	-	-	-	-	63	-	-
Crepidula onyx Sowerby, 1824	-	-	-	-	-	-	-	-	-	-	1	-	-
Crepidula sp. indet.	-	-	-	-	-	-	-	-	-	-	-	R	-
Crucibulum spinosum (Sowerby) 1824	-	-	-	-	-	-	-	-	R	-	22	-	-
Epitonium tinctum (Carpenter) 1864	-	-	-	-	-	-	-	-	-	-	5	-	-
Iselica fenestrata (Carpenter) 1864	-	-	-	-	-	-	-	-	-	-	1	-	-
Melampus olivaceous Carpenter, 1857	-	-	-	-	-	-	-	-	-	-	4	-	-
Nassarius tegula (Reeve) 1853	-	-	-	-	-	-	-	-	R	-	11	-	R
Neverita reclusiana (Deshayes) 1839	-	1	-	-	-	-	-	-	-	-	-	-	-
Terebra sp. indet.	R	-	-	-	-	-	-	-	-	-	1	-	-
Tricolia compta (Gould) 1855	-	-	-	-	-	-	-	-	-	-	25	-	-
Triphora pedroana Bartsch, 1907	-	-	-	-	-	-	-	-	-	-	1	-	-
Turbonilla tenuicula Gould, 1853	-	-	-	-	-	-	-	-	-	-	4	-	-
Turritella gonostoma Valenciennes, 1832	F	92	R	-	F	-	R	-	F	R	38	-	-
Pelecypoda													
Anomia peruviana Orbigny, 1846	-	1	-	-	-	-	-	C	-	-	2	-	-
Argopecten abietis abbotti (Hertlein & Grant) 1972	-	21	-	-	-	R	R	R	-	-	-	R	R
Argopecten sp. indet.	-	-	-	-		F	-	-	R	-	3	R	-
Chione californiensis (Broderip) 1835	F	63	-	-	R	F	-	-	C	R	29	A	A
Chione fluctifraga (Sowerby) 1835	-	-	-	R	-	R	-	-	-	-	-	-	-
Corbula luteola Carpenter, 1864	-	-	-	-	-	-	-	-	-	-	4	-	-
Crassinella pacifica (C.B. Adams) 1852	-	2	-	-	-	-	-	-	-	-	23	-	-
Cryptomya californica (Conrad) 1837	-	-	-	-	-	-	-	-	R	-	18	-	-
Diplodonta subquadrata (Carpenter) 1856	-	4	-	-	-	-	-	-	-	-	-	-	-
Felaniella sericata (Reeve) 1850	R	3	-	-	-	-	-	F	-	-	345	F	-
Laevicardium substriatum (Conrad) 1837	-	-	-	-	-	-	-	-	-	-	12	-	-
Lucinisca nuttalli (Conrad) 1837	R	8	-	-	-	-	-	-	-	-	-	R	F
Lyonsia californica Conrad, 1837	-	-	-	-	-	-	-	-	-	-	4	-	-
Megapitaria squalida (Sowerby) 1835	1	-	-	-	-	-	-	-	-	-	-	-	-
Nucula exiqua Sowerby, 1833	-	1	-	-	-	-	-	-	-	-	26	-	-
Ostrea lurida Carpenter, 1864	R	1	-	-	-	-	F	-	-	C	62	F	F
Pecten vogdesi Arnold, 1906	R	7	-	-	-	R	-	-	-	-	-	-	R
Pitar newcombianus (Gabb) 1865	-	1	-	-	-	-	-	-	-	-	-	F	R
Psammotreta viridotincta (Carpenter) 1856	-	-	-	-	-	-	-	-	-	-	1	-	-
Tagelus californianus (Conrad) 1837	-	-	-	-	-	-	-	-	-	-	9	R	-
Tellina meropsis Dall, 1900	-	-	-	-	-	-	-	-	-	-	18	R	R

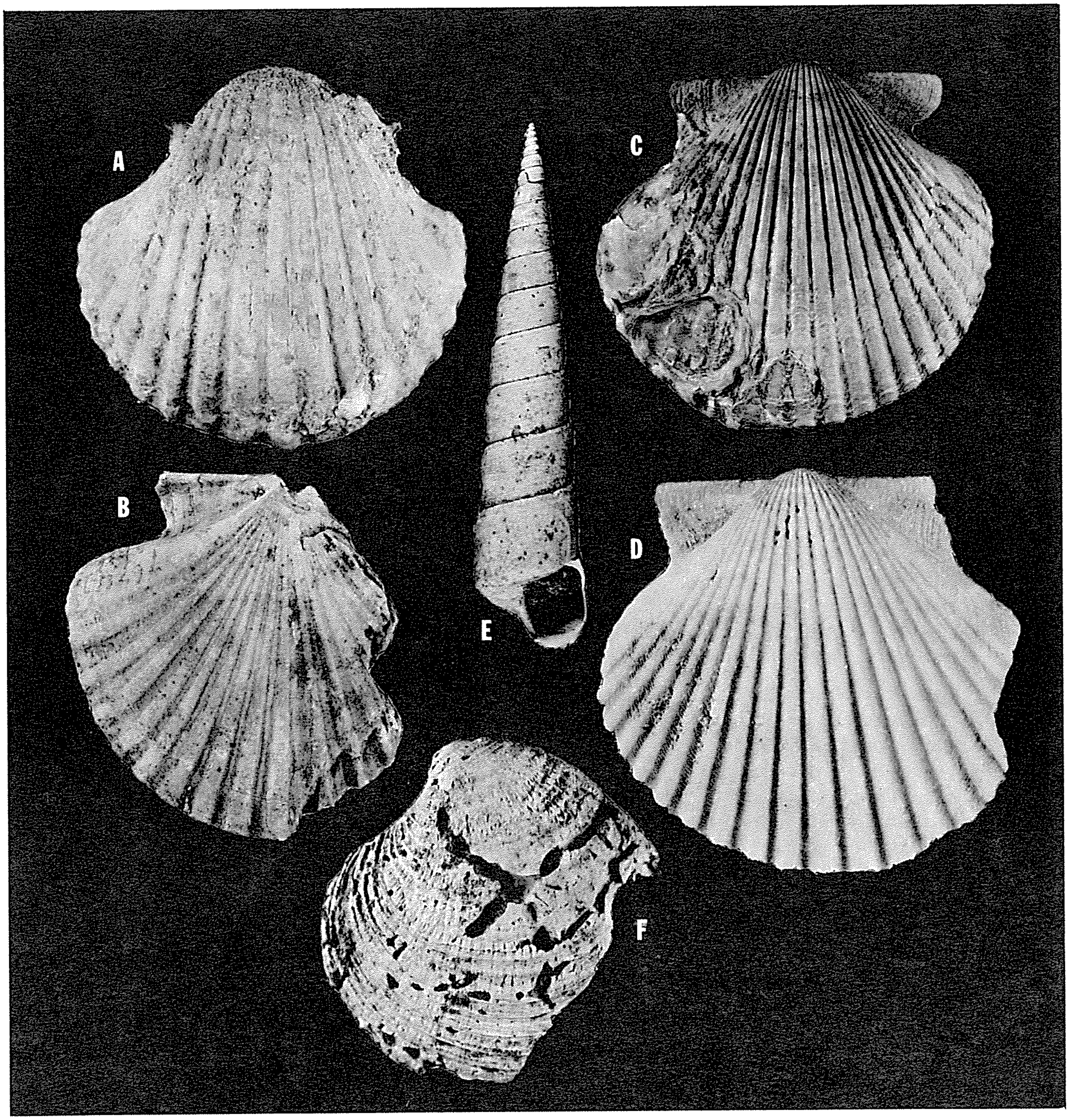

Plate 1 - A, B. *Pecten vogdesi* Arnold. A) SDSNH cat. 14159, from SDSNH loc. 0706, exterior of right valve, .6 x. B) same lot, exterior of left valve, .7 x.

C, D. *Argopecten abietis abbotti* (Hertlein and Grant). C) SDSNH holotype 04334, from SDSNH loc. 0716, exterior of right valve, .5 x. D) SDSNH cat. 21395, SDSNH loc. 3064, exterior of left valve, 1.2 x.

E. *Turritella gonostoma* Valenciennes. SDSNH cat. 12347, SDSNH loc. 0716, 1.1 x.

F. *Chione californiensis* (Broderip). SDSNH cat. 21202, SDSNH loc. 3020, exterior of left valve showing sponge borings, 1.3 x.

PALEOENVIRONMENT

Perhaps the most obvious environmental parameter of the Broadway Fauna is water temperature. Of 38 reported molluscan taxa, 7 are locally extinct, southern extralimital species. These species and their present northern range end-points are: *Turritella gonostoma* (Gulf of California, Baja California, Mexico); *Diplodonta subquadrata* (San Ignacio Lagoon, Baja California, Mexico); *Felaniella sericata* (San Ignacio Lagoon, Baja California, Mexico); *Megapitaria squalida* (Scammon Lagoon, Baja California, Mexico); and *Psammotreta viridotincta* (Gulf of California, Baja California, Mexico). *Argopecten abietis abbotti*, an extinct species, is closely related to the modern *A. circularis*. This high percentage of southern extralimital species suggests that water temperatures were warmer than today during accumulation of the Broadway Fauna.

In terms of degree of exposure, the majority of the faunal elements reflect protected marine conditions. *Cerithidea californica*, *Nassarius tegula*, *Turritella gonostoma*, and *Tagelus californianus* are today restricted to the quiet waters of bays or estuaries.

Substrate indices in the fauna suggest both mud and sand bottoms. *Cerithidea californica*, *Melampus olivaceous*, *Turritella gonostoma*, and *Lyonsia californica* reflect a mud or sandy-mud substrate, while *Chione californiensis*, *Cryptomya californica*, *Felaniella sericata*, and *Lucinisca nuttalli* reflect a sand or muddy-sand substrate. It is probable that these two bottom types contributed respective molluscan species into a common post-mortem accumulation site.

As regards water depth the majority of the fauna indicates a littoral to sublittoral environment. Several taxa, including *Cerithidea californica* and *Melampus olivaceous*, are today strictly littoral species while others such as *Pitar newcombianus* are restricted to the sublittoral zone. It appears that a mixing of these two depth zones has occurred with the shallower taxa probably being carried into deeper water into a sublittoral shell lag deposit.

The Broadway Fauna is dominated by taxa requiring normal marine salinities. A minor brackish water element is indicated by the presence of *Cerithidea californica* and *Melampus olivaceous*. As noted above these species were probably transported after death, in this instance from a restricted back-bay habitat out into the more open marine areas of the embayment.

PALEOGEOGRAPHIC SETTING

Valentine (1961, p. 356-359) described the late Pleistocene geography of the San Diego area and offered a model wherein Point Loma was an island (Loma Island) separated from the mainland by bay and estuarine environments. In this paper he defined a Pleistocene San Diego Embayment south of Loma Island that was connected by a narrow strait (Loma Strait) to a Pleistocene Mission Embayment to the north. This basic paleogeography apparently persisted throughout the late Pleistocene and is applicable to the Broadway Fauna. At that time the protection from direct wave attack afforded by Loma Island allowed protected bay and estuarine conditions to exist in Loma Strait (Loma Portal localities) and along the mainland shoreline of the San Diego Embayment (downtown and Logan Heights localities).

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REGISTER OF LOCALITIES

The Pleistocene localities discussed in this paper are grouped below by the institution in which they are housed.

CALIFORNIA ACADEMY OF SCIENCES

CAS loc. 791 - Excavation of Union Building, San Diego, 10-20 feet below surface. Collected by Mr. Kelsey, 2 February 1907.

CAS loc. 1137 - 31st Street and Logan Avenue, San Diego. Collected by Charles Sternberg.

CAS loc. 1407 - Oyster bed on southwest corner of Curtis and Rosecrans Streets on east side of Point Loma. Collected by L. G. Hertlein, August 1928.

CAS loc. 1429 - Pleistocene overlying Eocene sandstone on NE end of Point Loma. Just south of intersection of Midway Drive and U.S. Government Dike on south side of San Diego River. In NE corner of Pueblo Lot 219, about 12 feet below top of cliff. Collected by L. G. Hertlein, August 1928.

CAS loc. 34791 - From Midway Housing Project, in cliffs at about 20-30 feet above base. About 100 yards from Highway. Collected by L. G. Hertlein, 14 July 1956.

CAS loc. 53976 - From a cistern 10 feet below the surface -- probably at the southeast corner of intersection of 21st and "J" Streets. Collected by H. Hemphill ca. 1882.

SAN DIEGO NATURAL HISTORY MUSEUM

SDSNH loc. 0706 - Basement of lot for building of Southern Title Guarantee Company, 3rd near Broadway at a depth of 18 feet. Collected by Mr. Scalley, 22 April 1914.

SDSNH loc. 0716 - From cut at Frontier Housing Project, north end of Point Loma. Collected by Patrick Hanratty, April 1945.

SDSNH loc. 3020 - 32nd Street between Greely and Logan Avenues. Collected from a low cut for a driveway on east side of 32nd Street near crest of hill. Elevation approximately 40 feet above sea level. Collected by J. P. Kern and A. Ross, ca. 1973.

SDSNH loc. 3064 - Pipeline trench along Broadway collected at a depth of 13 feet below street level. Lithology a reddish-brown, poorly sorted, subangular coarse to fine-grained, argillaceous, fossiliferous sand, locally calcareously cemented. Elevation approximately 31 feet above sea level. Collected by Dorian Mills, 23 June 1980.

SDSNH loc. 3126 - From 15 feet below the surface at corner of 8th and "H". Collected by C. R. Orcutt, 1888.

SDSNH loc. 3132 - 2nd Street near "A". From a sewer trench 6 feet below the center of the street. Collected by C. R. Orcutt, 16 April 1889.

SDSNH loc. 3133 - 32nd Street near its intersection with Logan Avenue on south side of street in fresh cut along alley easement. Collected by T. A. Deméré, 8 January 1981.

SAN DIEGO STATE UNIVERSITY

SDSU loc. 2530 - Bank in vacant lot facing Midway Drive northeast of Grove Drive, northeastern Point Loma. Elevation approximately 30 feet above sea level. Collected by J. P. Kern, ca. 1975.

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QUATERNARY RELICT SOILS, SAN DIEGO COUNTY

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INTRODUCTION

Many of the soils that cover the mesas of San Diego are paleosols of the relict variety, that is, surface soils that owe most of their characteristics to an earlier climatic regime. These relict soils are especially well displayed on the gently west-dipping, well-developed coastal terraces that have formed in the San Diego area from Late Pliocene to present. The terraces have received varying names in different parts of the region. This discussion will focus upon the area north of Mission Valley where Ellis and Lee (1919) and Hanna (1926) described and named three major terraces. The oldest and easternmost is the strongly dissected Poway Terrace which ranges from about 250 to 375 m elevation and apparently is a nonmarine surface stripped upon resistant conglomerate layers within the Poway Conglomerate (Figure 1). The youngest and topographically lowest is the marine La Jolla Terrace which is developed near the modern shoreline to the west. The intermediate terrace is the Linda Vista Terrace (Figure 2).

LINDA VISTA TERRACE

The Linda Vista Terrace was cut by the eastward-transgressing ocean and then capped by sedimentary rocks during the regression of the sea over the cut platform. The terrace covers an extensive area, ranges in elevation from about 100 to 150 m above sea level, is not severely dissected, and has some good exposures of its weathering profiles on and within the sedimentary cap. The sedimentary rocks resting upon the platform are mixed nearshore marine and fluvial deposits of conglomerate and sandstone up to several meters thick. The sediments were largely derived by erosion and reworking of the Eocene sedimentary rocks which underlie and crop out east of the paleoshorelines. This caprock was referred to as the Lindavista terrace fill by Hanna (1926) and is regarded as the Lindavista Formation by most geologists. However, most authors concerned with the pedology of the San Diego area have called this sedimentary body the Sweitzer Formation following Hertlein and Grant (1944). Upon the Linda Vista Terrace are elongate ridges up to 15 m high and several km long that trend north-south to northwest-southeast. They were formed primarily as wind-blown, back-beach dunes during stillstands of the retreating sea (Hertlein and Grant, 1944; Emery, 1950; Peterson, 1970).

In the Tierrasanta housing development, grading operations during construction uncovered fossiliferous nearshore rocky bottom and sandy deposits within the regressive Lindavista Formation. Kennedy (1973) collected and described the fauna which are of Late Pliocene to Early Pleistocene age. This locality is seaward of the pronounced 100 m high beach cliffs that mark the eastern boundary of the marine Linda Vista Terrace below the higher, nonmarine Poway Terrace (Figure 1). Therefore the Linda Vista Terrace dates back to at least the Early Pleistocene and possibly the Late Pliocene.

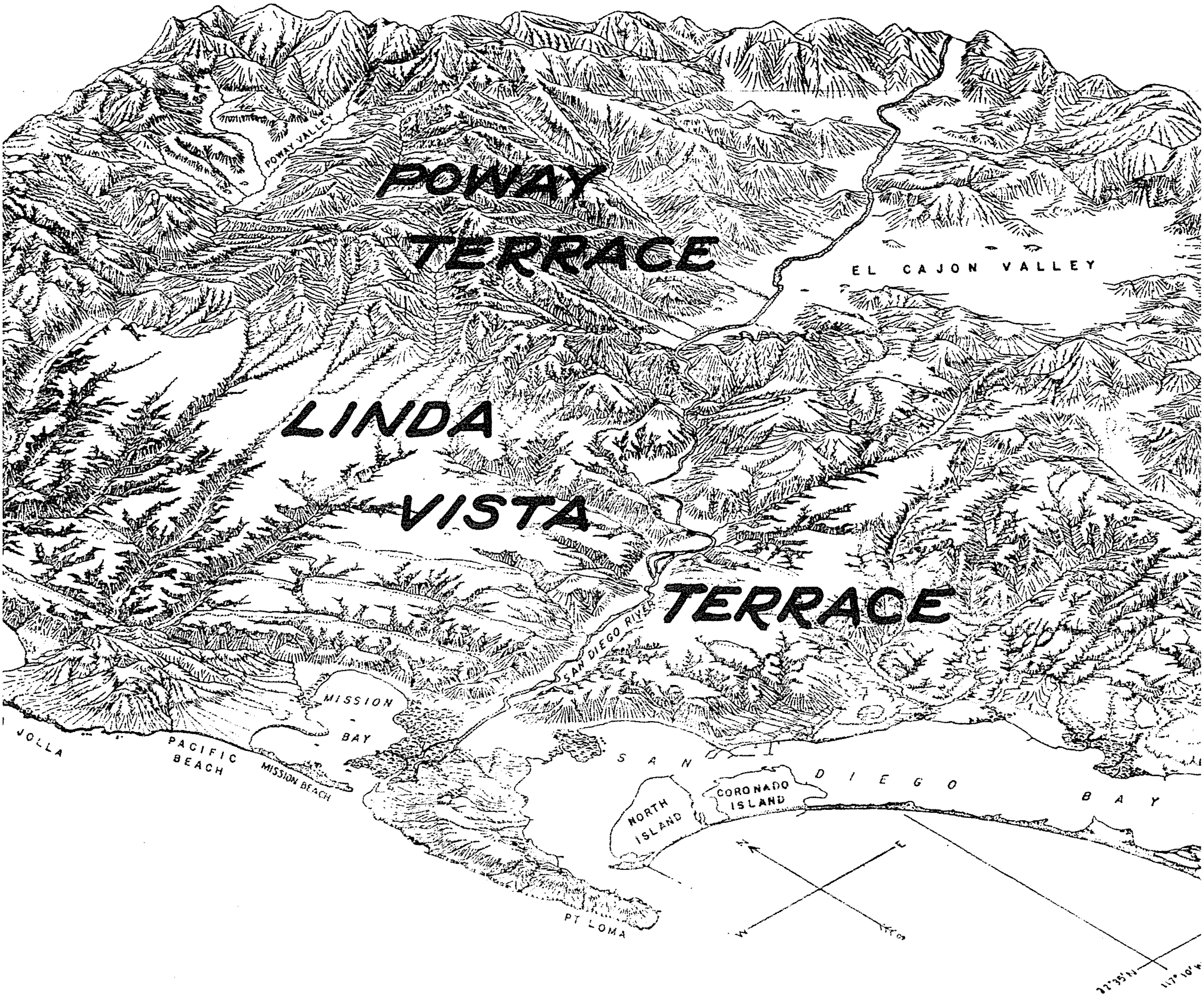

Figure 1. Physiography of San Diego. Modified from Hertlein and Grant (1944).

The weathering profiles of the Linda Vista Terrace are characterized by pronounced reddish color due to precipitation and oxidation of iron-bearing minerals at depths ranging up to at least 15 m, acid pH readings of 4.3 to 6, and a discontinuous one m thick hardpan. Additionally the back-beach sand ridges contain opalized root tubes and a prominent layer of small pebble-sized, iron-stone concretions (Figure 3). The above characteristics seem peculiar indeed when the present climate is considered. Today the Linda Vista Terrace is part of the coastal plain province where mean annual temperature is about 17°C with warm dry summers and mild winters, average annual rainfall is about 25 cm with most falling during the winter months, and evapotranspiration is high with the result that rainfall usually does not penetrate deeply. Coastal plain soils forming under the present climate are thin and leached only near the surface, are low in organic matter and locally have some accumulation of calcium carbonate particularly when they have formed on caliche-bearing Eocene rocks. The incompatibility of the modern climate and the thick red soils led Carter (1957) to conclude they are relicts of an earlier humid climate.

The two soil series that best display the relict soil characteristics are the Carlsbad and Redding. A brief description of their salient properties compiled largely from Storie and Carpenter (1934), Carter (1957), and Bowman _et al._ (1973) will be presented before considering their conditions of formation in more detail.

REDDING SERIES

The Redding is developed upon the sandstones and conglomerates of the Lindavista Formation; the entire volume of the formation shows the effects of soil-forming processes. Carter (1957) pointed out that the Redding occurs on the higher, older terrace levels, is a maturely developed soil with advanced decay of igneous cobbles, extreme hardpans, cemented substrata, and pronounced development of gilgai or vernal pool topography. Bowman _et al._ (1973) mapped 61,994 acres of Redding soil in the coastal plain province of San Diego County and classified it as an Alfisol of the Abruptic Durixeralf subgroup. A generalized profile is given in Table 1.

Table 1. Generalized profile of the Redding Soil Series

A_1 0-15 cm thick; yellowish brown, gravelly sandy loam; nonsticky; pH = 5.8

A_2 10-35 cm thick; light brown, gravelly loam; nonsticky; pH = 5.5

B_t 30-55 cm thick; yellowish red, gravelly clay; sticky; thick clay films; pH = 4.5

C_m 35-75 cm thick; yellowish red, discontinuous iron- and silica-cemented hardpan; pH = 4.2

The hardpan is below the main zone of clay accumulation and, in some localities, has been traced by Carter (1957) as a continuous layer extending under the Carlsbad Series soils.

CARLSBAD SERIES

The Carlsbad is developed upon the dominantly wind-deposited, back-beach sand ridges that rise above the general terrace level. Bowman et al. (1973) mapped 7,480 acres of Carlsbad soil in the coastal plain province of San Diego County and classified it as an Inceptisol of the Haplic Durochrept subgroup. The profile of the Carlsbad is similar to the Redding except for a prominent layer of subspherical, apparently iron-oxide cemented sandstone concretions (Figure 3) above the maximum clayey illuvial horizon which in turn rests upon the mottled iron- and silica-cemented hardpan (Figure 4). Emery (1950) reported that the iron-stone concretions range from 2 to 30 mm diameter, average 9 mm diameter and have concentric bands of cement roughly parallel to the outer surface. A generalized soil profile is derived by combining the observations of Bowman et al. (1973) and features exposed in roadcuts through a back-beach ridge on Eastgate Mall just north of Miramar Road (Table 2).

Table 2. Generalized profile of the Carlsbad Soil Series

A	0-8 cm deep; pale brown, loamy sand; fine granular structure, very friable, nonsticky; pH = 6
B_{ir}	8-70 cm deep; pale reddish brown, gravelly loamy sand; friable; hard; nonsticky; loaded with small pebble-sized iron-stone concretions; pH = 6.5
B_t	70-150 cm deep; pale yellowish brown, reddens with depth, sandy clay; weak; sticky; pH = 5.5
C_m	150-250 cm deep; reddish with light bluish-gray mottling; iron- and silica-cemented sand; hardpan; irregular thickness due to varying depths of cementation; very hard; siliceous root clasts; nonsticky; pH = 6.0

At some localities the sandstone continues below the hardpan for greater than 15 m thickness and it all contains the prominent oxidized iron mineral precipitated during the formation of the soil. Smith et al. (1977) reported that the original precipitate was a ferrous iron-rich phyllosilicate similar to nontronite or glauconite. The ferrous iron implies an abundance of organics which may have been co-precipitated. During later diagenesis, oxidation changed the iron to the ferric state thus destroying the crystallinity of the phyllosilicate. This oxidation destroyed whatever organics may have been present. Only in the most advanced diagenetic stages were some blebs of iron oxide created. Emery (1950) plotted the depth distribution of Fe_2O_3 and reported enrichment covering a broad depth that was well below the concretion-bearing layer. He also stated that the sandstones contain fewer feldspar grains near the surface due to more complete weathering. Another interesting feature is the presence of opaline root tubes which show mobilization and reprecipitation of silica.

PALEOCLIMATIC INTERPRETATION

It is difficult to pinpoint the formative conditions of the relict soils known as the Redding and Carlsbad Series. The original upper layers of the soil profile have been stripped by erosion and reconstructions must be

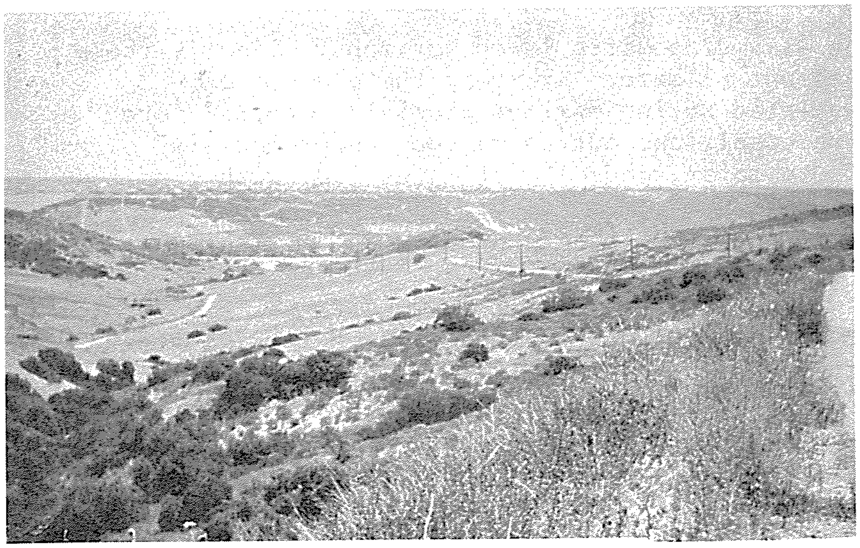

Figure 2. A portion of the Linda Vista Terrace viewed looking south toward Tierrasanta.

Figure 3. Iron-stone concretion layer (Bir horizon) in Carlsbad Soil Series. Locality is roadcut through prominent back-beach ridge along Eastgate Mall just north of Miramar Road.

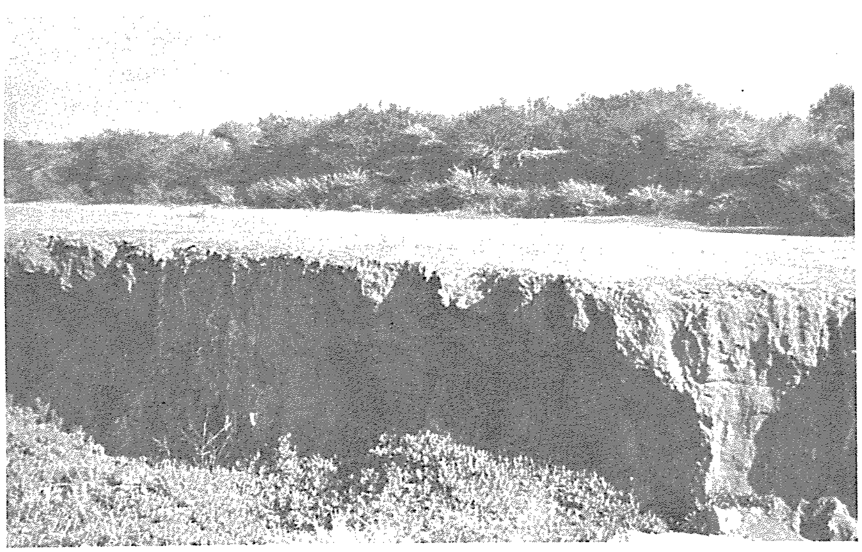

Figure 4. Stripped surface on hardpan (Cm horizon) in Carlsbad Soil Series. Locality is in quarry atop back-beach ridge on Eastgate Mall just north of Miramar Road.

based on interpretations of the less diagnostic lower horizons. Clearly these soils did not form under the present climate. Are they the product of Spodosol-like conditions that existed during maximum glacial advances? Are they the product of Ultisol-like conditions during maximum interglacials? Are they a composite of both these moist, podzolic climates? Or with simple north-south shifts of climatic belts the composite paleosol may have formed during a wetter glacial time from a climate that presently exists in the Pacific Northwest and have been little changed by an interglacial desert climate as presently exists to the south in the coastal deserts of Baja California Sur. Whatever paleoclimate or combination of paleoclimates produced these soils, they have been affected negligibly by the present mild, semi-arid to arid climate which has prevailed for the last several thousand years.

Carter (1957) called upon 15° latitudinal shifts of climatic belts at San Diego between interglacial and glacial times to explain the relict soils mantling the Linda Vista Terrace and other localities. During a glacial advance the climate of the present-day Pacific Northwestern United States would have shifted to San Diego with rainfalls of 50 to 100 cm per year. The rare stands of Torrey Pines in San Diego today are described as probable remnants of Ice Age forests that thrived in the former climate. Strongly humid soil conditions and the organic acids associated with conifer forests produce iron and clay movement from the A to B horizon. Carter (1957) referred to the whole profile as a massive humid soil with iron cementation, pH's in the low 4's, and depth of weathering approaching conditions more commonly found in humid tropical regions.

Crocker (1956) noted that the Redding Series is co-extensive with the Sweitzer Formation (=Lindavista Formation) and nearly co-extensive with the underlying marine-planed, Eocene Poway Conglomerate. Crocker determined the pH of 100 samples of Lindavista Formation and Poway Conglomerate and found nearly 90% with pH less than 5. Inspection of the pH values led Crocker to claim that the acidity of the Redding soils was inherited from the source rocks.

Crocker's (1956) assumptions about the depth of rock affected by the soil-forming processes may not have been correct. Crocker claimed that Lindavista Formation (Sweitzer) samples were collected at depths that would have been only insignificantly influenced by soil-forming processes yet the thickness of the Formation is described as only 2 to 6 m. But the downward transference and precipitation of iron-bearing minerals from the soil-forming interval extends to tens of meters depth in permeable sandstones and conglomerates. Not only are the back-beach sand ridges on the Linda Vista Terrace affected throughout their entire thickness (locally up to 25 m) but along the modern sea cliffs the Eocene and Cretaceous sandstones underlying the Lindavista Formation are cemented by the same iron-bearing mineral and even contain "cannonball" concretions of the same cement (Smith *et al*., 1977).

Crocker's (1956) claim of acidic Poway Conglomerate source rock is questionable. The Late Eocene rocks contain an abundance of caliche beds, an immature clay mineral suite, salt-fractured clasts and exotic fluvial conglomerates which all testify to a semi-arid climate with about 50 to 65 cm of annual rainfall and potential evapotranspiration greater than precipitation (Peterson and Abbott, 1979). The calcium carbonate precipitated in the soils give alkaline pH's to the Eocene strata. Crocker's (1956) samples of Poway Conglomerate source rock were collected from roadcuts going down the steep Poway grade descending into Poway Valley. The low pH's of those samples are due to the high acidity of organic acid-rich Pleistocene groundwater that leached the caliche from the Poway Conglomerate as it flowed to exit on the steep slopes around Poway Valley. Hence, the acid pH's of Crocker's samples are further evidence of the length and severity of the Pleistocene climates of San Diego.

The Ice Age climate of southern California is still difficult to pinpoint and must be assessed from regional studies. In 1953, Flohn (in Flint, 1971) graphed the latitudinal precipitation patterns. He showed that near the southern extent of the westerlies wind belt in the northern hemisphere the precipitation could well have been significantly greater than at present. The CLIMAP project member's report (1976) showed that 18,000 years before present, the ocean off California was 6 to 8°C colder. They reported that radiolarian species now found in cool waters off Washington, Oregon and northern California were present at least 1,000 km to the south in the California Current. The paleoclimate model for July of 18,000 years ago (Gates, 1976), shows a simulated surface air temperature over southern California that was 11°C colder than at present. This model showed the maximum zonal westerlies in the northern hemisphere displaced toward the south. Van Devender (1977) examined radiocarbon dated, pack rat midden sticks and found woodlands existed in the southwestern United States deserts during the Late Wisconsin. He attributed the flora to southward displacements of the subtropical Pacific high anticyclone and the polar jet stream and winter storm track. The Late Wisconsin climate probably had heavy winter precipitation. These studies all suggest that the Ice Age climate of southern California was more like that presently found in the Pacific Northwestern United States. This climatic condition may have produced Spodosol-like soils.

Buckman and Brady (1969) stated that Spodosol formation is likely on coarse-textured parent materials subject to ready leaching in a cold, temperate, humid climate under a forest vegetation. They further stated that Spodosol development is encouraged by decomposition of litter from low base species such as pine trees which creates strongly acid water that percolates and leaches deep into the profile. Ponomareva (1964) showed that fulvic acids will corrode hornblende and biotite to its constituent ions and still maintain a low pH. It was the corrosion of these minerals plus magnetite that produced most of the iron-bearing minerals precipitated in the paleosol profile.

The permeable sandstone and conglomerate of the Lindavista Formation fit the source rock requirement for Spodosol formation and the remnants of the Torrey Pine forests testify to the existence of acidic litter suitable for extensive leaching. During glacial advances a colder, more humid climate was present. The Aquod suborder further fits the portions of paleo-weathering profile remaining today, i.e. an iron-oxide mottled hardpan upon which perched water tables would have rested during seasonal saturation. The requisite accumulation of abundant organics at the surface is not verifiable because of erosion.

Another possibility is that the paleosol was produced wholly, or in part, under a moist, subtropical climate. Carter and Pendleton (1956) discussed the red-yellow podzolic soils (Ultisols) in the inner part of the southeastern United States which are interpreted to be relict soils. They have iron-enriched B horizons, bright red colors, enormous depth of weathering and pisolitic iron concretions seemingly related to alternate wetting and drying in association with sandy soils and good aeration. Buckman and Brady (1969) described Ultisols as usually moist soils developed under warm to tropical climates generally under forests. Ultisols have clay horizons, accumulations of iron oxides, acidic pH's, and maintain some weatherable minerals. These characteristics also fit the Redding and Carlsbad Series although not as convincingly.

The Redding and Carlsbad Series have acid pH's in originally well-drained sandy and gravelly soils, a well established illuvial clay layer above a mottled iron- and silica-cemented hardpan, precipitates of originally ferrous iron-bearing minerals to tens of m depth, and, in the Carlsbad series, abundant iron-stone concretions. These characteristics were imparted during a much wetter climate, or climates, aided by large amounts of organic acids freed from decomposing litter. The minor development of soil under today's semi-arid climate means that, in effect, large areas of San Diego's coastal plain expose relict soils.

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Batiquitos Lagoon or estuary at mouth of San Marcos Creek. Photo taken by Dr. John S. Shelton on November 24, 1959 looking toward site now occupied by La Costa.

THE LA COSTA AVENUE FAULT: AN EXAMPLE OF A SECONDARY STRUCTURE DEVELOPED IN A STRIKE-SLIP ZONE

by

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The La Costa Avenue fault is visible from southbound Interstate 5 in the roadcut on the south side of Batiquitos lagoon near Leucadia (Figure 1). This north- to northeast-trending, normal fault,offsetting Eocene sandstones and mudstones is an example of a secondary structure developed within a strike slip fault zone. Basal Pleistocene terrace deposits are faulted and subsequent deposits are draped across the fault illustrating the growth fault nature of the La Costa Avenue fault (Figure 2). Indistinct stratigraphy within the stratigraphic units makes correlation across the fault difficult, but the base of the shale unit is dropped approximately four meters to the southeast. Down-dip striae are visible on the caliche zone developed on the fault plane; no oblique motion is evident.

The existence of normal faulting in an area dominated by strike-slip faults has been described in the context of "wrench" style tectonics by Moody and Hill (1956) and Wilcox, Harding and Seely (1973). Orientation of the structures related to "wrench" or strike-slip faulting can be best illustrated by viewing the fault system in terms of simple shear. A model representing simple dextral shear is shown in Figure 3. Axes of compressional folds and reverse faults are developed parallel to A-A', normal to the principal axis of compression B-B'. Tensional features such as normal faults and associated drag folds are developed parallel to B-B'. Conjugate strike-slip faults, both synthetic and antithetic, are commonly formed at low and high angles, respectively, to the primary fault. Since the shear angle ψ increases with increasing simple shear strain, the orientation of these secondary structures will change with time. Ramsay (1967, p. 88) states that at initiation and early stages of simple shear, the principal axes of resulting strain make an angle of 45° to the shear plane. As deformation continues, the axes of principal strain will rotate towards parallelism with the primary fault (Figure 4). This phenomenon has been well documented along the San Andreas fault by Sylvester and Smith (1976).

It is emphasized that simple shear has the most general application to strike-slip faulting; faulting seldom acts along idealized, straight, planar faults. In reality, convergent and divergent motions along strike-slip faults produce structures that range in size from local to regional in extent (Crowell, 1974).

This orientation of the La Costa Avenue fault fits nicely into the simple shear model. The Rose Canyon fault zone, which extends offshore from La Jolla, parallels and controls the north- to northwest-orientation of the coastline (Moore, 1972). The N25E strike and steep 65°-70° SE dip of the La Costa Avenue fault corresponds to the direction to be expected during the small, early movements along the associated strike-slip fault. The small offset and inferred time of movement relate well to the Pleistocene movement on the Rose Canyon fault described by Gastil, Kies, and Melius (1979).

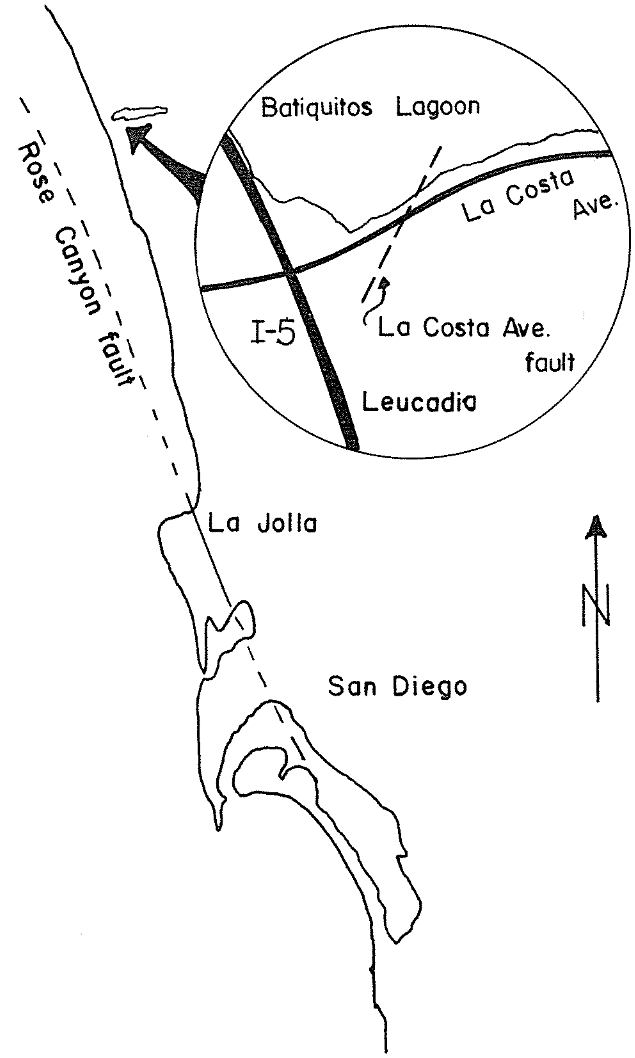


Figure 1. Location map showing Rose Canyon fault and La Costa Avenue fault (inset).

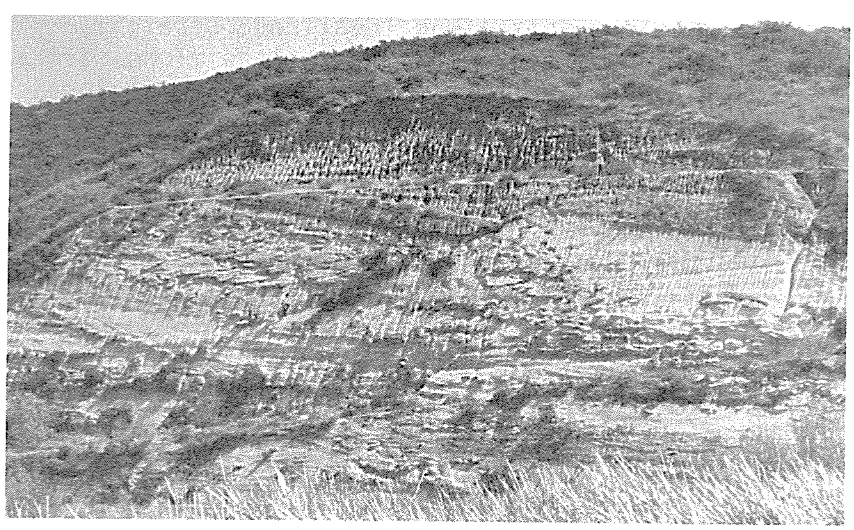


Figure 2. Photo of La Costa Avenue fault showing offset of dark mudstone and basal Pleistocene terrace deposits.

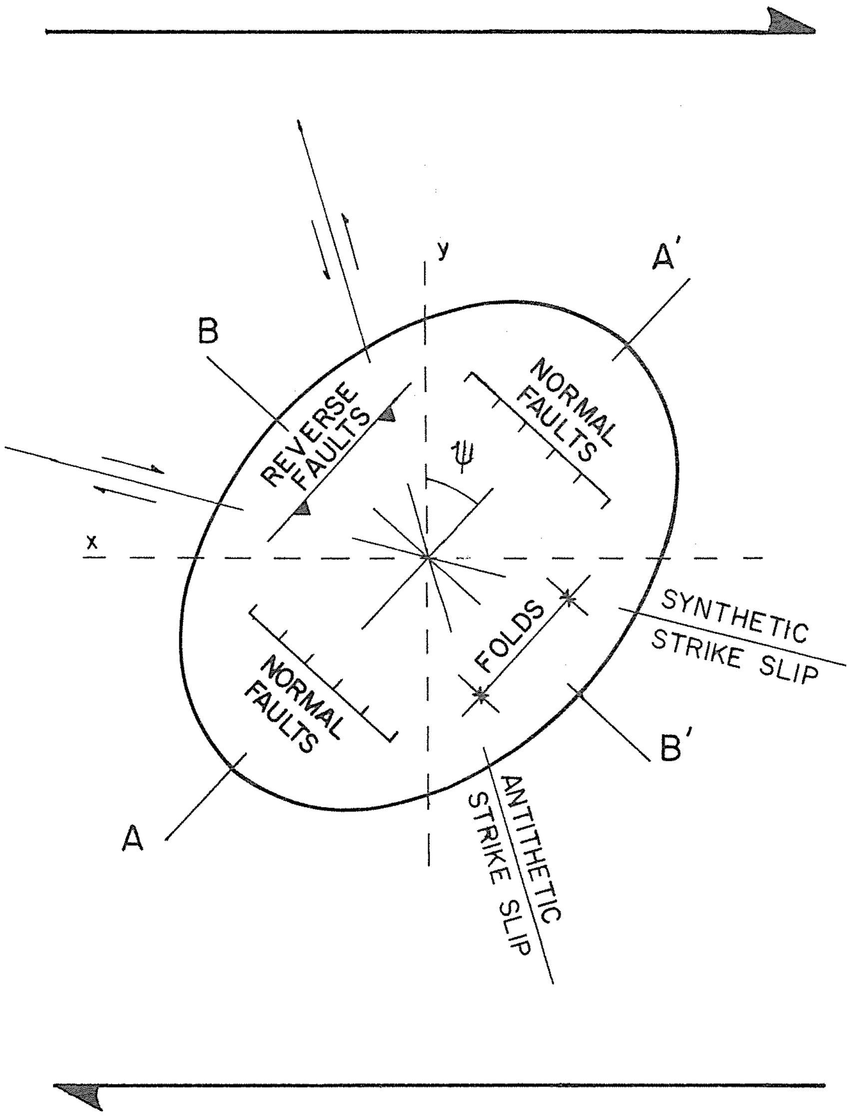
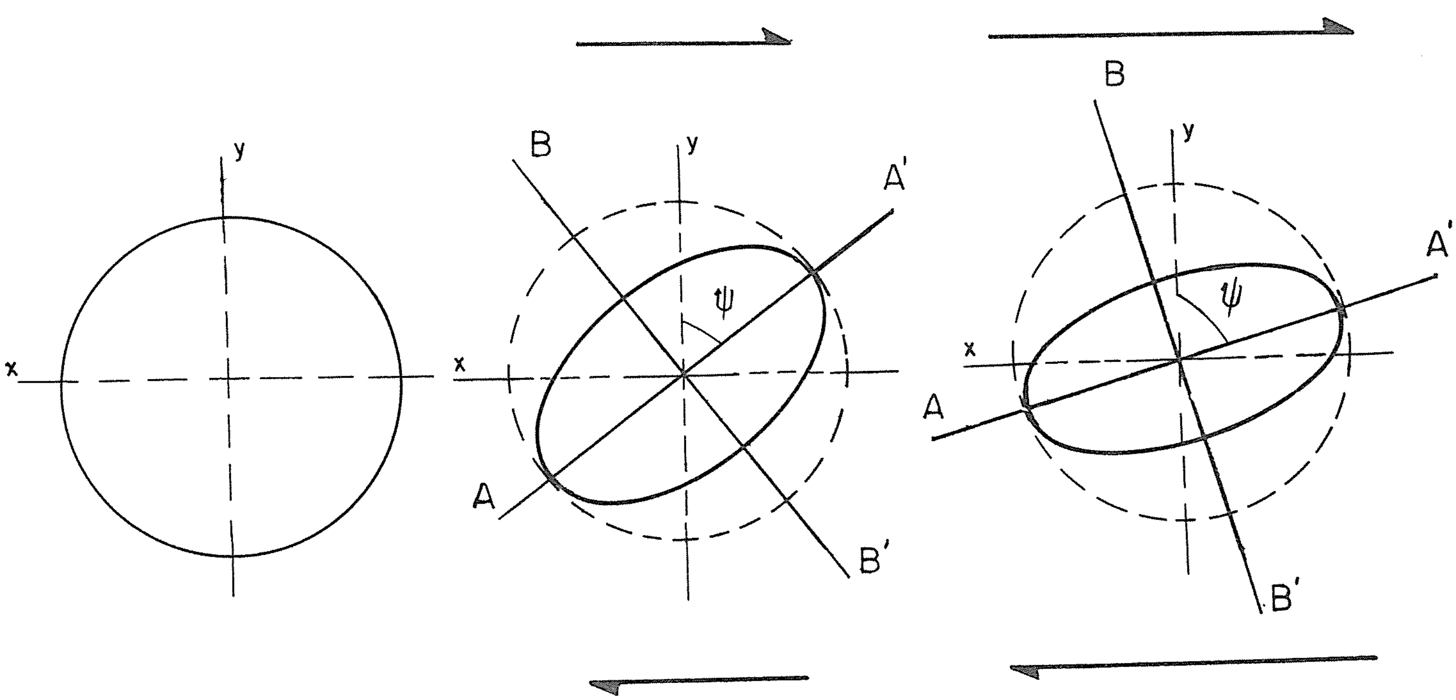


Figure 3. Simple dextral shear mode 1, showing orientations of resultant structures as relates to strain ellipse (after Harding, 1974).

Figure 4. Progressive simple shear mode 1, sh showing rotation towards parallelism of principal strain axes with respect to shear.



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ANOTHER LOOK AT AN OLD LAGOON

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BACKGROUND

The Batiquitos Lagoon region lies about one mile south of Leucadia and extends approximately two and one half miles inland. The lagoon covers roughly 800 acres and is presently closed to the ocean. Lagoon vegetation is dominated by the Coastal Salt Marsh community with the majority of the lagoon being barren salt flats. Salinity peaks in the summer and is minimized in the late spring. Salinity figures range from over 60% to about 10% and are affected by rain and runoff rather than tidal waters (Mudie et al, 1976).

The lagoon is one of several coastal lagoons within San Diego County. Table 1 provides some comparative information between Batiquitos Lagoon, Los Penasquitos Lagoon and San Dieguito Lagoon. All have been significantly impacted by historic development and were undoubtedly quite different in prehistoric times.

TABLE 1. Comparison of Three Lagoons

Lagoon	Area (Acres)	Salinity*	Depth
Batiquitos	800	10-60%	0.5 feet maximum
Los Penasquitos	320	10-90%	25 feet maximum (channel)
San Dieguito	604**	10-35%	2 feet average

*High salinity levels occur when the lagoons are closed. Low levels occur with high influx of fresh water. Average salinity of ocean water is about 33.5 parts per 1000.

**Before construction of Del Mar Race Track and associated facilities.

Archaeological surveys have been completed on approximately 65 percent of the Batiquitos region, and a total of 102 sites have been recorded. This region has been subject to more archaeological examination than perhaps any other single area in San Diego County. The primary reason for this is the development that has occurred in the area. In 1961, Warren et al. dealt with the region in association with four other areas in the county. In 1963, Crabtree et al. published a summary of their investigations around the lagoon, and Warren and Pavesic (1963) published an analysis of a shell midden on the lagoon. This work was sponsored before development of Interstate 5.

The explanation of prehistoric cultural occupation of the region employs the generally accepted developmental triad of pre-milling, milling/pre-ceramic, and post-ceramic periods. In the Batiquitos region specifically, it is generally held that the area has been occupied relatively consistently from before 7,000 years ago until about 4,000 years ago, with a decrease in shell availability causing a shift in the subsistence pattern of local inhabitants and a change in emphasis away from the lagoon.

There are two major discussions of this explanation. One is presented by Shumway et al. (1961) and one by Warren et al. (1961). These arguments are evaluated in some detail by Warren and Pavesic (1963) and Bull et al. (1977). Shumway et al. present their argument as follows:

> At least for southern California and northwestern Baja California it seems probably that sea level rose rapidly from the termination of Wisconsin time, about 10,000 years ago, until the beginning of La Jolla occupation, and has continued to rise (at a slackened rate) since about 7,000 years ago. During the period of rapid rise the rocky foreshore was maintained to a greater degree than at present, so as to furnish a plentiful supply of such seafood as the California mussel and the rock oyster. During this period the valley-mouth estuaries were maintained with sufficient depth and with sufficient connections to the sea to provide an abundance of such bay molluscs as the scallop and the Chione clams. These conditions seem to have persisted in southern California, more or less, until about 1,000 years ago.
>
> As the rise in sea level slackened (to become slight in recent centuries) the rocky foreshore became largely replaced north of La Jolla by sandy beaches as sand accumulated. At the same time sedimentation in the stream mouths came to exceed the effects of the slackened rise in sea level, so that the former baylike estuaries became the more or less ephemeral and ecologically highly variable lagoons no longer suited for significant shellfish production. The shellfish-gathering populations seem eventually to have largely abandoned the coast north of La Jolla, although they persisted in southernmost California and northern Baja California where bays and rocky shores remained.
>
> The changing ecological conditions seem to have affected the food and life of the shellfish-gathering people along the coast of northern San Diego County. To the southward, where lagoons apparently were less developed, the bay shellfish supply seems to have been depleted early through changes in the habitat. The Scripps Estates Site seems to have been abandoned by La Jolla people about 5,000 years ago, although some shellfish-gathers lived nearby as late as about 600 years ago but nearer the remaining rocky shore of the La Jolla region; they fed largely on mussels and other rocky-foreshore molluscs. Near some of the larger lagoons, such as Batiquitos Lagoon, the consumption of bay molluscs in large numbers persisted until about 1,000 years ago. (1961, p. 116-119).

Warren and Pavesic (1963) assessed this argument in light of investigations conducted on the lagoon by Crabtree et al. (1963). They concluded:

> ...that the lagoons silted and reduced the food supply of the aboriginal population along the San Diego Coast appears to be an obvious and accepted fact. The disagreement lies in the date when the lagoons silted in to the extent that they could no longer support large populations of shellfish (1963, p. 418).

Working with materials from archaeological site SDi-603 on file at UCLA, Warren et al. (1961) proposed a decrease in the occupation of the coastal area beginning around 3,000 to 4,000 years ago.

It is the hypothesis of lagoon siltation and subsequent reduction of available shellfish that is of particular interest for this report. The implications of an ecologically stimulated change in the occupation of coastal San Diego County greatly influences the assessment of alternate models of population distribution and cultural development for local prehistory. The purpose of the present paper, therefore, is to evaluate the validity of the siltation concept.

DISCUSSION

The evidence for the siltation explanation is three fold:

1. Material remains recovered from archaeological sites near the lagoon provide clusters of radio carbon dates before the 3,000 and after the 1,000 year period.
2. A core sample taken in 1969 from the western end of the lagoon indicates a similar shellfish time range (Table 2).
3. The nature of the recent rise in sea level and the logical development of the lagoon suggests that siltation and associated sedimentary activity resulted in closing of the lagoon for a 2,000 year period.

TABLE 2. Radiocarbon Dates, From Core Sample, Batiquitos Lagoon (from Miller, 1966).

Lagoon Core Sample**		
Reference Number	Years Before Present	Depth (meters)
LJ-919	1,000±100	1.64-1.91
LJ-918	3,700±200	2.84-3.23
LJ-912	4,750±200	7.24-7.31
LJ-333	6,320 ±250	10.01-10.45

Table 3 gives the range of radiocarbon dates for the Batiquitos Lagoon region. There is a noticeable lack of 2,000 year old dates. There is, however, little basis for extrapolating this apparent gap to causative factors in the environment. The primary difficulty with this aspect of the explanation is that the dates have all been filtered through cultural systems. While a temporally continuous series of shell dates indicates an uninterrupted availability of shellfish, the lack of such a continuum cannot be accepted as evidence for a lack of shellfish, just a lack of their exploitation.

TABLE 3. Radiocarbon Dates, Batiquitos Lagoon Region*

Years Before Present	Reference
SDi-603	
7,300± 200	UCLJ-36
6,250±150	UCLJ-256
3,900±200	UCLJ-31
SDM-W-102	
1,075±150	UCLJ-245
870±200	UCLJ-242
825±200	UCLJ-243
SDi-213	
6,320±250	UCLJ-333
3,400±240	UCLJ-381
SDM-W-181A	
6,210±280	UCR-421
5,170±230	UCR-420
SDM-W-915	
6,880±280	UCR-434
SDM-W-588	
4,520±250	UCR-406
SDM-W-919	
8,160±360	UCR-436
SDM-W-106	
5,250± 50	UCLJ-3484
4,370±250	UCR-405
3,640±60	UCLJ-3485
1,210±180	UCR-407
SDM-W-49C	
550±150	UCR-422

Years Before Present	Reference
SDM-W-49A (Rancho Park North, A)	
710±40	LJ-3159
8,040±80	LJ-3243
6,900±280	UCR-432
8,010±80	LJ-3244
8,060±50	LJ-3245
8,030±80	LJ-3160
8,280±80	LJ-3161
8,110±80	LJ-3246
SDM-W-940	
1,500±50	LJ-3689
SDi-604	
3,500±200	LJ-35
SDM-W-951	
6,800±80	LJ-3719
SDM-W-942	
4,940±70	LJ-3720
SDM-W-149	
1,100±50	LJ-3844
1,580±60	LJ-3822
1,430±60	LJ-3820
1,460±60	LJ-3821
1,160±50	LJ-3845
SDM-W-948	
7,780±90	LJ-3688
SDM-W-179	
7,130±80	LJ-3717
7,430±80	LJ-3718

*These are uncorrected radiocarbon dates based on the C_{14} half-life of 5568±40 years.

The second basis for the siltation explanation is the core sample obtained from the lagoon. Little needs to be said about the validity and reliability of a single sample. This is particularly true when considering the variation expected in a lagoon depositional setting. Variation in the amount of incoming fresh water, increase and decrease in turbulence, and the amount and nature of incoming sediments can all modify the intra-lagoon molluscan viability. It is thus highly likely that no single sample could adequately describe the overall variance in the lagoon. The lack of shell in a portion of a sample could as easily have resulted from the alteration of a local habitat within a viable lagoon as from the termination and redevelopment of the lagoon as a whole.

The third and final component for the generally accepted explanation revolves around the lagoon system's logical development i.e. that the relative rise in sea level and slow accumulation of silt combine with the reduced tidal prism to decrease the viability of the lagoon over time. The explanation of reduced viability through siltation must take into consideration the effects of off-shore currents and the development of a sand bar at the mouth of the lagoon. The siltation of the lagoon would effectively limit the ability of floods to scour the lagoon as well as reducing the tidal prism. This view fails to consider the impact of historic factors on such a system. Any attempt to address the significance of the siltation argument must consider the following recent effects.

The Batiquitos Lagoon drainage system is comprised of three primary tributaries; the main and east branches of San Marcos Creek and Encinitas Creek. These transport the majority of the runoff from a 46 square mile area that ranges in elevation from sea level to 1,700 feet (Bull et al., 1977).

Historic impacts on Batquitos Lagoon and its drainage system have significantly altered natural processes. Commercial agriculture began in the early 1900's; as a result, siltation undoubtedly increased substantially. Specific alterations affecting the lagoon include the Pacific Coast Highway, Interstate 5, and the dam at Lake San Marcos (Bull et al., 1977). The dam has "...greatly reduced the volume and acouring potential..." of flood waters entering the lagoon (Mudie et al., 1976).

Thus, agriculture and urbanization in general would greatly increase the amount of silt deposited in the lagoon. This would, in turn, reduce the scouring potential of floods and increase the rate of reduction of the tidal prism. Development restricting the influx of fresh water would similarly reduce the viability of the lagoon system. Any explanation of prehistoric culture development would be significantly biased if it attempted to extent present hydrologic/physiographic conditions into prehistoric times.

The third item in the siltation model requires an explanation for the closing of the lagoon for over 1,000 years and its subsequent regeneration and continued viability for the last 1,500 years. It would appear that no demonstrable processes were in effect 3,000 years ago which would result in an extended closing of the lagoon, followed by action that would open it.

It would be a mistake to assess the siltation model without examining one of the primary bases for which it was proposed, principally the continued occupation of the coast by prehistoric populations. The argument is one that permits the continued use of the area by a single, genetically related group of individuals, relegating differences in the archaeological assemblage to ecological factors.

Archaeological evidence for the continual occupation of the coast is highly varied. Ezell (1977) reported the "association" of Yuman and Milling Stone stage components during his investigations at the Harris Site. Moriarty (1966) felt there is evidence for the continual occupation of the coast at the Spindrift Site.

The Spindrift Site supposedly represents a gradual, peaceful merging of the La Jolla III and the Diegueno populations. Moriarty's evidence, however, is incompletely presented with no data given and no reference indicating previous supporting evidence.

The argument presented by Moriarty for the continuity of the Spindrift deposit is based upon radiocarbon dates obtained every 50 centimeters on shell material. This, in itself is not sufficient to conclude that there is no break in the deposit.

One of the few other detailed discussions of cultural continuity between the La Jolla and Kumeyaay patterns is presented by Kaldenberg and Ezell (1976). Through his work at the Great Western Savings site, Kaldenberg identified a "...triple component archaeological site represented by artifacts of the San Dieguito cultural tradition, the La Jolla complex and the Kumeyaay peoples." Although Kaldenberg felt that occupational evidence for each cultural group is represented at the site, only continuity between the San Dieguito and La Jolla is proffered. The Late Prehistoric Stage occupation is considered the result of temporary campsites, while the two earlier stages used the area for extended habitation.

A complicating factor is the general consensus among local archaeologists and prehistorians that a continuity existed between the La Jolla pattern and those materials representative of early Kumeyaay areal occupation. The relationship between the La Jolla and the Luiseño patterns is generally thought to be discontinuous. Perhaps the best discussion presented to date of the basis for these assumptions is the work by True (1966). His arguments for the continuity of coastal southern California are as follows:

> 3. The continuity between the local San Diego area milling stone base and the historic Yuman (Hokan) speaking Diegueño is significant. Since there is no evidence for a break in this sequence, there is some basis for the suggestion that the culture of the milling stone horizon, at least in this area, probably was the result of Hokan-speaking peoples.
>
> 4. A similar situation probably prevailed within the Chumash territory to the north, where a number of traits were shared and where it is reasonable to suggest that the historic Chumash developed out of a similar and probably related milling stone substratum. This is more apparent if the specialized maritime elements are ignored in the north and if the specialized ceramic elements typical of the Diegueno territory are stripped away.
>
> 5. These apparent similarities are found only in the Diegueño (Hokan) area and are not present in the Shoshonean Luiseño territory.

While there appears to be a general consensus for the continual occupation of the San Diego coast from the Milling Stone to the Late Prehistoric Stage, there is little supportive evidence. Though references to multi-component sites are few, reporting of single component resources are more numerous.

Excavations on Batiquitos Lagoon make reference to single component Milling Stone Stage sites Warren et al. (1961) and Crabtree et al. (1963) refer to several single component resources. Only one site identified by Crabtree et al. is presented as multi-component while 38 are single component sites. Los Compadres is a recently investigated single pattern Milling Stone Stage site (Carrico, 1976). Late Prehistoric single period sites are identified at Molpa (True et al., 1974) and Temeku (McCown, 1955). Most recently, SDM-W-149 was determined to have only a Late Prehistoric component (Bull, 1977a).

While the sampling procedures for the resources investigated to date to not permit an unbiased estimate of the frequency of multi-component sites, present evidence suggests that the single pattern resource is the more common occurrence. It may, in fact, be that the continuity argument for which the siltation hypothesis was proposed is no longer viable. Linguistic evidence supports the discontinuity of prehistoric groups rather than the genetic relationship proffered by archaeologists (Bull, 1977b).

CONCLUSION

It seems apparent that the siltation argument was generated around a need to explain the variation in the archaeological record. Approximately 3,000 to 2,000 years ago a significant change is noted in the material record left by area inhabitants. This change is marked by the appearance of ceramics, finely worked projectile points, cremations and an apparent focus on non-coastal resources away from the more maritime orientation operating previously.

This appearance of "desert traits" in coastal San Diego sites corresponds to the suggested expansion of Uto-Aztecan and Yuman language families (Bull, 1977b). The siltation argument provides an ecological explanation for the noted change, and places socio-cultural explanations in a less significant role. The siltation model permits the existence of a geneological continuum in particular areas of the county between the populations responsible for the coastal focus resources and those responsible for the inland emphasis.

When the reduced viability of the lagoon is set aside as a tool for explaining prehistory, a clearer focus can be brought to the problems actually facing local archaeologists, the processual nature of the occupation of San Diego's coast. While the siltation argument may ultimately be correct, it is not necessary for a comprehensive understanding of local prehistory.

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TERTIARY LITHOSTRATIGRAPHIC VARIATIONS, SANTA MARGARITA RIVER TO AGUA HEDIONDA LAGOON

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INTRODUCTION

A wide variety of studies has been published on the Tertiary geology of northern San Diego County, especially for areas near San Onofre Nuclear Generating Station. This is the result of two entirely different factors. One relates to the controversy surrounding nuclear power plants and attendant concern about the geologic factors pertaining to plant siting. The other factor is that northern San Diego County contains Tertiary (particularly Eocene) formations which are transitional between Orange County and southern San Diego County sequences. It is the intention of the authors to combine a review of the literature with personal field studies in order to clarify the way in which the transition develops. Ideas presented herein were influenced strongly by Yerkes _et al_. (1965), Morton (1970), Walawender and Peterson (1978), Wilson (1972), Kennedy and Moore (1971) and Lohmar and Warme (1978). The paper will concentrate on a coastal strip which extends inland for approximately 5 km and reaches south from the Santa Margarita River to Agua Hedionda Lagoon (Figure 1). Detailed presentation of the authors' interpretations of field work, well data and offshore seismic data are found in Young (1980).

DESCRIPTION OF UNITS

The stratigraphic units within the study area consist of Eocene strata and Middle Miocene to Recent sediments deposited in basins formed by dextral shearing. Eocene Santiago Formation and Middle Miocene San Onofre Breccia form extensive terrigenous and shallow marine deposits. They dip southwest, extending into the offshore. Pliocene formations are restricted to isolated coastal outcrops.

EOCENE

Eocene sedimentary rocks crop out in a continuous belt from the Santa Ana Mountains south to San Diego. Yerkes _et al_. (1965) show an Eocene section in the Santa Ana Mountains consisting of a Middle Eocene basal marine conglomerate, overlain by a marine, fossiliferous sandstone which in turn is overlain by a thick, Late Eocene sandstone unit that contains marine and non-marine beds. In the San Diego metropolitan area, Kennedy (1975) showed a Middle Eocene marine conglomerate overlain by a sequence of units typical of an area experiencing transition from a marine to a non-marine environment. This sequence is overlain by the Late Eocene Poway Group which is non-marine to the east and lagoonal or nearshore marine to the west. Persons who have worked between the Santa Ana Mountains and metropolitan San Diego describe Eocene sequences which are quite different. Walawender and Peterson (1978) report an Early Eocene non-marine sequence overlain by a marine sequence which extends into the Late Eocene in the San Onofre Basin. Wilson (1972) reported a Middle Eocene marine sequence, overlain by a Late

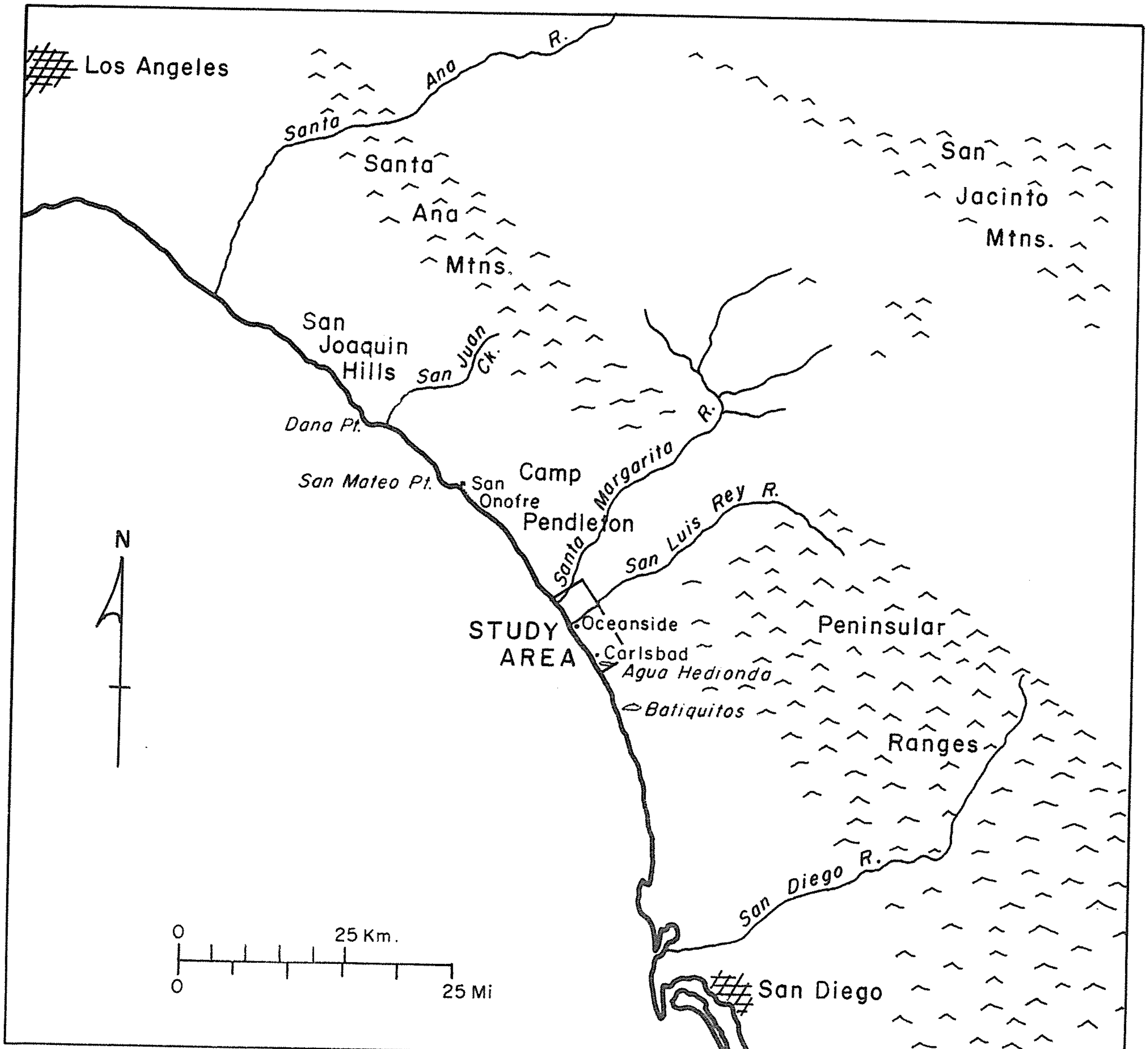


Figure 1. Index map.

Eocene non-marine sequence which in turn is overlain by Late Eocene marine beds in the Oceanside/Encinitas area. It is clear that the Eocene beds of the Santa Ana Mountains do not grade simply and directly into their equivalents in the San Diego metropolitan area. This report describes the lithostratigraphic changes which take place within the Santiago Formation for a portion of the region of transition.

WELL DATA

Six wells have been drilled which penetrated Eocene sedimentary rocks. Core lithologies and lithologic correlations are shown in Figure 2. Three wells (Henie 1, LaCosta and Borderland Exploration 1) were spudded into Eocene sedimentary rocks exposed at the surface. The other three wells (Holmes 2, Irwin Kelley 1 and Turner 1) were started in Quaternary or Holocene material overlying the Eocene.

OUTCROP DATA

Data taken from 30 outcrops were compiled and interpreted with data from the six wells. The locations of outcrops used in the preparation of this paper are shown on Figure 7. Outcrops can be divided into non-marine and (lower and upper) marine sequences.

The non-marine sequence contains deeply channeled, interbedded mudstones and sandstones as well as massive coarse sandstones. Channeled red to green mudstones are interbedded with coarse sandstones and conglomerates at outcrops 4 through 12, 17, 18, and 21. Relatively complex channel relationships often produce highly discontinuous bedding (outcrop 5, Figure 3). A distinctive conglomerate lens with a few Poway-type volcanic clasts is interbedded with red mudstone at outcrop 4.

The marine sedimentary rocks can be divided into two sequences, one below the non-marine beds and one above them. The lower marine sequence is best exposed in the southern portion of the area and contains the same channeling relationships as the non-marine sequence except on a smaller scale and with more continuity of bedding. The sequence also contains limestone concretions and burrowing. The sequence is well displayed in an exposure of Wilson's (1972) Santiago B unit found outside the study area on the south side of Batiquitos Lagoon (the first northern cliff exposure on the hillside east of Interstate 5 on La Costa Avenue). The Batiquitos Lagoon section contains crossbedding with dip directions which vary 180 degrees within the same sedimentary unit, indicative of an intertidal environment. Channeling directions trend northwest to west. Outcrop 3 (Figure 4) shows a lower marine sequence which is typical of the study area. It consists of alternating burrowed mudstones and coarse to medium sandstones. The lower marine sequence contains more mudstone in the study area than it does near Batiquitos Lagoon. An interfingering between lower marine and non-marine sequences may be seen in outcrop 17 (Figure 5) where lenticular limestone and burrowed sandstone are interbedded with coarse channeled sandstone.

The upper marine sequence is composed of sandstone and mudstone. Sandstones are micaceous and contain laminae of mafic minerals alternating with quartz- and feldspar-rich laminae. They are fine- to very fine-grained and typically exhibit thick bedding with occasional cross-bedded units. Some beds are calcareous and burrowed. The mudstones are sandy and occasionally are calcareous and burrowed. The upper marine sequence is exposed in

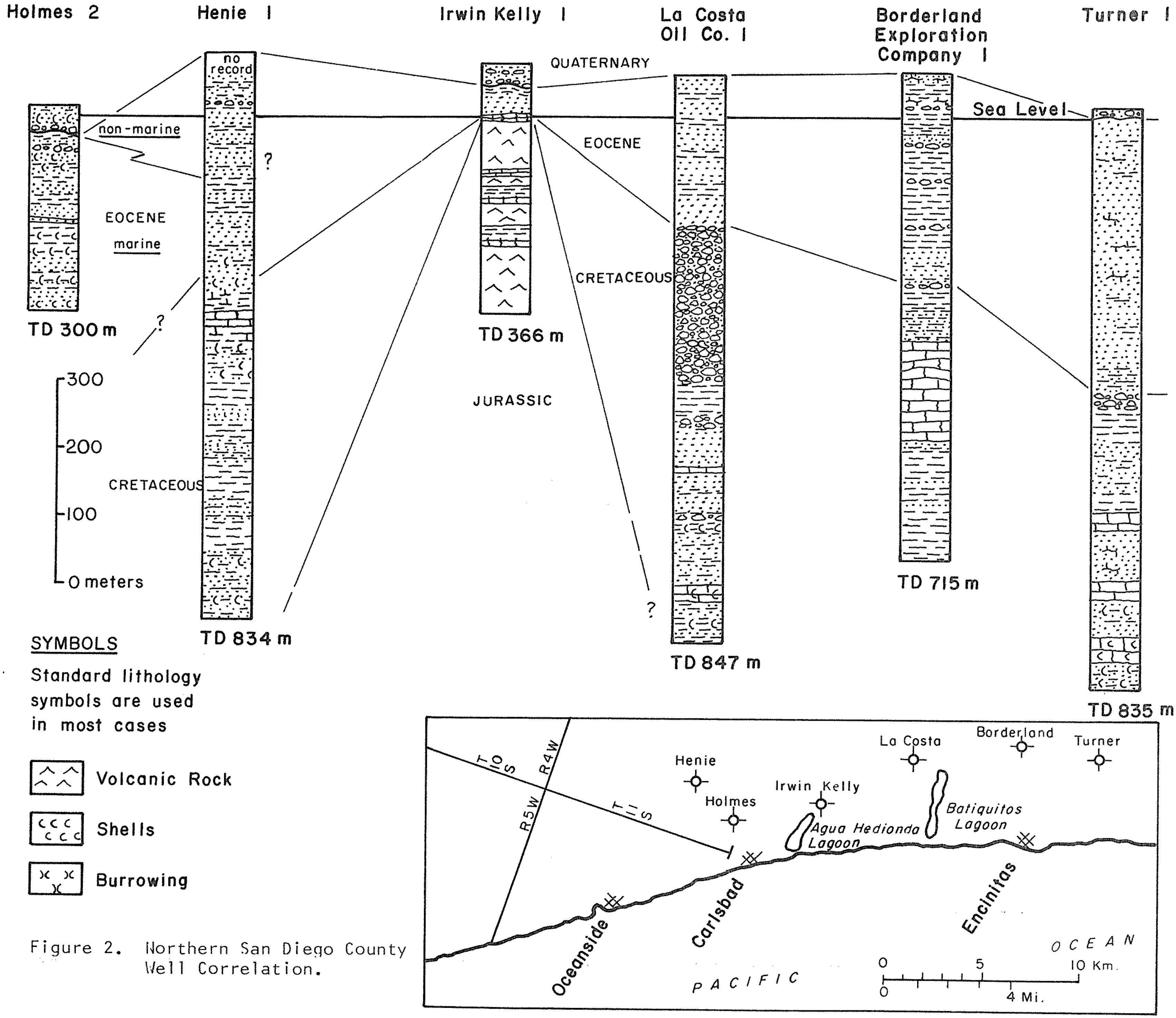


Figure 2. Northern San Diego County Well Correlation.

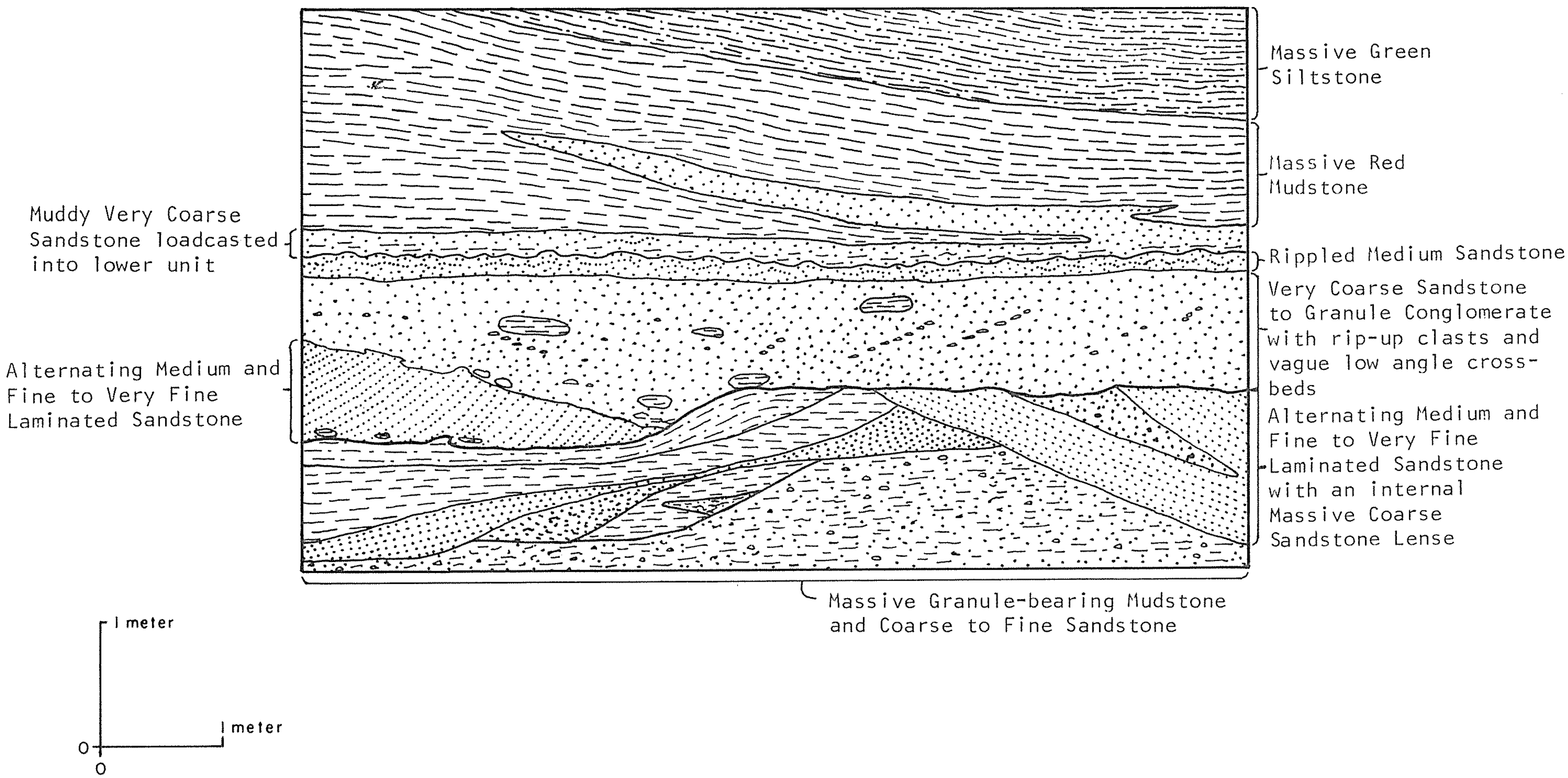
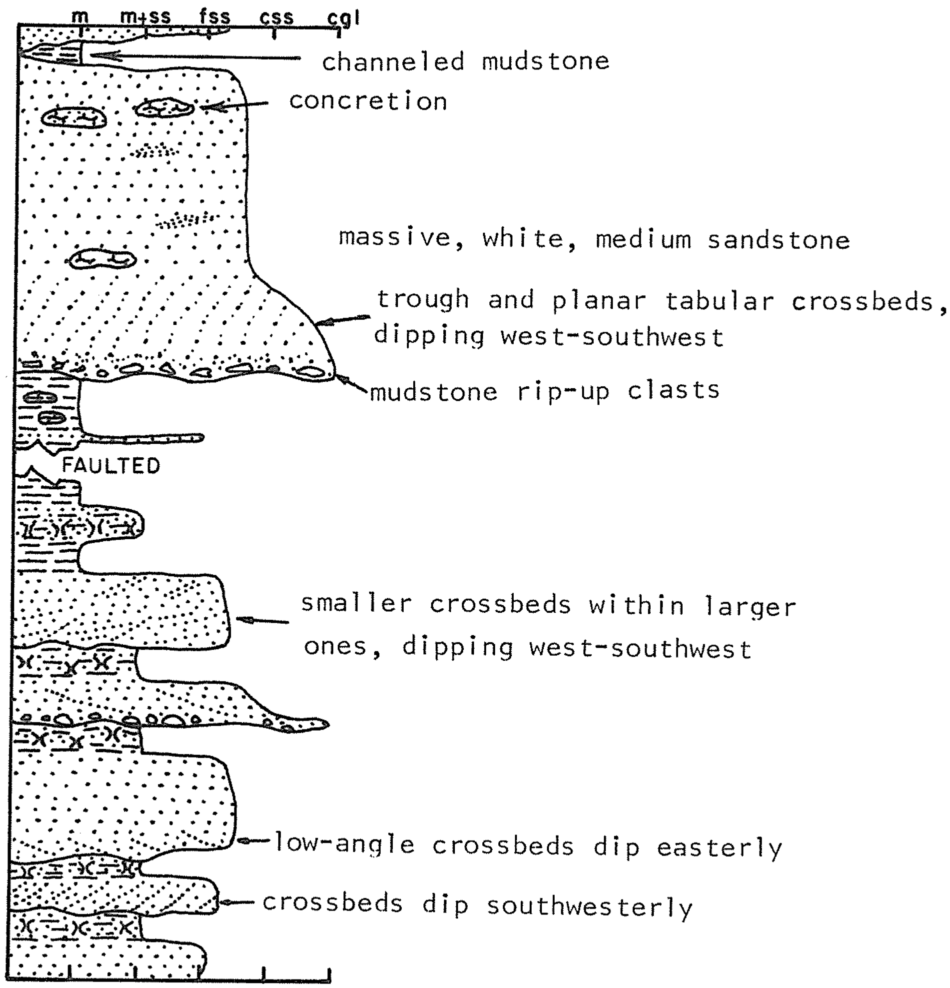


Figure 3. Outcrop 5. Non-marine sequence showing complex channeling relationships (view toward the southwest).



ABBREVIATIONS

m.	- mudstone
m.+ss.	- mudstone+sandstone
f.ss.	- fine sandstone
c.ss.	- coarse sandstone
cgl.	- conglomerate

Figure 4. Outcrop 3. Lower marine sequence of Eocene age.

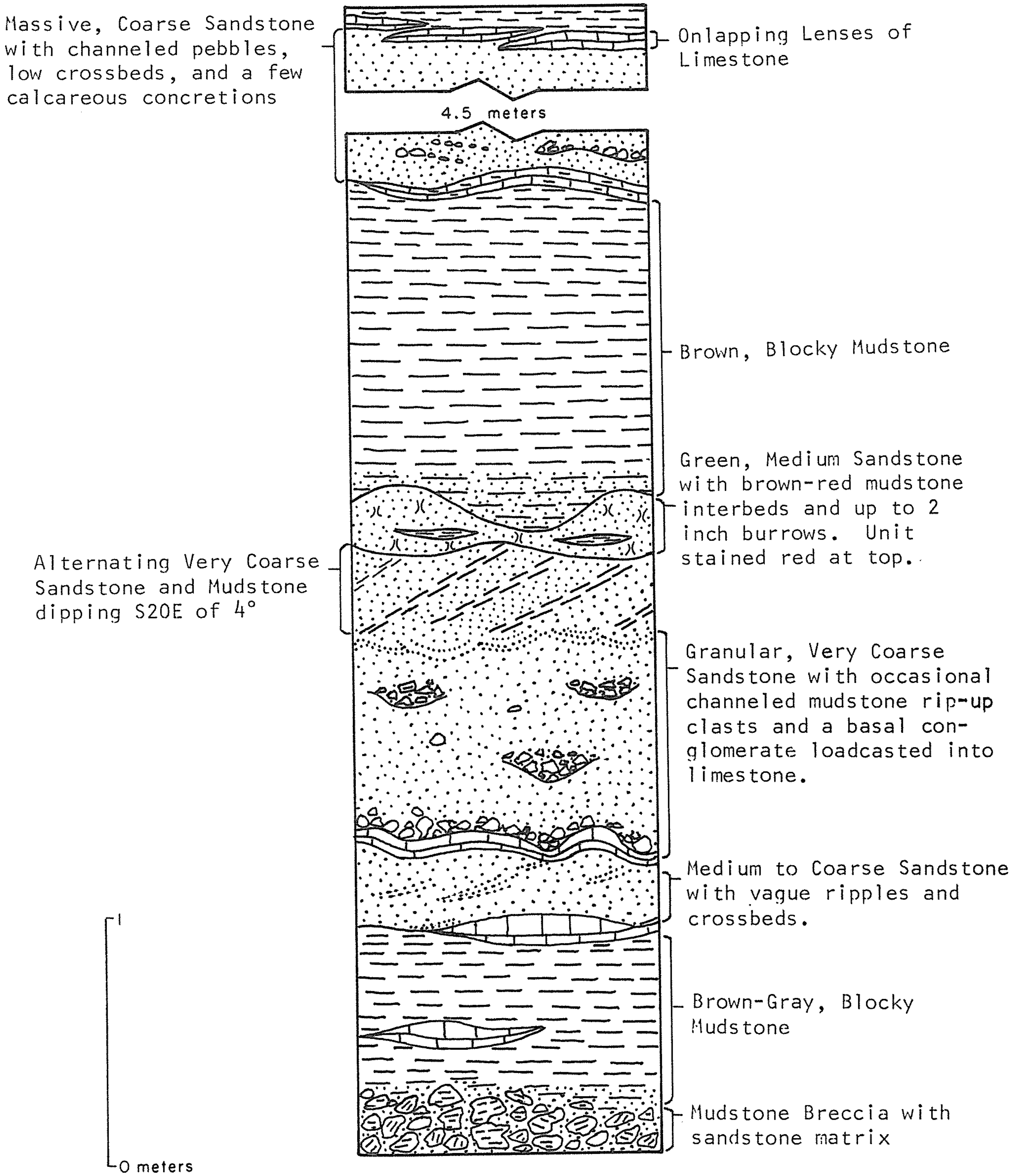


Figure 5. Outcrop 17. Interfingering between lower marine beds and non-marine beds of Eocene age.

outcrops 1, 20, 24, and 28. A typical sequence is overlain by the San Onofre Breccia in outcrop 24 (Figure 6).

OLIGOCENE-MIOCENE

Within the area of study, the Oligocene and Early Miocene were times of nondeposition and erosion. During Middle Miocene time, the northern half of the study area accumulated San Onofre Breccia. It is exposed best in outcrop 24 (Figure 6) and may also be seen in outcrop 25. The breccia within the area is typical of the San Onofre Breccia described by Stuart (1976, p. 310):

> muddy facies: red-brown and gray, mud-matrix breccia beds characterized by inverse grading and very poor matrix sorting; pebble- to boulder-size clasts; thin intercalations of calcareous, laminated sandstone; tuff and tuffaceous sandstone; rarely fossiliferous in laminated sandstone beds...(a) sandy facies: massive or crudely graded, gray, calcareous, sandy breccia and conglomerate; commonly with cross-bedded, gray calcareous, conglomeratic sandstone, fossiliferous... (and a) graded sandstone facies: gray, calcareous, graded sandstone; calcareous, massive and graded breccia-conglomerate; gray sandy mudstone; fossiliferous.

Miocene rocks younger than the San Onofre Breccia do not occur in the study area. The Monterey Formation or its equivalent is found nearby but outside the area. It is stratigraphically higher than the San Onofre Breccia and is recognized by its seismic signature offshore from Camp Pendleton. Limited exposures of the upper Monterey Formation occur along the shore of Camp Pendleton north of Las Pulgas Canyon.

PLIOCENE

Presumed Pliocene sedimentary beds onlap the San Onofre Breccia and are overlain by Pleistocene terrace deposits. The beds are alternating (or are transitional between) marine and nonmarine sandstones and conglomerates. Lithologically they closely resemble the Niguel and San Diego Formations. Moyle (1973) has correlated the beds within the study area with the sandstone seen along the coast near Las Pulgas Canyon and has correlated both of these with the San Mateo Formation.

Limited outcrops suggest a varying lithology in Pliocene sedimentary rocks changing in facies from northeast to northwest. In the southeast the San Mateo Formation has a maximum thickness of 18 meters in outcrop; dipping less than 3 degrees to the west, it appears horizontal. Beds of poorly sorted conglomerate with slightly muddy sandstone matrix alternate with muddy, white, massive, very fine to fine sandstone. The sandstone contains occasional hematitic horizons as well as some slightly burrowed horizons. The conglomerates consist of clasts which are well-rounded and have the following lithologies: granitic, quartzite, silicic volcanic, and sandstone. Some clasts are reworked from the San Onofre Breccia. The San Mateo Formation is exposed in outcrops 25, 29, and 30. A slight variation is seen at outcrop 25 where sandstone is more prevalent than conglomerate.

Inside Camp Pendleton to the northwest, the Pliocene sequence begins with a highly mottled and gypsiferous, muddy, red and gray, very fine sandstone with some interbedded mudstones. These beds are overlain by a slightly muddy,

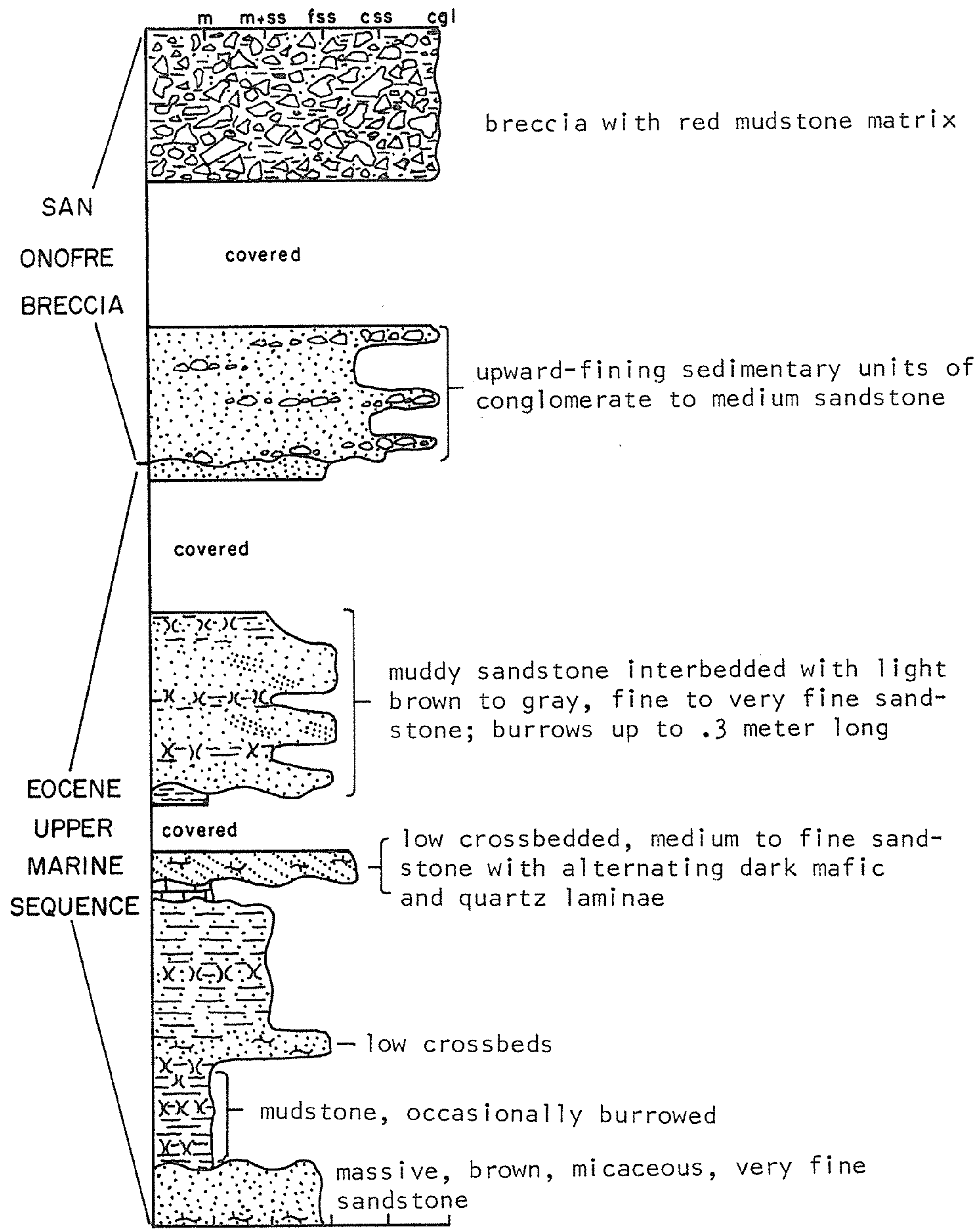
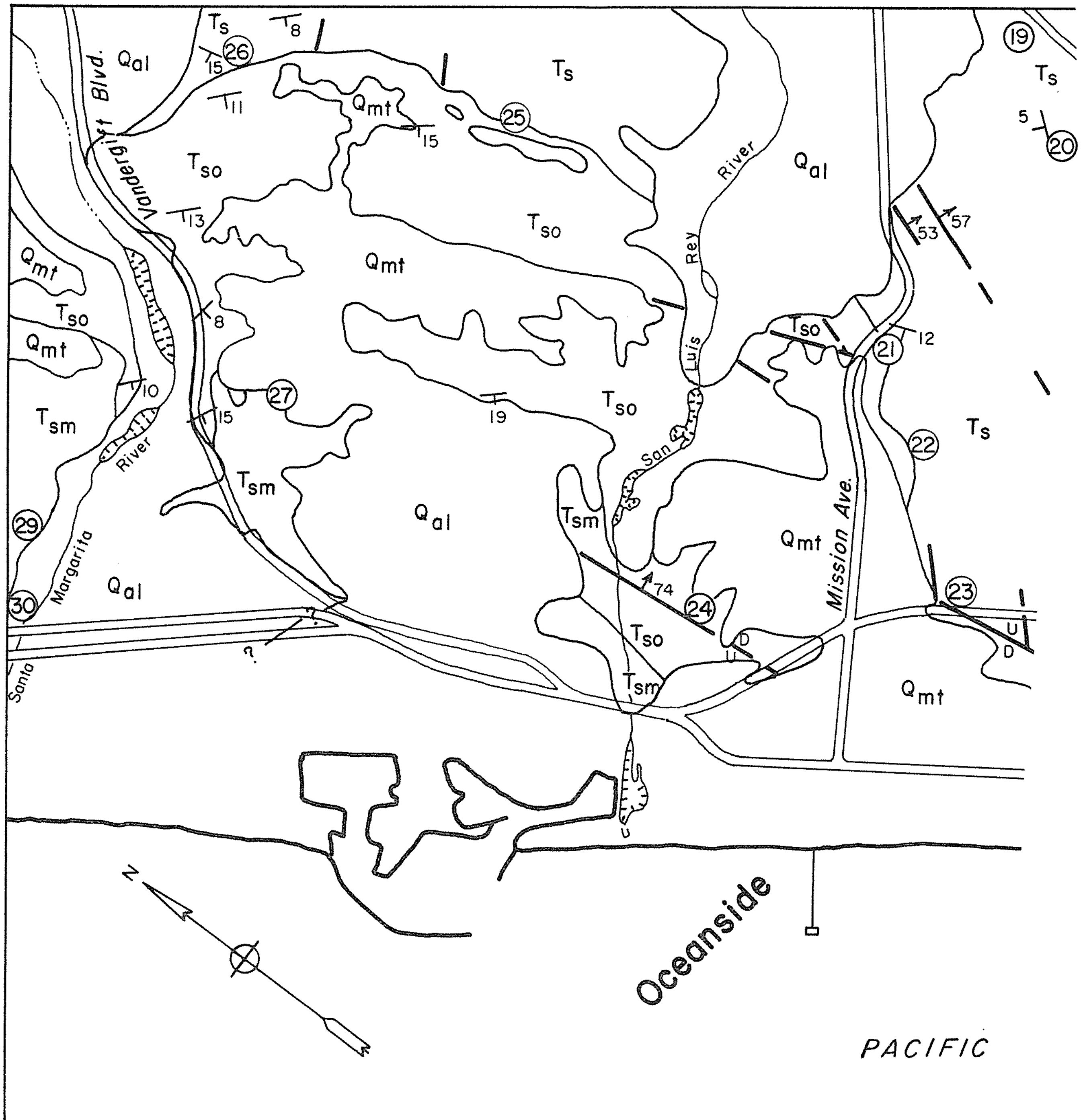


Figure 6. Outcrop 24. Eocene and Miocene strata.

ABBREVIATIONS

m = mudstone
m ss = mudstone sandstone
fss = fine sandstone
css = coarse sandstone
cg.l = conglomerate



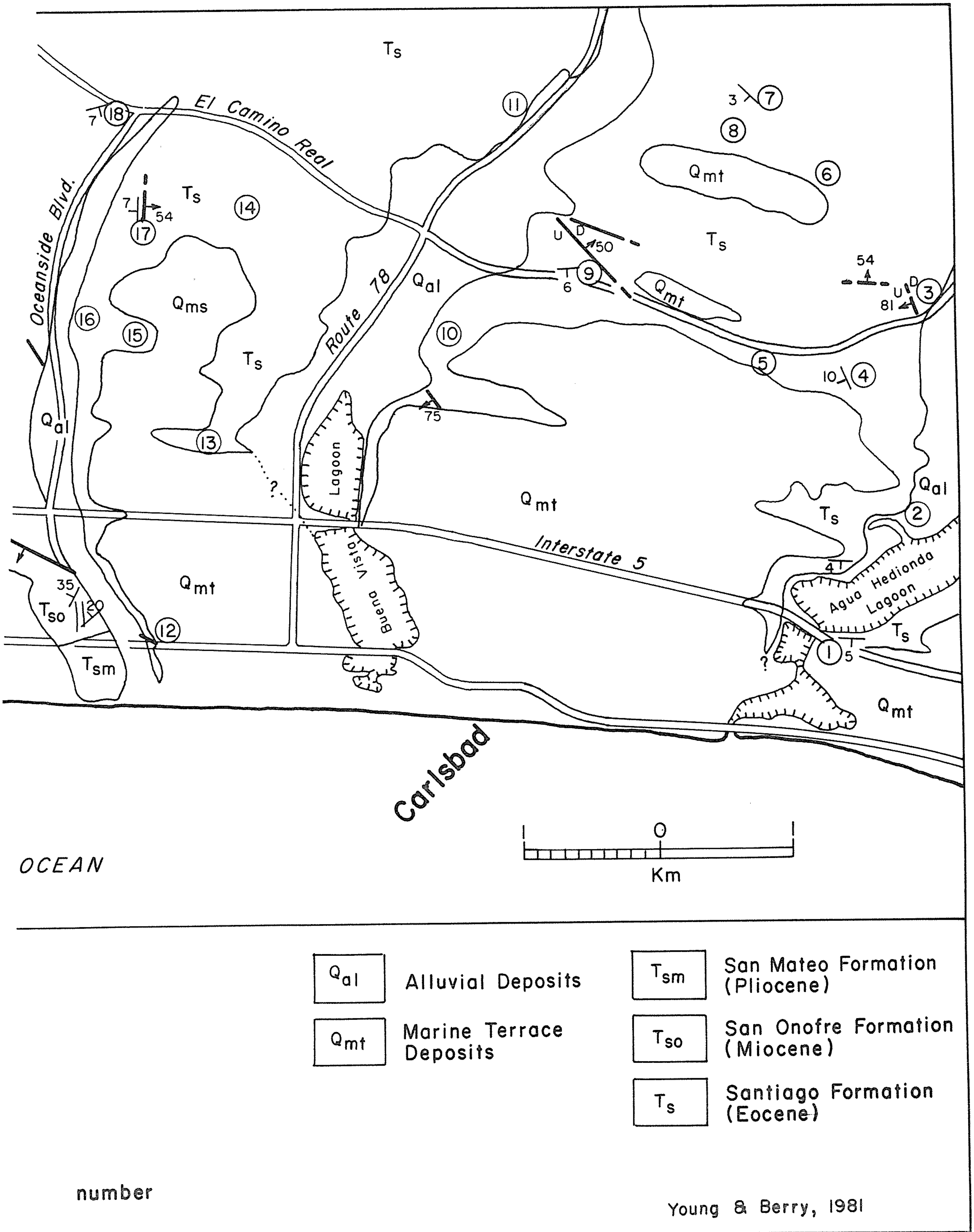
LEGEND

Faults

Ponds or Lagoons

13 Outcrop, location and

Figure 7 — GEOLOGIC MAP: CARLSBAD / OCEANSIDE AREA


Ts
El Camino Real
Oceanside Blvd.
Route 78
Qal
Qmt
Qms
Tso
Tsm
Lagoon
Buena Vista
Interstate 5
Agua Hedionda Lagoon
Carlsbad
OCEAN
0
Km
Qal Alluvial Deposits
Qmt Marine Terrace Deposits
Tsm San Mateo Formation (Pliocene)
Tso San Onofre Formation (Miocene)
Ts Santiago Formation (Eocene)
number
Young & Berry, 1981

white, mottled, very fine to fine sandstone, which is separated into approximately two-foot beds by thin, muddy, micaceous and hematitic laminae.

INTERPRETATIONS

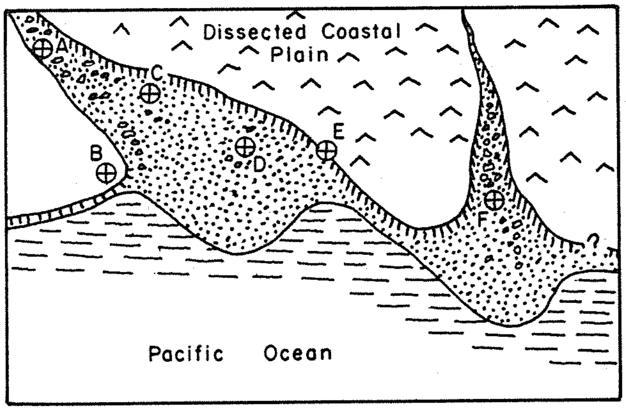
It is particularly important at this point to stress that the interpretations presented herein would not be possible without the work of many other geologists. Despite this, a great deal of work remains to be done before paleogeographic reconstructions can be made with confidence. This is particularly true for the Pliocene. Accordingly, the interpretations and paleogeographic reconstructions presented in this report are preliminary and subject to revision as more data are acquired.

EOCENE

A paleogeographic interpretation of Eocene strata was attempted by combining the well and outcrop data of northern San Diego county with data from previous stratigraphic studies. A lithologic correlation was attempted between published stratigraphic sections measured in the Santa Ana Mountains and San Diego, and at several locations in-between. Sections within the study area, metropolitan San Diego and Santa Ana Mountains contain basal marine sedimentary rocks overlain by non-marine sedimentary rocks, but a problem is created because the San Onofre Basin and San Juan Creek sections contain basal non-marine sedimentary rocks overlain by marine sedimentary rocks.

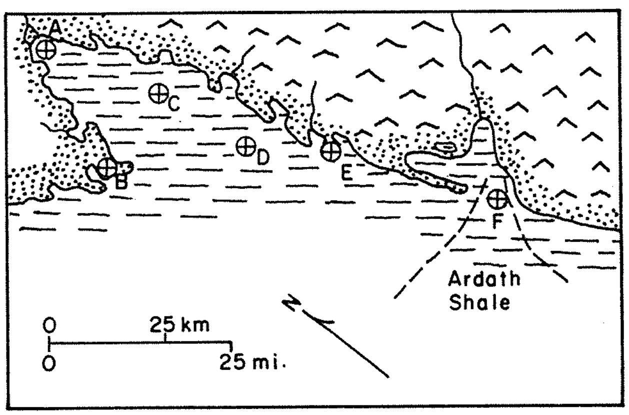
The stratigraphic reversals outside the area of study represent departures from the general sequence of sedimentary strata which reflects the global cycle of sea level changes (Vail et al., 1977). The study area is assumed to lie within the limits of the maximum transgressions and regressions of sea level. It is further assumed that local tectonic uplift or subsidence did not mask the global cycle. The same assumptions hold for the Santa Ana Mountains and metropolitan San Diego. The best preservation of sediments would occur during gradual subsidence. The global cycle shows a prominent drop in sea level at the beginning of Middle Eocene time, followed by a general rise and fall of sea level, until the end of Eocene time. Two relatively short drops in sea level occur; at the middle of Middle Eocene and at the beginning of Late Eocene. In general, marine sediments would accumulate at the initial rise in sea level, followed by non-marine sediments during the fall, with non-marine incursions of sediment at the middle of Middle Eocene and the beginning of Late Eocene.

A check on the predicted succession of sediments is provided by the metropolitan San Diego section. During the initial fall in sea level at the beginning of the Middle Eocene, the Mount Soledad Formation was deposited in a restricted deep canyon. During the following rise in sea level, the Delmar and Torrey formations were deposited on the nearby shallow shelf, while Ardath Shale was deposited in the deeper submarine canyon over the Mount Soledad Formation. The rise in sea level was followed by the short mid-Middle Eocene fall and rise in sea level and the deposition of the upward-fining Scripps Formation. Next was the early Late Eocene fall in sea level and the progradation of the Friars and Stadium Formations, followed by the rise in sea level and the deposition of the Mission Valley Formation. Lastly, another drop in sea level ended Eocene time with the deposition of the Pomerado Conglomerate.



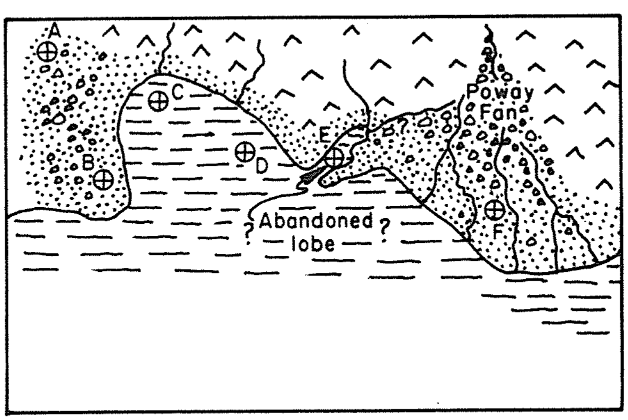
EARLY EOCENE

Coarse clastic deposition during a sea level low stand made up the Mount Soledad Formation in San Diego and the lower Santiago Formation in the Santa Ana Mountains. A valley probably extended from the Santa Ana Mountains to the coast.



MIDDLE EOCENE

Sand bar and lagoonal deposition during a rise in sea level made up the Delmar, Torrey and Santiago A Formations in San Diego and the middle Santiago Formation in the Santa Ana Mountains.



LATE EOCENE

Extensive alluvial fan deposition during probable rejuvenation of sediment supply made up the Poway Group in San Diego and the upper Santiago Formation in the Santa Ana Mountains.

Figure 8. Eocene Paleoenvironments. A = Santa Ana Mountains; B = San Joaquin Hills; C = San Juan Creek; D = Northern Camp Pendleton; E = Oceanside; F = North San Diego City.

Now that the lithologic changes in the area of study and in metropolitan San Diego have been correlated to global sea level changes, it remains to explain the San Onofre Basin and San Juan Creek areas.

These sections appear to have accumulated sediments principally during a relative rise in sea level, since they contain upward-fining sequences exclusively. Unfortunately, dates are lacking within these northern sections, making any correlation with the San Diego section questionable. But, assuming that local tectonic subsidence was not responsible for the relative rise in sea level in these areas, and all other factors were equal with the surrounding sections, then a reasonable explanation for the succession of sediments to the north would be that these two areas were principally lower in elevation than the surrounding areas throughout Eocene time. The lower elevation would mean that these sections were deeply submerged and thus unable to reflect Middle to Late Eocene transgressions and regressions being below the lowest sea level. They were able, however, to accumulate great amounts of non-marine sediments on-shore along the surrounding highlands during the very low sea level in Early Eocene time.

Data and interpretations of the authors and other investigators have been synthesized and are presented in Figure 8 as graphic reconstructions of paleo-environments for the Early, Middle and Late Eocene.

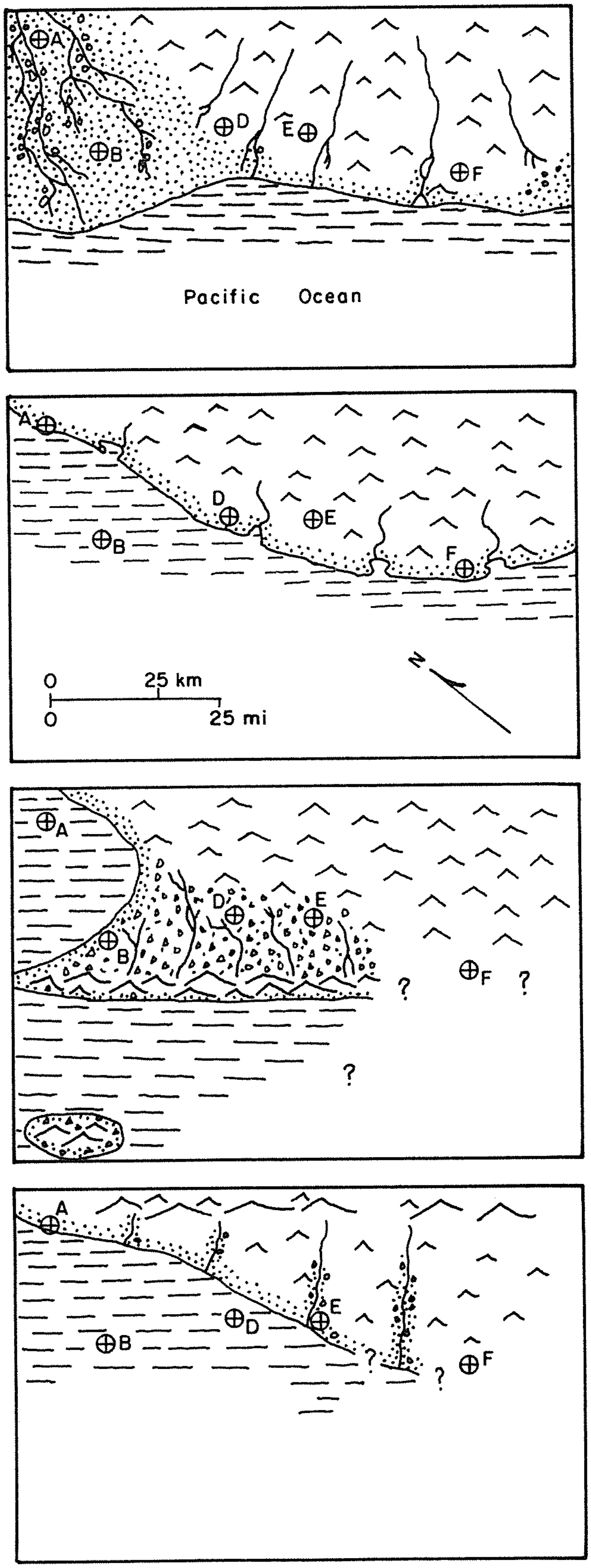
Oligocene and Miocene

Within the study area, Oligocene through Early Miocene time is represented by nondeposition and erosion. To the north, outside the study area, within the San Joaquin Hills (Figure 1), a more complete section exists representing relatively continuous deposition up to Early Pleistocene in the southern lobe of the Los Angeles basin called the Capistrano Embayment (Ingle, 1973b).

During Middle Miocene time, the study area and the Capistrano Embayment began to accumulate an unusual breccia, the San Onofre Breccia. Within the area of study the extensive outcropping of San Onofre Breccia was first studied and reported on in a classic paper by Woodford (1925). Woodford proposed that the breccia was part of an alluvial fan deposited in an arid climate from a western source. Further work by Stuart (1975, 1976, 1979) explored the occurrence of this unusual breccia within southern California. Work by Ehlig (1977) on San Onofre Breccia outcrops within the study area, revealed that: (1) the coarseness of the breccia increases from south to north and from the base upward; (2) the lower muddy facies is usually "relatively fine grained sediments representing distal fan deposits" (Ehlig, 1977, p. 9); (3) the San Onofre "actually represents a coalescence of fans derived from several draining systems emanating from a relatively linear range front" (Ehlig, 1977, p. 13).

All evidence points to the San Onofre Breccia having been deposited as an alluvial fan into the study area from an anomalous, nearby, western, mountainous terrane sometime during early Middle Miocene. Junger (1974) suggested that the mountainous terrane was approximately 8 km offshore from Laguna Beach.

Lithologic correlation of stratigraphic sections within the San Joaquin Hills, Santa Ana Mountains and this study area must remain somewhat speculative. Unfortunately, there is only an Eocene lower limit to the age of



OLIGOCENE

Nondeposition and minor erosion occurred in the study area while coarse sandstones of the Sespe Formation were deposited to the north.

EARLY MIOCENE

A marine transgression occurred north of the study area allowing deposition of marine siltstones, mudstones and sandstones of the Vaqueros and Topanga Formation.

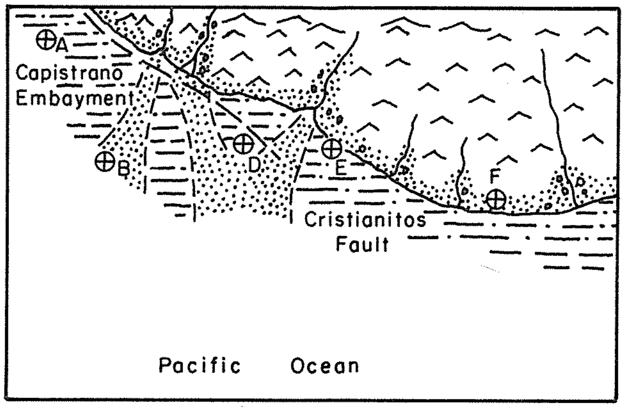
MIDDLE MIOCENE

(modified from Stuart, 1979)
A southwestern mountainous terrain shed sediment into the study area as alluvial fans, which made up the San Onofre Breccia.

LATE MIOCENE

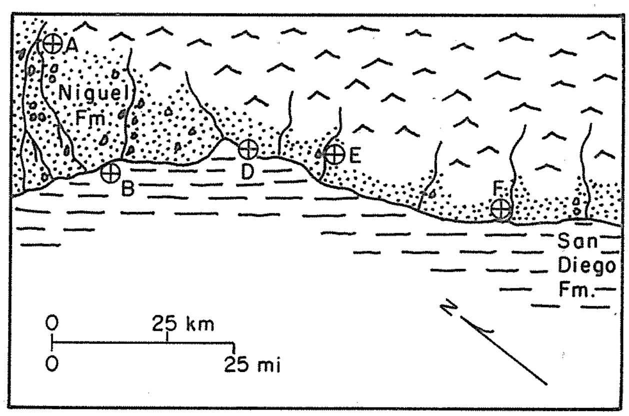
Rapid subsidence to bathyal depths caused a marine transgression and deposition of Monterey shales in the Camp Pendleton area.

Figure 9. Oligocene and Miocene Paleoenvironments. A = Santa Ana Mountains; B = San Joaquin Hills; D = Northern Camp Pendleton; E = Oceanside; F = North San Diego City.



EARLY PLIOCENE

Predominantly fine to coarse sandstones accumulated in the study area in a coastal wedge while turbidites accumulated offshore.



LATE PLIOCENE

The Niguel Formation prograded in the modern day shoreline, to the north, while sediments probably continued to accumulate in small amounts within the study area as part of what is called the San Mateo Formation.

Figure 10. Pliocene Paleoenvironments. A = Santa Ana Mountains; B = San Joaquin Hills; D = Northern Camp Pendleton; E = Oceanside; F = North San Diego City.

the San Onofre Breccia within the study area. It is still not known whether a western source area presented sediments first to the San Joaquin Hills area, or to the San Joaquin Hills and the study areas simultaneously.

Graphic reconstructions of paleoenvironments for Oligocene through Miocene time are presented in Figure 9. These are based largely on a synthesis of work by Ingle (1973a,b), Stuart (1975, 1976, 1979), Ehlig (1977), Junger (1974), Artim and Pinckney (1973), Scheidemann (1977), Woodford (1925), and Kennedy (1975). Contributions of data by the authors were small owing to limited exposures of Oligocene/Miocene strata in the area of study.

PLIOCENE

During Late Miocene to Early Pliocene time, the Camp Pendleton area subsided, and was filled rapidly by coarse sandstone turbidites (San Mateo Formation). Turbidites were funneled into the Las Pulgas area from the rising Peninsular Ranges to the east. The study area remained near sea level and received sediments which formed a coastal alluvial wedge. The coastline extended in a more north-south direction than today, probably along the Cristianitos Fault. By Late Pliocene, a prograding wedge, as seen within the modern day San Joaquin Hills, moved westward within the Los Angeles Basin area, while few sediments collected in the study area. A major regression ended Pliocene deposition.

Graphic reconstructions of Pliocene paleoenvironments have been attempted (Figure 10) for sake of completing the set for Tertiary time. They should be considered highly speculative at best. The following publications were relied on heavily during their development: Ehlig (1977), Woodford (1925), Ingle (1973b), Piper and Normank (1971), Vedder et al. (1957), Gastil and Higley (1977), Moyle (1973), and Yerkes et al. (1965).

SUMMARY OF CONCLUSIONS

The Tertiary history of the area of study can be divided into three segments. The Eocene is represented by sandstones and mudstones of lagoonal, littoral and near-shore marine origin, overlain by prograding delta and tidal sandstones and mudstones. These prograding units interfinger or grade upward into marine mudstones (upper marine unit). The second segment includes Oligocene and Early Miocene, a time of erosion and non-deposition. Both the first and second segments of the geologic history of the area were contemporaneous with subduction of the Farallon Plate. The third segment is from Middle Miocene to the close of the Tertiary. This last subdivision of Tertiary history is characterized by initiation of the formation of the southern California borderland. Basins and highlands created by east-west extension related to right lateral transform faulting imposed a significant control on the stratigraphy. In Middle Miocene time a landmass to the west or southwest shed fan sediments into the area (San Onofre Breccia). The breccia is overlain by the youngest Tertiary unit in the area (San Mateo Formation) which contains a mixture of turbidite and shallow marine sandstone beds.

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Drowned mouth of Santa Margarita River, north of Oceanside, California. Photo taken by Dr. John S. Shelton on November 24, 1959.

THE VERTEBRATE FOSSILS OF THE MARINE CENOZOIC SAN MATEO FORMATION AT OCEANSIDE, CALIFORNIA

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ABSTRACT

Vertebrate fossils occur in two different horizons in a marine rock unit referred to the San Mateo Formation exposed at Oceanside in San Diego County, California. The rock unit rests upon the San Onofre Breccia and is overlain by terrace deposits. Sharks, bony fishes, birds, and mammals including a mixture of terrestrial and marine taxa comprise two separate faunal aggregates in this formation. The lower faunal aggregate at the base of the rock unit is here named the San Luis Rey River Local Fauna, and the upper one is named the Lawrence Canyon Local Fauna. No fossil invertebrates are known from this rock unit, but the joint occurrence of horses of the genera *Pliohippus* or *Dinohippus* and the salmon *Smilodonichthyes* indicate a Hemphillian North American Land Mammal Age for both local faunas. This is the first systematic recording of these faunal units which include a southern range extension of the salmon *Smilodonichthyes rastrosus*. The whale *Nannocetus*, and the flightless auk *Praemancalla* have their first documented post-Clarendonian occurrences here. The extinction of *Praemancalla* and its apparent evolutionary replacement by *Mancalla* apparently occurs within the time span represented by this rock unit. The Lawrence Canyon Local Fauna contains the rare otter *Enhydriodon*, and the San Luis Rey River Local Fauna contains several new species of birds.

INTRODUCTION

The name San Mateo Formation was first used by Woodford (1925:217), who gave little description of it. Woodford grouped it among "Post-Capistrano Formations," and described it as nearshore marine shelf deposits composed of tilted arkosic sands, gravels, and schists, with rare fossils. He indicated that the formation is doubtfully correlated with the San Diego Formation, is questionably of Pliocene age, overlies the Capistrano Formation, and is overlain by Pleistocene gravels and alluvium. Woodford mapped outcrops of the San Mateo Formation (combined with Pleistocene terrace deposits) along the south side of Arroyo San Mateo near San Onofre in San Diego County (1925: pl. 24), on the east side of Aliso Creek three miles north of Dana Point in Orange County (pl. 35), and in a strip along the sea coast from south of San Juan Capistrano to the town of Oceanside.

The name San Mateo Formation has continued to be used in various reports and planning documents, and Rogers (1965) shows it occurring in the northern Oceanside area, while at the same time calling it questionably

Pliocene in age. Vedder (1972:167) stated that the type section of the San Mateo Formation near San Onofre "may be a channel deposit within the lower part of the Capistrano Formation." Barnes (1976) labeled these strata at Oceanside the San Mateo Formation, placing their age as latest Miocene to early Pliocene between 10 and 5 million years old, and correlated them with the Almejas, Drakes Bay, Purisima, Capistrano, Jacalitos, and Etchegoin Formations, with the "Jacalitos" and "Etchegoin" provisional molluscan stages (of Addicott, 1972), and the Hemphillian North American land mammal age.

Despite these uncertainties, and pending more detailed geologic studies, the fossil bearing strata reported here may be provisionally assigned to the San Mateo Formation. These outcrops are at the extreme southern extent of Woodford's (1925:pl. 23) mapped outcrop of post-Capistrano Formation (San Mateo Formation and Pleistocene terrace) sediments. Frazier (1970) reported sharks, fish, birds, sea lions and whales in gravel quarries here, and Barnes (1976) summarized the whales from these same rocks. Domning (1978:75,158-159) described sea cow bones and listed preliminary identifications of some of the fossils from the same localities. The vertebrate fossils reported in the present paper were collected by personnel of the University of California Museum of Paleontology (Berkeley) and of the Natural History Museum of Los Angeles County, as well as some private collectors, in Lawrence Canyon and on both sides of the San Luis Rey River northwest of Oceanside. The localities are in gravel quarries and other man-made exposures, and the fossils were collected as surface specimens that have been exposed by natural weathering and also by screening. Bones and teeth are usually disassociated and scattered through the sediment laterally and vertically. No invertebrate fossils have been found at the Oceanside outcrops of the San Mateo Formation. Several terrestrial mammal bones have been collected at the same localities as the marine vertebrates.

Geologic and paleontologic evidence indicates that there are two main vertebrate fossil producing horizons within the San Mateo Formation at Oceanside. These horizons are well exposed and stratigraphically superimposed in the quarry face on the southeast side of Lawrence Canyon (see Fig. 1).

The lower horizon is in relatively fine gray sands just above the contact with the underlying San Onofre Breccia. This outcrop (locality LACM 4297 = UCMP V68147) produced the aggregate faunal assemblage that characterizes our new San Luis Rey River Local Fauna. Some of the fossils from this horizon are well-preserved delicate items while others are associated skeletons. Other nearby localities (UCMP V68144 = SDSNH 2957 = LACM4298, north of Loretta Street; UCMP V68145 = SDSNH 3004 = LACM 4299, north of the San Luis Rey River; UCMP V6881) are in a similar lithology and yield taxa referred to the same local fauna but their stratigraphic context is less clear.

Stratigraphically higher in the hillside above LACM locality 4297 (= UCMP V68147), and separated from it by several tens of feet of intervening sand and gravel beds, is a fossiliferous gravel bed in a coarse sand matrix. This horizon is nearly at the top of the exposed section at this site. This bed (locality LACM 4301 = UCMP V68106 = SDSNH 2643) produced the faunal assemblage that characterizes our younger Lawrence Canyon Local Fauna. Bones and teeth in this bed consist of disassociated and in some cases water worn and broken isolated bones and teeth. Other nearby localities (UCMP V6880, V68146, V68148) are probably from approximately the same stratigraphic level.

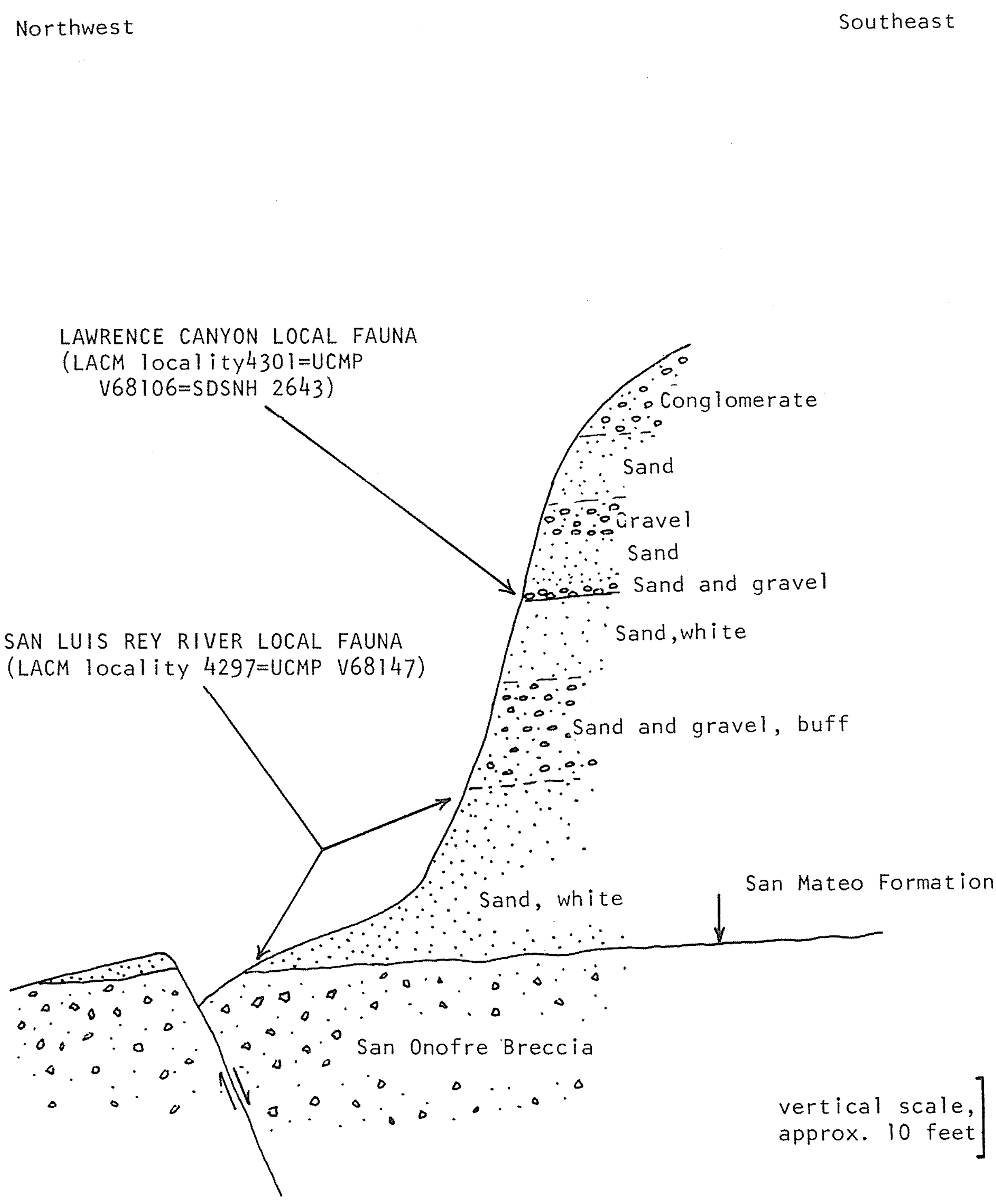

Fig. 1. Generalized geologic cross section of the San Mateo Formation at Lawrence Canyon in Oceanside. At this site, the two local faunas are in stratigraphic sequence. The amount of offset on the fault has not been measured. Relative thicknesses of the beds are variable, and this cross section was compiled from field notes and field sketches.

This paper documents these two local faunas, presents preliminary faunal lists, and sets the stage for more detailed systematic accounts of the fossil vertebrates. We give brief accounts of some of the more critical or significant taxa in these local faunas. We list some of the more diagnostic characters for particular taxa and cite published illustrations.

We have made faunal comparisons with other west coast marine rock units. We have followed the chronologies used by Barnes (1976:fig.2) and Repenning and Tedford (1977:table 1). Critical comparative assemblages are from the Monterey Formation and the superjacent Capistrano Formation in Orange County, the San Diego Formation at San Diego, the Almejas Formation on Isla Cedros, Baja California, the Purisima Formation along the central California coast south of San Francisco, the Drakes Bay Formation at Point Reyes Peninsula north of San Francisco, and the Merced Formation inland from there. Barnes (1976) and Repenning and Tedford (1977) have reviewed chronologic positions of these rock units and described marine mammals from them.

Important specimens were collected and placed in museum collections by A. Brian Brockmeier, Larry Danielson, and Ken Frazier, Thomas A. Deméré of the San Diego Society of Natural History helped to acquire and make available several critical specimens.

Within the text, certain Museum specimens are cited to vouch for our taxonomic determinations. Institutional acronyms for these are: LACM - Natural History Museum of Los Angeles County; SDSNH - San Diego Society of Natural History; UCMP - University of California Museum of Paleontology (Berkeley); UCR - University of California at Riverside.

Table I. Taxa of the San Luis Rey River Local Fauna

Isurus cf. *I. oxyrhynchus* -- mako shark
Isurus cf. *I. hastalis* -- mako shark
Carcharodon sulcidens -- great white shark
Myliobatoidea -- bat ray
Smilodonichthyes rastrosus -- saber-toothed salmon
cf. *Pimelometopon* -- sheepshead
Istiophoridae -- marlin
Gavia sp. -- loon
Diomedea sp. -- albatross
Uria new species -- Murre
Cepphus new species -- guillemot
Aethia sp. -- auklet
Praemancalla sp. -- flightless auk
?Falconidae -- falcon
aff. *"Stenodelphis" sternbergi* -- long snouted dolphin
Nannocetus sp. -- primitive baleen whale
Odobeninae -- walrus
Otariinae -- sea lion or fur seal
Hydrodamalis cuestae -- sea cow
Pliohippus or *Dinohippus* -- horse
Camelinae -- camel

Table 2. Taxa of the Lawrence Canyon Local Fauna

Hexanchus sp. -- six gill shark
Isurus cf. *I. oxyrhynchus* -- mako shark
Carcharodon megalodon -- great white shark
Carcharodon sulcidens -- great white shark
Carcharhinus sp. -- bay shark
Prionace sp. -- blue shark
Pristiophorus sp. -- saw shark
Squatina sp. -- angel shark
Dasyatidae -- ray
Myliobatoidea -- bat ray
Chimaeridae -- rat fish
Smilodonichthyes rastrosus -- saber-tooth salmon
cf. *Pimelometopon* sp. -- sheeps head
Teleostei spp. -- many undescribed bony fishes
Mancalla sp. -- flightless auk
Accipitridae -- eagle
aff. *"Stenodelphis" sternbergi* -- long snouted dolphin
Stenella or *Delphinus* -- dolphin
Phocoenidae -- porpoise
Odontoceti, *incertae sedis* -- dolphin
Scaldicetus cf. *S. grandis* -- sperm whale
Nannocetus sp. -- primitive baleen whale
Balaenula sp. -- right whale
Odobeninae -- walrus
Otariinae -- sea lion or fur seal
Hydrodamalis cuestae -- sea cow
Pliohippus or *Dinohippus* -- horse
Camelidae -- camel

SAN LUIS REY RIVER LOCAL FAUNA - SYSTEMATIC ACCOUNT

Following are some of the diagnostic characters of some of the taxa in the aggregate faunules from the lower part of San Mateo Formation which constitute the San Luis Rey River Local Fauna. Most of these are from the basal fine sand at the southeast side of the quarry in Lawrence Canyon.

Class Osteichthyes
Order Salmoniformes
Family Salmonidae
Smilodonichthyes rastrosus Cavender and Miller, 1972

One vertebra (UCMP 88703) from the lower sand bed (UCMP Loc. V68147) and three vertebrae (UCMP 88652, 88653, 119996) and a premaxilla (UCMP 88651) from the probably stratigraphically correlative outcrop on the north side of San Luis Rey River (UCMP loc. V68145) are identifiable as this large filter-feeding salmon. The premaxilla bears the characteristic single large tooth, and the large well preserved vertebrae have minute reticulated networks of bony struts on their lateral surfaces.

Order Perciformes
Family Labridae
Pimelometopon sp.

A small fragment of a mandible with one tooth (UCMP 124953) indicates the presence of a labrid fish in the lower unit (UCMP V68144). The specimen may belong in the same genus as the modern sheepshead, *Pimelometopon*.

Family Istiophoridae

Some associated bones, LACM 119247, of a single individual represent a large marlin.

Class Aves
Order Gaviiformes
Family Gaviidae
Gavia Forster, 1788
Gavia sp.

A nearly complete tarsometatarsus, UCMP 88656, from locality UCMP V68145, closely resembles that of the modern species of loons, *Gavia pacifica* (Lawrence, 1858) and *G. stellata* (Pontoppidan, 1763). A notable distinction is the very high posterior position of the distal foraman in the fossil. Four extinct Tertiary species of loons have been named from North America: *Gavia brodkorbi* Howard, 1978 (Late Miocene, Monterey Formation, Orange County, California); *Gavia concinna* Wetmore, 1940 (Pliocene, Etchegoin Formation of Monterey County, San Diego Formation of San Diego County California, and Bone Valley Formation of Florida); *Gavia howardae* Brodkorb, 1953 (Pliocene, San Diego Formation); and *Gavia palaeodytes* Wetmore, 1943 (Pliocene, Bone Valley Formation, Polk County, Florida). The tarsometatarsus has not been recorded for any of these species and therefore it is not appropriate to attempt to assign the fossil to a species.

Order Procellariiformes
Family Diomedeidae
Diomedea Linnaeus, 1758
Diomedea sp.

A distal left tibiotarsus, LACM 119353, from locality LACM 4297 resembles the tibiotarsus of the Recent Black-footed Albatross, *Diomedea nigripes* Audubon, 1839, in the rounded contour of the external condyle (viewed laterally) and slight notch in the distal surface of the internal condyle. The fossil is narrower, however, in the area of the ligamental bridge and is about 8 per cent smaller in over all breadth of the distal end.

Four fossil species of *Diomedea* have been described: *Diomedea anglica* Lydekker, 1891 (Early Pleistocene and Late Pliocene of England and Early Pliocene of Florida [see Brodkorb, 1963:242]); *D. milleri* Howard, 1966 (Middle Miocene, Sharktooth Hill Bonebed in Kern County, California); *D. thryidata* Wilkinson, 1969 (Late Miocene of Australia); and *D. californica* Miller, 1962 (Sharktooth Hill Bonebed and, tentatively [Howard, 1978] Late Miocene, Monterey Formation, California). A tarsometatarsal shaft of *Diomedea* sp., close in size to that of *D. nigripes*, also was recorded (Howard, 1968) from an earlier facies of the Monterey Formation in Orange County. Both the tibiotarsi of *D. ?californica* from Orange County and the Florida specimen of *D. anglica* are markedly larger than the one from the San Mateo Formation. The ulna is the only recorded specimen of *D. milleri*, and is smaller in proportion to the comparable element of *D. nigripes* than is the tibiotarsus from Oceanside.

Order Charadriiformes
Family Alcidae
Uria Brisson, 1760
Uria, new species

Associated elements of one individual of a murre (UCMP 88704 from locality UCMP V68147) closely resemble comparable elements of *Uria aalge* (Pontoppidan, 1763) and *U. lomvia* (Linnaeus, 1758), the two living species of murres. Notable distinctions are found in the spacula, coracoid and ulna. The dorsal surface of the fossil scapula is more concave, the coracoid is stouter and the scapular facet more cup-shaped, the ulna is shorter with a more rounded shaft.

The genus *Uria* was tentatively recorded from the Monterey Formation of Orange County (Howard, 1978) based on a portion of a humerus with stockier proportions than the humerus of *U. aalge* and *U. lomvia*. This is true of the ulna here referred to *Uria*, new species. The only other fossil record for the genus in North America is *Uria antiqua* (Marsh, 1870) from North Carolina, of lower Pliocene age. According to Olson (1978:100) the holotype humerus of this species is wrongly assigned to the genus *Uria*.

Cepphus Pallas, 1769
Cepphus, new species

A guillemot humerus, from locality LACM 4297, has the curvature characteristic of species in the genera *Uria*, *Alca* Linnaeus, 1758 and *Cepphus*, as distinquished from the straighter shaft found in the puffins of the genera

Fratercula Brisson, 1760 and *Lunda* Pallas, 1811. This fossil is distinguished from the humerus of *Uria* and *Alca,* however, by the less bladelike compression of the shaft. It resembles this element of *Cepphus columba* Pallas, 1811, the living Pigeon Guillemot, in this character, but is shorter, with distinctive characters of the pectoral attachment, deltoid crest and ectepicondylar process.

The genus *Cepphus* was tentatively recorded (Howard, 1978) from the Monterey Formation of Orange County. That specimen, an ulna, suggests a species comparable in size to the one represented by the humerus from Oceanside, but there is no clear indication that the two elements represent the same species. There are no other Tertiary records of *Cepphus*.

Aethia Merrem, 1788

A small auklet humerus (LACM 107031 from LACM locality 4297) resembles the referred humerus of *Aethia rossmoori* Howard, 1968 from the type locality of that species in the Monterey Formation of Orange County. It also resembles a humerus from a higher level of the Monterey Formation in Orange County identified by Howard (1978) as *?Aethia* sp. Similarities are in the rounded shaft, the brachial impression which is bordered externally by a slight rise, and the attachment of anterior articular ligament which faces more palmad than laterally. In size, the fossil from Oceanside is between these two previously recorded humeri. All three fossils differ from specimens of modern auklets, *Aethia pusilla* (Pallas, 1811) and *A. pygmaea* (Gmelin, 1789) in the greater depression of the brachial area and the different position of the attachment for the anterior articular ligament. Distally, LACM 107031 is further distinguished from the humerus of the living species of *Aethia* in lacking the deep depression between the internal and medial tricipital ridges. This condition is also suggested in the fossil humerus from high in the Monterey Formation.

Praemancalla Howard, 1966
Praemancalla sp.

The flightless auk, *Praemancalla,* is the most common bird in the San Luis Rey River Local Fauna. Fossils include: from one locality LACM 4297, LACM 107028, skeletal elements of one individual consisting of carpometacarpus, ulna, tibiotarsus, tarsometatarsus, pedal phalanx and thoracic vertebra; LACM 107030 end of coracoid; and LACM 119406, sacrum with pelvic bones; from locality UCMP V68147, UCMP 102428, axis vertebra; from locality LACM 4298, LACM 107029, right humerus; from locality UCMP V68145; UCMP 95119, end of left scapula; and UCMP 95118, left femur.

Extinct mancalline auks of the genera *Mancalla* Lucas, 1901 and *Praemancalla* are distinguished from Recent species of the family Alcidae by the transverse compression of the shafts of the wing bones and the shortening of the ulna and carpometacarpus. These characters coincide with a specialized flipperlike wing, a specialization that is more advanced in *Mancalla* than in *Praemancalla*.

The five known species of *Mancalla* are from latest Miocene and Pliocene deposits in California and Baja California, Mexico. The two species of *Praemancalla* are from the Late Miocene Monterey Formation in Orange County.

Wing and shoulder girdle bones of *Praemancalla* differ from those of species of *Mancalla* as follows: humerus with deltoid crest poorly developed, capital groove forming a wide angle, and distal end lacking a papilla on the palmar surface above the condyles; ulna with a prominent olecranon; carpometacarpus with a raised pisiform process; coracoid with more medially, less posteriorly oriented triosseal canal; scapula with flatter ventral surface of the proximal end and longer acromion. The sacrum and axis vertebra resemble those of *Mancalla diegensis* (Miller, 1937) and *M. cedrosensis* Howard, 1971, though with certain small distinctions. These distinctions, combined with the larger size of the Oceanside specimens (as observed, also, in the vertebra associated with the *Praemancalla* wing bones of LACM 107028), justify assignment to *Praemancalla*.

The large femur (UCMP 95118) is distinctly different from that of any modern bird. Its relatively slender shaft, bent toward the median side distally, resembles the holotype femur of *M. diegensis*. It differs from that specimen and the femora of all species of *Mancalla,* however, in the depression of the shaft adjacent to the fibular crest. It is referred to *Praemancalla* because its size is commensurate with that of the tibiotarsus and tarsometatarsus associated with the wing elements of *Praemancalla* specimen LACM 107028.

Of the two previously described species of *Praemancalla, P. lagunensis* Howard, 1966 is from the lower part of the Monterey Formation in Orange County, and *P. wetmorei* Howard, 1976 is from the upper part. The *Praemancalla* bones from Oceanside appear to represent *P. wetmorei*.

Family Falconidae

An incomplete clavicle, UCMP 88597, from UCMP locality V6880 resembles this element of the falcons in the prominent, round coracoidal facet.

Class Mammalia
Order Cetacea
Family Pontoporiidae
aff. *"Stenodelphis" sternbergi* Gregory and Kellogg, 1927

A weathered, incomplete skull, LACM 121590 from LACM locality 4297 is congeneric with a skull (LACM 6238) referrable to this species from the San Diego Formation. I have already pointed out (Barnes, 1973; 1976:333) that the species requires a new generic allocation. The skull from Oceanside is not complete enough, however, to determine if it is most closely related to *"S." sternbergi* or to an older species which is known from the Purisima and Almejas Formations (Barnes, 1976:332, table 5).

Family Cetotheriidae
Nannocetus sp.

A partial skull, UCMP 94648, of a small baleen whale from the lower sand (UCMP locality V68147) shares with the partial cranium of the holotype of *Nannocetus eremus* Kellogg, 1929 the following characters: a posteriorly directed postglenoid process that is aligned anteroposteriorly with the zygomatic process, a deep recess between the glenoid fossa and the ear region, a gently curved dorsal surface of the supraorbital process which inclines gently to the cranial vertex, rostral bones which do not penetrate into the cranial vertex beyond the midpoint between the orbits, and a deep anteroposteriorly elongate recess between the dorsal surface of the zygomatic process and the lateral wall of the braincase.

A periotic, LACM 119528, from the same locality closely resembles the holotype periotic of *N. eremus* and the two periotics have in common small size, a flattened and ventrolaterally sloping cerebral surface lateral to the internal acoustic meatus, a small pointed anterior process which has a strong ventral keel, a small cochlea, and a flattened posterior surface.

The posterior end of a lower jaw, UCMP 88667, from similar sands north of San Luis Rey River (UCMP locality V68145) bears a large angular process below its condyle. The specimen shares in common with *Herpetocetus scaldiensis* Van Beneden, 1872 of late Miocene age from Belgium, small size, a posteriorly extended angular process, and an anterodorsally sloping articular surface. The mandibles studied by Van Beneden (1882: pls. 103, 104) have a longer angular process an an articular surface which is broader dorsally than does the specimen from Oceanside, which has a deeper medial groove separating the angular process from the condyle. Whitmore and Barnes (in manuscript) have discovered phyletic affinities between *Herpetocetus* and *Nannocetus*, and this mandible section from Oceanside probably is *Nannocetus*.

Order Carnivora

Family Otariidae

Subfamily Odobeninae

Three bones from UCMP locality V68145 in the sands north of the San Luis Rey River are assigned to the San Luis Rey River Local Fauna and show walrus-like morphology. A calcaneum (UCMP 96073) and a humerus (UCMP 88693) show *Odobenus*-like features, and a radius, UCMP 96076, is generally odobenine and shares features in common with radii referred to both *Pliopedia pacifica* Kellogg, 1921 and *Dusignathus santacruzensis* Kellogg, 1927 by Repenning and Tedford (1977: pl. 24, fig. 4; pl. 16, fig. 5).

Subfamily Otariinae

Two mandibles (UCMP 88689, 88690 from UCMP locality V68145 show some resemblances to females of *Thalassoleon mexicanus* Repenning and Tedford, 1977, the fossil fur seal from the Almejas Formation, but some characters, including the smooth cheek tooth crowns are more similar to the living Guadalupe fur seal, *Arctocephalus townsendi* Merriam, 1897. A third mandible, in contrast, has a more robust tooth and a more vertical coronoid process than males of *T. mexicanus*. More than one species of otariine, perhaps one a fur seal, the other a sea lion, may be present in this local fauna.

Order Sirenia

Family Dugongidae

Hydrodamalis cuestae Domning, 1978

This ancestral Steller's sea cow was identified by Domning (1978) from the lower sand unit on the basis of a right rostral fragment, UCMP 86345 from UCMP locality V68145. Subsequently a nearly identical left rostral fragment, SDSNH 21076 has been recovered from the same site. Various rib and vertebral fragments probably referrable to the same species have been found in most outcrops of the lower sand unit (SDSNH 22655, and see Domning, 1978).

Order Perissodactyla
Family Equidae
Pliohippus Marsh, 1874
or *Dinohippus* Quinn, 1955

An isolated upper cheek tooth, UCMP 88695 from locality UCMP V68145 is distinclty curved labially and has the protocone united with the protoconule. The anteroposterior length of the crown is 29.0 mm. Isolated cheek teeth of the *Pliohippus/Dinohippus* grade are not generically diagnostic and this single specimen prohibits meaningful species comparisons.

Order Artiodactyla
Family Camelidae
Subfamily Camelinae

A water-worn astragalus (UCMP 88698) with narrowly separated proximal trochlea indicates the presence of a cameline camel in the lower unit (UCMP V68145). The astragalus is 87.6 mm long and 56.7 mm in distal width suggesting this camel was the size of *Camelops* (see Webb, 1965).

LAWRENCE CANYON LOCAL FAUNA - SYSTEMATIC ACCOUNT

Following are some of the diagnostic characters of some of the taxa from the upper part of the San Mateo Formation which comprise the Lawrence Canyon Local Fauna. The majority of these are from a single locality in a gravel bed near the top of the exposed section at the southeast side of the quarry in Lawrence Canyon (= localities LACM 4301 = UCMP V68106 = SDSNH 2643).

Class Osteichthyes
Order Salmoniformes
Family Salmonidae
Smilodonichthyes rastrosus Cavender and Miller, 1972

One large vertebra, UCMP 88595, from the upper gravel bed (UCMP V6880 = LACM 4301) is similar to vertebrae discovered in the lower strata and has the characteristic reticulated pattern on its centrum that is characteristic of *Smilodonichthyes rastrosus*.

Class Aves
Order Charadriiformes
Family Alcidae
Mancalla Lucas, 1901
Mancalla sp.

From locality LACM 4301 = UCMP V68106, 30 humeri (1 complete, LACM 119165), 13 ulnae (8 complete, LACM 119279-119283, 119286, 119288-119289), 10 coracoids (1 nearly complete (UCMP 88614), 9 scapulae, 6 tibiotarsi, 5 tarsometatarsi (1 complete, LACM 119298), 3 carpometacarpi, 2 pedal phalanges, 1 radius, 1 wing phalanx, 1 thoracic vertebra have been collected for a total of 81 bones. Preservation of this material is imperfect, but for those elements that have been previously described for both *Mancalla* and *Praemancalla* these bones clearly show the characteristics of the former. Among the humeri the capital groove is notch-like, and a papilla is present above the tip of the distal condyles. On the ulnae the olecranon is level with the cotylae, not projecting proximally, and at the distal end there is no projection overhanging the tendinal pit. The radius is bladelike; the carpometacarpi lack a distinct pisiform process. The coracoids have the triosseal canal dorsally (posteriorly) oriented, and the scapular facet laterally placed. The scapulae are markedly concave on the ventral surface, the acromion is short, the glenoid facet medially projected. The tibiotarsi lack the notable flare of the distal end which is observed on the tibiotarsus associated with the wing bones of *Praemancalla* (LACM 107028) from the lower horizon. On those tarsometatarsi in which the shaft is preserved, the anterior face is depressed along the external side, but acutely raised above the middle trochlea.

There are four previously named species of *Mancalla: M. californiensis* Lucas, 1901, from the early Pliocene Repetto Formation in Los Angeles, and the Repetto Formation in Corona del Mar, Orange County, California (Howard 1949:196 and 1970:3); *M. cedrosensis* Howard 1971, from the Almejas Formation on Isla Cedros, Baja California, Mexico; *M. diegensis* (Miller 1937) and *M. milleri* Howard 1970, both from the Pliocene San Diego Formation in San Diego, California.

The best preserved proximal end of a humerus (LACM 119222) from Oceanside shows one of the diagnostic characters described for *M. cedrosensis* (Howard 1971:11): "area below head, between pectoral attachment and pneumatic fossa oval and deeply depressed." Four other less well preserved humeri also suggest this character (LACM 119224, 119269, 119273, 119372). On the basis of size, some small specimens, including scapulae (LACM 119264 and 119262), humeri (LACM 119166 and 119272), ulna (LACM 119283), radius (LACM 119292) and carpometacarpus (LACM 119290) agree with comparable elements from the San Diego Formation that have been assigned to *M. milleri* (Howard, in manuscript).

Order Falconiformes
Family Accipitridae

The proximal portion of a first phalanx of digit 1 (LACM 119310), represents a small eagle of indeterminate genus and species.

Class Mammalia
Order Cetacea
Family Pontoporiidae
aff. *"Stenodelphis" sternbergi* Gregory and Kellogg, 1927

A total of four isolated periotics, LACM 119532, SDSNH 23052 (three right periotics) are virtually identical to periotics identified as *"Stenodelphis" sternbergi* from the San Diego and San Joaquin Formations (see Barnes, 1973:37-38, fig. 2a-b; 1976:333). Since there are no periotics associated with skulls of an apparently geologically older undescribed species which is known from the Purisima and Almejas Formations (see Barnes, 1976:332; table 5), there is no way to decide how closely related these might be to the species from the upper local fauna at Oceanside. A fragment of a cranial vertex, LACM 119533, shows the elevated and assymmetrical structure of the frontals and nasals that is characteristic of this genus. The closest living relatives of these animals are the La Plata dolphins or Franciscanas of coastal waters off the east coast of South America.

Family Delphinidae
Stenella Gray, 1866 or *Delphinus* Linnaeus, 1758

Two Periotics (UCMP 96504, and SDSNH 23051 from Localities UCMP V-68106, and SDSNH 2643 respectively) closely resemble those identified as *Stenella* sp. or *Delphinus* sp. (Barnes, 1973a: 39, fig. 2, e,f) from the San Diego Formation, in their small size, manner of elevation of the cerebral orifice of *aquaeductus cochleae*, and in the anterior extension of the border of the *foramen centrale* toward the anterior process. In overall shape of the periotic and positions of other foramina, they resemble periotics of Recent species of both *Stenella* and *Delphinus*. At the present time, there is no information which would confirm to which genus these fossils are most closely related.

Family Phocoenidae
Genus and species undescribed

Three isolated periotics (SDSNH 23049, 23053, and 23054) are probably conspecific with a series of isolated periotics and a periotic from a skull from the Capistrano and Almejas Formations which Barnes (1976:332, table 5) has previously labeled Phocoenidae sp. A. At the time of that writing, this taxon had not been recognized at Oceanside. These periotics have general delphinoid characteristics as well as a large cochlea which protrudes anteriorly and is separated by a deep cleft from a relatively small and anteromedially directed anterior process. The posterior articular facet of these periotics has a smooth surface and a rounded posterior margin. Skull parts of this taxon (Barnes, in manuscript) show it to be a generalized phocoenid which is not closely related to Recent harbor porpoises, *Phocoena phocoena* (Linnaeus), 1758.

Odontoceti, *incertae sedis*

Some relatively distinctive delphinoid periotics (LACM 119364, SDSNH 23048, 23050) have been found in the upper horizon. Periotics of this same species, which Barnes (1976:332, table 5) labeled as Odontoceti sp. B, have been discovered in the Almejas, Purisima and Capistrano Formations. This type of periotic has yet to be discovered in a fossil skull, however, and apparently represents an undescribed species. The periotic is characterized by being elongate in an antero-posterior plane, by having a prominent posterior process, a relatively low cochlea which is broadly joined to the anterior process with no cleft separating them, and by having the internal acoustic meatus elongate anteriorly.

Family Physeteridae
Scaldicetus cf. *S. grandis* (Du Bus), 1872

One tooth (UCMP 88700) with an incomplete crown from the upper horizon (UCMP loc. V68146) is similar to teeth from Europe assigned to the fossil sperm whale *Scaldicetus grandis* by Abel (1905: figs. 3,4) and by Menesini and Tavani (1968: pl. 16, figs. 1, 2, and pl. 17) in posessing a large, curved, bulbous root with an encircling bulge between the middle and the crown, and a relatively small, conical crown covered with wrinkled enamel and set off from the root by a rather distinct neck. The enamel on the crown is not well preserved but is definitely finely wrinkled. Most of the crown has been worn away by an occluding tooth from the opposite jaw (whether upper or lower is not known). Some of the teeth illustrated by Menesini and Tavani (1968) show similar wear.

Menesini and Tavani (1968) summarized the generic names that have been applied to Miocene sperm whales with teeth like the one from Oceanside, and concluded that the name *Scaldicetus* Du Bus, 1867 is a senior synonym of *Palaeodelphis* Du Bus, 1872, *Hoplocetus* Gervais 1848-1852, and *Apenophyseter* Cabrera, 1926. *Scaldicetus* is therefore known from Miocene deposits of Italy, Argentina, Belgium, and California. Barnes (1976: 330, 332, 334, tables 4, 5 and 6) previously reported teeth of *Scaldicetus* from the contemporaneous Drakes Bay Formation, the older Monterey Formation, and the younger upper part of the Capistrano Formation and the San Diego Formation.

Family Cetotheriidae
Nannocetus sp.

One isolated posterior process of a periotic (SDSNH 23055) is similar to that in the holotype of *Nannocetus eremus* Kellogg, 1929. This process, as on the geologically older species, *N. eremus*, is relatively short, broad, expanded distally, flat ventrally, rugosely sutured to the paroccipital process, and transversely grooved ventrally for the facial nerve. Whitmore and Barnes (in manuscript) have described the significance of this unique posterior process of the periotic in *Nannocetus eremus* as well as in *Herpetocetus scaldiensis* Van Beneden, 1872, a related species from Europe.

Family Balaenidae Gray, 1825
Balaenula sp.

UCMP 83223 an incomplete cranium, from locality UCMP V-6880 in common with primitive bowhead or right whales, and closely resembles a skull from the Merced Formation in Northern California identified as *Balaenula* sp. nov. (Barnes, 1976: 334, table 6). It agrees with *Balaenula* Van Beneden, 1872 by having an occipital shield which broad posteriorly and narrow anteriorly, a glenoid fossa of the squamosal located ventrally, large ventrally descending falcate processes of the basioccipitals, relatively highly arched basioccipital, no distinct foramen ovale, relatively broad ventral surface of the squamosal with a sharp anterior margin between the glenoid fossa and the auditory capsule, a vertical lateral wall of the cranium, and a deep crease where the supraorbital process joins the cranium. The specimen is slightly smaller than the one from the Merced Formation, and had an estimated zygomatic width of 82 cm and an estimated exoccipital width of 56 cm. In contrast with the specimen from the Merced Formation, the paroccipital processes are not thick, the bony lumen of the external auditory meatus is shallower, and the zygomatic process of the squamosal is not as heavy.

Order Carnivora

Family Mustelidae

Enhydriodon aff. *E. lluecai* Villalta and Crusafont, 1945

An isolated left $M_{\bar{1}}$ of an otter from the upper bed is in a private fossil collection. A cast (LACM 121591) has been made of it. The tooth represents the same species as a jaw fragment (UCMP 32970) with an $M_{\bar{1}}$ from the Hemphillian age marine Etchegoin Formation in California's San Joaquin Valley (see Repenning, 1976). The new specimen confirms the morphology of the missing anterior end of the $M_{\bar{1}}$ as restored by Repenning (1976: fig. 2,f), and in addition has a cingulum around the anterior and lingual sides of the trigonid. We agree that this California Hemphillian otter is related to *E. lluecai* of late Miocene age from Spain, but show its affinities as being slightly more distant than was implied by Repenning.

Family Otariidae

Subfamily Odobeninae

An atlas vertebra, UCMP 88623, is walrus-like in its characters. Beyond this, the lack of described atlases for other late Miocene and Pliocene walruses such as *Pliopedia, Dusignathus, Aivukus* Repenning and Tedford, 1977, *Pontolis* True, 1905, and *Valenictus* Mitchell, 1961 prohibits further identification of this bone.

Subfamily Otariinae

Museum collections include several isolated teeth and bones of true sea lions or fur seals from the upper gravels. Because of the incomplete record of the otariines during this time span, and complicating factors such as individual variation and sexual dimorphism, more precise identifications would probably be premature. Several cheek teeth (LACM 119366, 119546, 119547, 119548, SDSNH 14073) are two rooted or have a single bilobed root and a simple crown with a finely cusped lingual cingulum. These resemble cheek teeth of *Thalassoleon* spp. except for their more prominent cingular cusps. Both male and female sizes seem to be included.

A humerus (UCMP 88714) is similar to one of a male of the fossil fur seal *Thalassoleon mexicanus* from the Almejas Formation (Repenning and Tedford, 1977: pl. 22, figs. 7-8), but shows enough differences to suggest that it represents a different species.

Order Perissodactyla

Family Equidae

Pliohippus Marsh, 1874

or *Dinohippus* Quinn, 1955

An isolated upper cheek tooth, UCMP 119322, from the upper gravel beds can be identified no more precisely than the one mentioned previously from the lower sands. This specimen is smaller than the other tooth, measuring 21.6 mm. in anteroposterior crown length. It is however similarly curved labially, and its protocone is united with the protoconule.

CONCLUSIONS

Pending further geologic studies, the marine sediments that overlie the San Onofre Breccia at Oceanside are provisionally called the San Mateo Formation. The two major vertebrate fossil producing horizons are the lower and older San Luis Rey River Local Fauna and the upper Lawrence Canyon Local Fauna. Both are newly named here. They are both Hemphillian in age in the North American land mammal chronology, latest Miocene and between approximately 5 and 9 million years old. Horses of the *Pliohippus/Dinohippus* grade both high and low in the section indicate an age no later than Hemphillian. Similarly, the large filter-feeding saber toothed salmon, *Smilodonichthyes rastrosus* which is found at both levels in the rock unit has previously been reported in deposits of Hemphillian age in Oregon and Northern California. The otter, *Enhydriodon aff. E. lluecai*, has been found previously in the Hemphillian age Etchegoin Formation of central California.

Smilodonichthyes rastrosus had only been recorded previously from fresh water deposits, but Cavender and Miller (1972) postulated that it was anadromous. This, the first published marine occurrence, supports that concept, and suggests that the species is a useful tool for correlating between terrestrial and marine chronologies. The presence of the large breeding teeth of males in the same strata with fossil bones of terrestrial mammals indicates a relatively near-shore environment of deposition for these rocks, probably near the mouth of a major river. This is also the most southerly record of *S. rastrosus*.

The flightless mancalline auks are the most abundant birds in both local faunas. The genus *Mancalla* accounts for virtually all of the birds and the majority of the fossils in the upper beds that produce the Lawrence Canyon Local Fauna. The older San Luis Rey River Local Fauna includes the first post-Clarendonian (= post Monterey Formation) record of the more primitive genus *Praemancalla*, and the San Mateo Formation apparently spans the time in which *Praemancalla* became extinct and *Mancalla* appeared. Many of the birds in the older San Luis Rey River Local Fauna are new species.

Both local faunas contain the small, primitive baleen whale *Nannocetus*, this being its geologically youngest recorded occurrence (see Barnes, 1976: 329, table 4). Other types of cetaceans, especially the relatively common pontoporiid dolphin called aff. *"Stenodelphis" sternbergi*, in both local faunas, have been reported in other west coast deposits such as the Almejas, Capistrano, and Purisima Formations.

The otter *Enhydriodon* aff. *E. lluecai* has, on morphological grounds, been suggested as an ancestor of the living sea otter, *Enhydra lutris*, by Repenning (1976). We agree with this and find it significant that all three published specimens were collected in marine rocks, although it could be argued that they represent animals that lived in fresh water and whose remains were fortuitously washed out to sea.

In overall aspects, both local faunas are similar to the fossil assemblages from the Almejas Formation on Isla Cedros in Baja California and the Capistrano Formation in Orange County. Owing to its close proximity to the mapped outcrops of the Capistrano Formation, the faunistic similarity may corroborate Vedder's (1972) suggestion that the San Mateo Formation is a facies of the Capistrano Formation.

Based on the vertebrate taxa in the San Luis Rey River local Fauna and the Lawrence Canyon Local Fauna, we correlate the San Mateo Formation at Oceanside with the Almejas, Capistrano, and Purisima Formations and we believe that it is younger than the Monterey Formation in Orange County and older than the San Diego Formation in San Diego. The latter has never produced *Smilodonichthyes*, has yielded the horse *Equus* sp. and is Blancan in age.

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THE SKYLARK DRIVE LANDSLIDE, OCEANSIDE, CALIFORNIA

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ABSTRACT

Following the 1977-78 winter rains, landslide movement occurred in the Skylark Terrace Subdivision in Oceanside, California, which moderately to severely damaged ten single-family residences valued at nearly $1,000,000 along Partridge Lane and Skylark Drive. The homes were constructed on land prepared by hillside cutting and filling in 1959. The history of the site reveals that no geologic analysis of the site was done although a preliminary soils investigation was performed and a soils engineer was retained to control grading.

Analysis of aerial photographs and downhold geologic logging has recognized the presence of ancient landsliding that is situated on out-of-slope bedding that dips between 6 and 16 degress. The 1977-78 active landslide occurred due to a combination of (a) increased hydrostatic pressures, (b) surcharge on slide-prone terrain by compacted fill, and (c) the presence of ancient slide planes and adversely dipping strata. It is estimated that the corrective grading costs could range from $1,000,000 to $2,000,000. All of the damaged homes were comdemned by the City of Oceanside and many have required demolition.

This subdivision is a classic case in which inclusion of engineering-geologic requirements in the grading code would have provided information on geologic weakness and ancient landslides.

SUMMARY OF FINDINGS

1. Bedding in the Eocene Santiago Formation dips out-of-slope at between 6 and 16 degress.

2. The Skylark Terrace Subdivision overlies an area of ancient block-glide landslides not recognized during the original geotechnical studies. The ancient slide is believed to be stable at present (factor of safety = 1.3).

3. Grading of the development created a potentially unstable condition by surcharging slide-prone areas with additional fill.

4. The sliding and ground distress were initiated by build-up of internal hydrostatic pressures resulting from the heavy rainfall of 1977-78.

5. Approximately 185,000 to 200,000 cubic yards of material comprise the active slide mass.

6. Slide movement is still occurring but no monitoring is being done. Accelerated movement and/or enlargement of the distressed areas is possible as the headscarp and flanks increase in height.

7. Alternative 1 for correction is removal of the entire active slide mass and replacement and recompaction. This would restore the area for rebuilding at a cost of possibly $2 million.

8. Alternative 2 consists of re-grading the slope at the head of the slide to a 3.5:1 and installing a buttress fill in the toe of the slide at a cost of approximately $1 million. Rebuilding could be accomplished using deep foundation support.

BACKGROUND AND GENERAL DESCRIPTION

GENERAL DESCRIPTION OF SKYLARK TERRACE SUBDIVISION

The area developed as Skylark Terrace Subdivision (Figure 1) was created by excavation (cutting and filling) of the once north-to northwest-sloping hillside located immediately adjacent to and south of Alta Loma Creek, Oceanside. The property was developed by cutting the upper slopes and filling in a portion of the Alta Loma Creek and flood plain and a once northwest-flowing raving extending southeastward beneath what is now the intersection of Sarbonne Drive and Dunstan Road. The original site topography is illustrated on Figure 2 and may be compared to the present day topography as shown on Figure 3. The lower area of Skylark Terrace is located along the creek bottom at approximately elevation 50 feet and the upper portion of the development at elevation 250 to 260 feet. Residential one-story, single-family, wood-frame structures were constructed in late 1959 to early 1960. Graded cut and fill slopes were constructed to maximum heights of 55 to 85 feet, respectively, and at inclinations (slope ratios) of between 1 to 1 horizontal to vertical (45 degrees) and 2 to 1 (26 degrees). Some cut and fill slopes were constructed with slope benches (presumably for slope drainage control) while others were not.

Landscaping within the Skylark Terrace Subdivision is not unusually lush and probably does not demand excessive irrigation. Most of the slope areas are sparsely vegetated to weed-covered and support only a few scattered trees. The steep, high cut slope along the south side of Sarbonne Drive varies from little or no vegetation to moderate vegetation with ice plant. Extensive irrigation systems are not evident on the slopes.

Drainage of Skylark Terrace is diverted principally along roadways, curbs and gutters, converging on the lower elevations of the project and then off-site. Existing drainage of individual residences does not generally conform to the concept of sloping lots toward the street, and roof gutters and downdrains are not generally in use. Much of the water falling on the Skylark Subdivision probably infiltrates the subsurface soil and geologic units. Additionally, there is no record that indicates placement of a subdrainage system along the

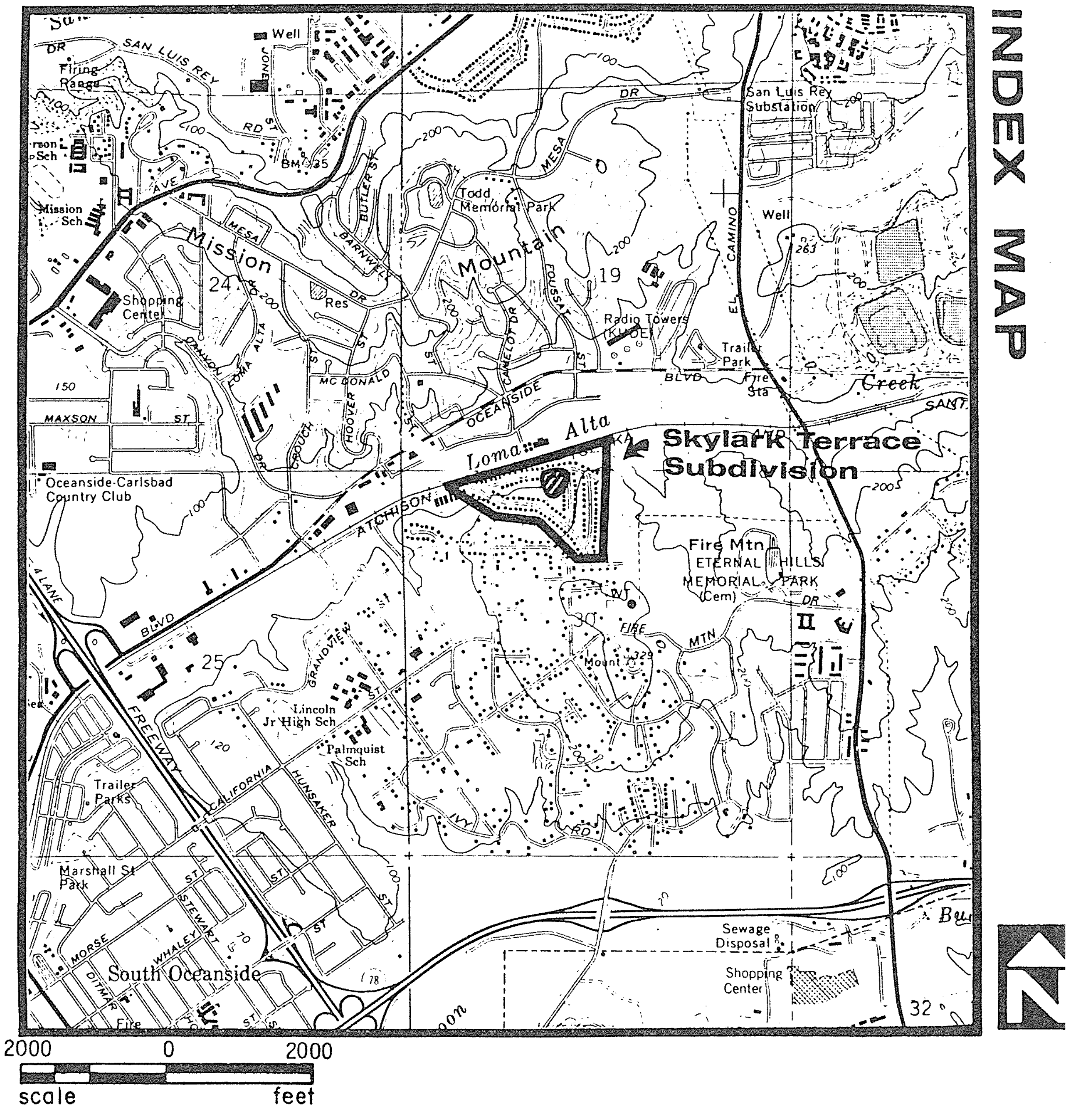


FIGURE 1.
SKYLARK TERRACE SUBDIVISION
OCEANSIDE, CALIFORNIA
SOURCE: U.S.G.S. SAN LUIS REY QUADRANGLE

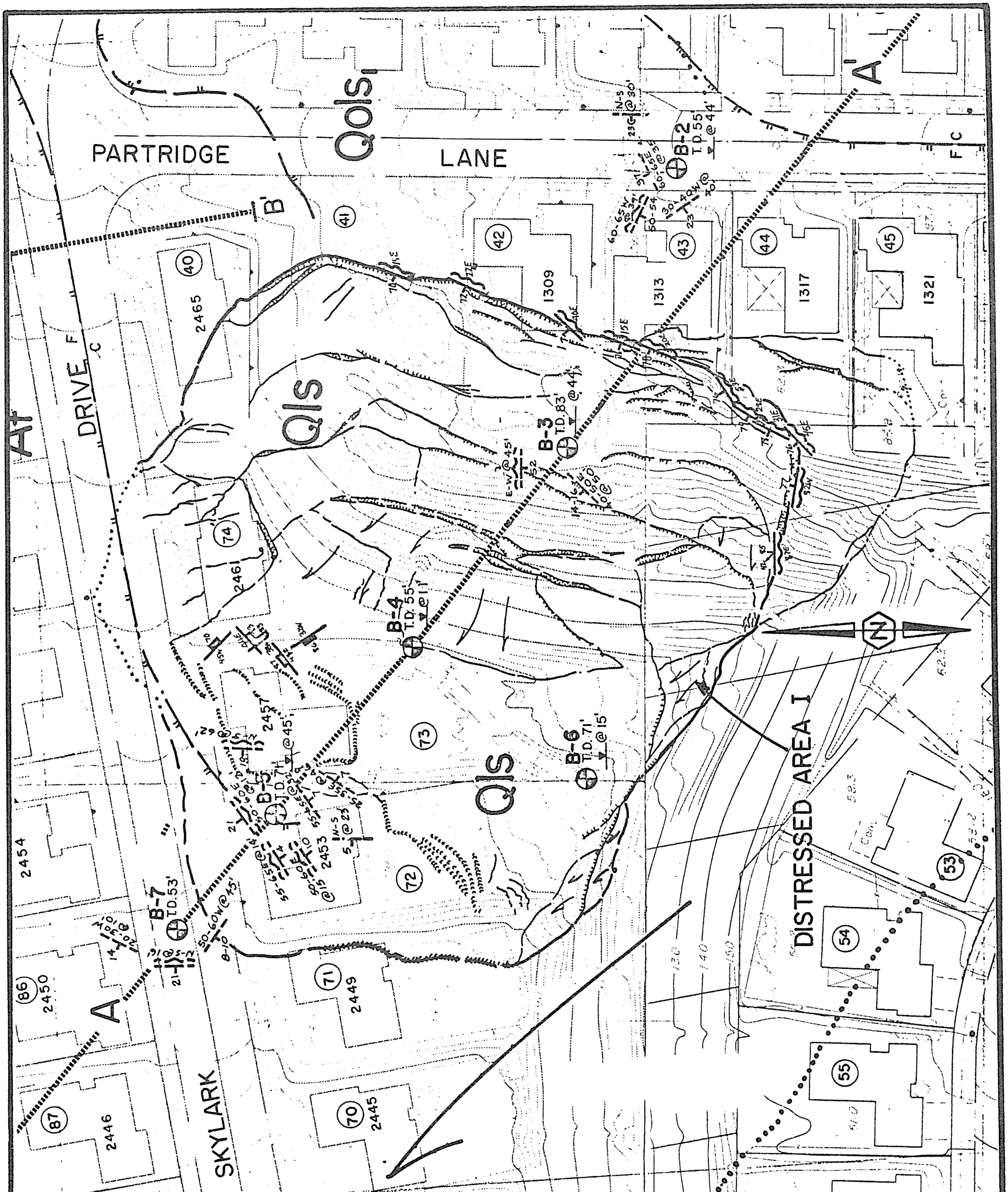
SURFICIAL DEPOSITS

Af	MAN-MADE FILL
Qoal+Qal	ALLUVIUM, UNDIFFERENTIATED
Col	COLLUVIUM
Qls	ACTIVE LANDSLIDE
Qols	ANCIENT LANDSLIDES
Tsb	BEDROCK DEPOSITS
Ss+Slt(Tsb)	GEOLOGIC UNITS AND SANDSTONE SILTSTONE, SANTIAGO FORMATION

SYMBOLS

12	BEDDING ATTITUDE, DASHED WHERE BURIED
50	JOINT ATTITUDE, DASHED WHERE BURIED
10	RUPTURE SURFACE ATTITUDE, DASHED WHERE BURIED
Qols	LIMITS OF ANCIENT LANDSLIDES, DOTTED WHERE BURIED, DOTTED ARROWS INDICATE PROBABLE DIRECTION OF MOVEMENT
Qls	LIMITS OF ACTIVE LANDSLIDE, DOTTED WHERE BURIED BY PAVEMENT, HATCHURES INDICATE SCARPS: ARROWS INDICATE DIRECTION OF MOVEMENT
	MOLE-TRACKS, THRUSTING OF LANDSLIDE TOE
C F	LIMITS OF FILL PER TWINING LABORATORIES, INC. (1959)
@ 20' B-9 T.D. 80'	BORING LOCATION; T.D. INDICATES TOTAL DEPTH: INDICATES STATIC WATER LEVEL OR PERCHED CONDITION
A A'	CROSS SECTION
GC-4 T.D. 30'	GEOCON, INCORPORATED BORING LOCATION SHOWING TOTAL DEPTH

LEGEND FOR GEOLOGICAL MAP
AND CROSS-SECTION A-A'
SKYLARK LANDSLIDE



40 20 0 40

Scale in Feet

GEOLOGICAL MAP
SKYLARK LANDSLIDE
(Please see page 74 for Legend)
FIGURE 2.

now filled but previously existing northwest-draining canyon (approximately beneath Sarbonne Drive). The absence of such a sub-surface drainage system has probably contributed to maintenance of an artificially high groundwater table (depth at which a static water level would exist) and subsequent saturation of natural ground beneath the sub-division that might not otherwise be present.

DEVELOPMENT HISTORY AND PAST REPORTS

The earliest documents referring to the subject subdivision were communications that are recorded within departments of the City of Oceanside dated in 1952. A report of the soils investigation conducted on the property by Woodward-Clyde-Sherard & Associates, dated April 28, 1959, addressed only the soils characteristics of the property; no geologic work was reported. As development commenced in 1959, numerous reports of compaction testing and inspection were submitted by Twining Laboratories, dated from April 30, 1959 up to the final report dated October 15, 1959. No mention of geologic details is present in these reports. Some mention is made in early reports of an area in the central part of the subdivision which was believed to be underlain by creep conditions and this area was apparently treated differently than other areas of the project before receiving fill although the details of such action are not described in the consultant's final reports.

Communications which recently focused attention on problems at Skylark Terrace Subdivision included a report of home distress at 2502 Skylark Drive by Benton Engineering, dated May 15, 1978, a letter from the City of Oceanside to one of the residents dated September 19, 1978, and a preliminary geologic review report by William J. Elliott, dated November 22, 1978.

Leighton and Associates, Inc. became involved in the project in March 1979 when requested to review all reports and communications relative to Skylark Terrace Subdivision.

HISTORY AND DESCRIPTION OF DISTRESS

Discussions with the homeowners indicate that some distress was first recognized within the development as far back as 1968, but with no obvious damage to other homes until the recent sliding. It was in 1968 that the home on Lot 41 was removed. The bulk of the damage was sustained following the heavy winter rains of 1977-1978.

Figure 3 indicates the approximate areal extent of the distressed areas as mapped in the field. The landslide denoted as Distressed Area I has a length of about 360 feet, total width of about 310 feet and involves a total slope height of about 55 feet. Destroyed and threatened real estate losses are estimated to be approximately one million dollars.

Houses located behind the slide headscarp are threatened by undermining as a result of sliding. At the toe of the slide horizontal movements pushed against other structures.

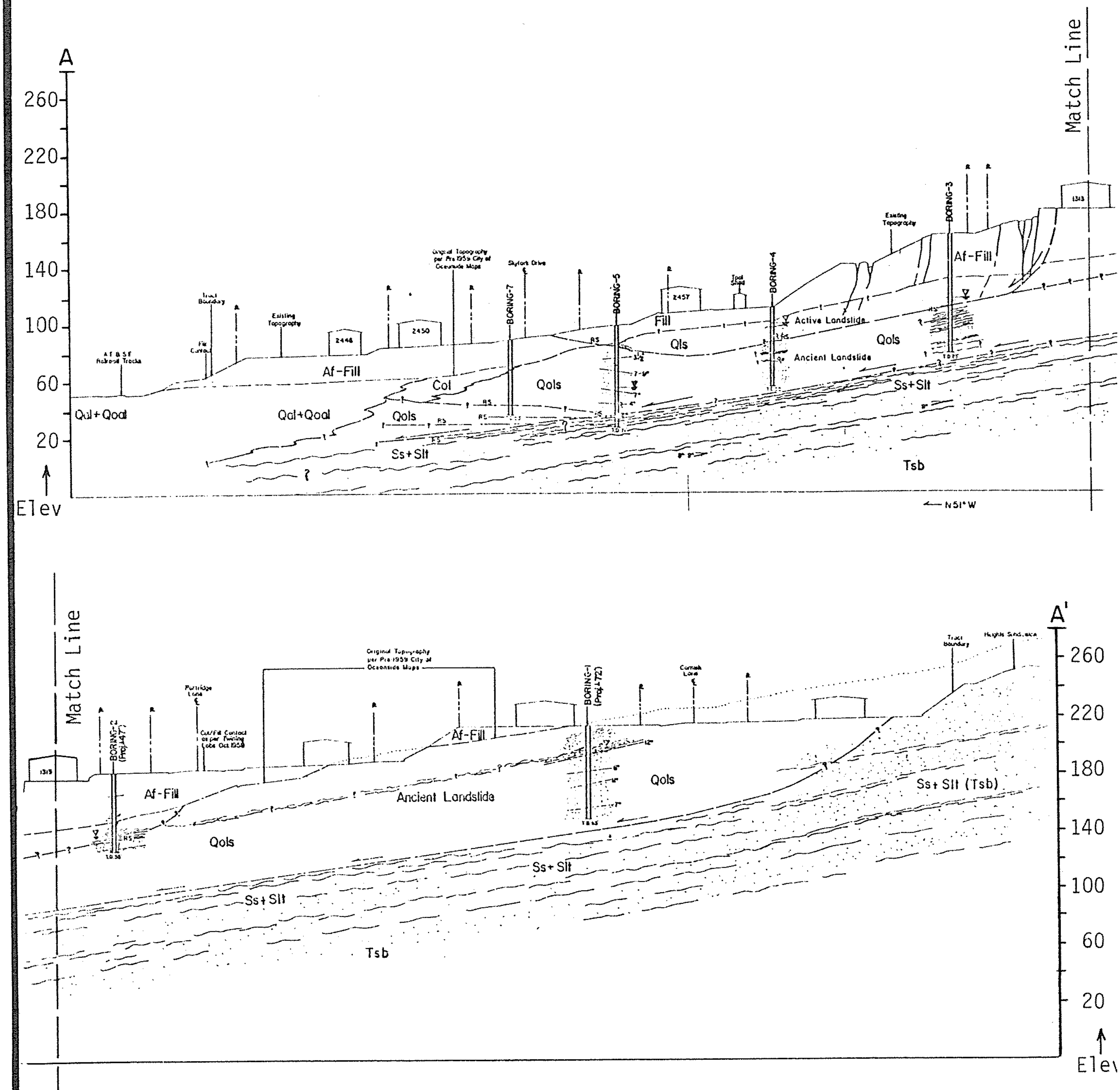


FIGURE 3.
GEOLOGIC CROSS-SECTION A-A'
SKYLARK LANDSLIDE
(Please see page 74 for Legend)

TABLE 1. PARAMETERS OF ACTIVE LANDSLIDE (DISTRESSED AREA I)

Time of Occurrence	1968; winter of 1977-78
Type of Movement	Continuing creep
Dimensions of Landslide	
Length	360 feet
Width	310 feet
Maximum Height of Headscarp	10-12 $\pm$ feet
Area Involved	Approximately 2 acres
Maximum Thickness	50 $\pm$ feet
Volume	170,000 $\pm$ cubic yards
Amounts of Movement	
Horizontal Displacement	10-15 feet
Vertical Displacement	10-12 feet
Rate of Movement At Time Of Investigation	Creeping 1/2 to 1 inch per week (estimate)
Movement Direction	N60^{o}W

Slide movement in Skylark Drive was observed as buckling of the street necessitating continued maintenance by the City of Oceanside. Street utilities continue to sustain moderate distress. Relief holes have been drilled in the pavement along the S.D.G.&E. gas mains to monitor seepage of gas from possible broken lines. Water mains have been repeatedly repaired. The degree of damage to the sewer system is unknown.

Secondary distress headward, due to active sliding, has occurred within the yards of Lots 44 and 45 (See Figure 3) and includes tension cracking of the earth materials due to stress relief at the face of the headscarp.

As of late 1980, creep movement was still occurring within the active landslide (Distressed Area I). The rate of movement has not been accurately determined but once approached about 1/2-inch to 1-inch per week.

Maximum vertical displacement in the headscarp area of the slide is approximately 10 to 15 feet and the maximum vertical uplift in the toe area of the slide is approximately 4 to 5 feet. Horizontal displacement of the slide mass is estimated to be on the order of 10 to 15 feet westward.

ANCIENT LANDSLIDING

Presence of Ancient Landsliding. As determined from aerial photographic analysis and logging of test borings, the Skylark Terrace Subdivision is situated on an area of ancient landsliding.

Cause of Ancient Sliding. Ancient block-glide type landsliding occurred in response to geologic bedding conditions and weak sedimentary siltstone or claystone strata. The bedding in the Skylark area dips westerly to northwesterly (out of slope) at between 6 to 16 degress, and is inclined flatter than the natural slopes which were once present, resulting in an unsupported condition and subsequent sliding of the hillside.

Depth of Sliding. As interpreted from this investigation, the ancient basal rupture surface is present beneath the Skylark Terrace at a depth of between 60 and 80 feet. The toe area of the ancient sliding (the downhill limit) is believed to be buried by modern-day alluvial deposits and be located at a depth of approximately 60 feet.

Stability of the Ancient Landsliding. The ancient landsliding beneath Skylark Terrace has been analyzed in consideration of the present land configuaration of cuts and fills and is calculated to possess a factor of safety of 1.3. Under existing conditions, no movement along the basal rupture surface of the ancient landslides (60 feet and deeper) underlying the site at depth is anticipated. This does not include secondary rupture surfaces of ancient landslides closer to the surface.

GEOLOGY

The general geologic structure of the subject area is predominantly westward-dipping strata of the Eocene Santiago Formation (Wilson, 1972). The bedrock units are locally warped with bedding planes being most well developed within the siltstones and claystones. The regional and local bedding strikes generally north-south and slightly west and east of north-south, dipping generally westerly between 6 and 16 degrees (Figure 3).

Rupture surfaces within the active and ancient slides generally correspond to the regional trend of the bedding planes (Cross-Section A-A', Figure 3). Along the margins of the active and ancient slide, rupture surfaces may be warped to form a bowl-shaped structure whose axis plunges in the direction of sliding. Some bedding attitudes obtained within the ancient and active slide masses are erratic as a result of dislocation but most correspond generally to the underlying local bedrock attitudes.

Numerous joint surfaces exist within the bedrock units which strike generally northeastward to northwestward and dip steeper than 45 degrees. Jointing is more predominant in the siltstone than in the sandstone unit of the bedrock. Within the ancient and active landslides, bedrock materials often display open tensional fractures that are most probably the result of slide movement.

No tectonic faulting was recognized at the site. The nearest known fault is an easterly-to northeasterly-striking fault exposed along the west side of Downs Street, approximately one-half mile southwest of Skylark Terrace. This fault is not indicated as being an active fault, and is most probably inactive. If it intersects the Skylark Terrace Subdivision it may locally affect bedding and the hydrogeologic conditions beneath the site.

GEOHYDROLOGY

As described earlier, the sandstones and siltstones of the Santiago Formation are interbedded and bore hole information suggests that they play an important role in the control of groundwater within the landslide masses. During the investigation innumerable seeps and varying levels of water were found to exist, usually with water being perched within a permeable sandy stratum just above a relatively impermeable siltstone layer. Within the active landslide (Qls), water was encountered as shallow as 11 and 15 feet (Borings 4 and 6, respectively) and as deep as 45 feet (Borings 3 and 5). A particularly significant anomaly existed in the groundwater levels between Borings 4 and 5 (Cross-Section A-A', Figure 3) which suggests that the phreatic surface in the toe area of the active landslide had not yet stabilized or that water was migrating vertically to lower levels through a permeable zone not cut off by the active landslide rupture surface. This extreme difference in water levels over such a short distance also suggested that the toe of the active landslide was located within ancient slide materials which have been highly fractured or displaced, juxtaposing impermeable strata and permeable strata and permitting differences in water levels to exist. For engineering calculations, a piezometric surface was assumed slightly above the phreatic surface indicated by the geotechnical investigation. This assumption was based upon laboratory moisture contents and calculated percent saturation which indicated for all of the borings that the water table was probably higher before the occurrence of the active landslide. A complete knowledge of the piezometric surface was not obtained due to vandalism of piezometers that were placed in all of the borings. It was assumed that the piezometric surface in each of the drilled borings was at approximately the depth of the highest active seepage or free water inflow observed during the investigation.

Groundwater conditions within the ancient slide mass (Qols) consisted of a saturated condition with free water being most prevalent in the granular coarse sandstone beds and increasing in volume with depth. Water inflow during drilling of several borings was of sufficient quantity to induce caving of the drill hole and curtailment of the drilling operations.

The water present in the subsurface was most likely the result of infiltration of irrigation water and rainfall. Sandy materials predominate within Skylark Terrace. Since completion of the project water has continued to accumulate in the subsurface. As no record of adverse seepage from slopes or rising water through house slabs or yards has been supplied by residents, the water table has probably been consistent and has predictably fluctuated with changes in the seasons and variations in rainfall cycles. With the occurrence of the wet season of 1977-78, and the frequency of storms, it is most likely that saturated conditions in the soil units overlying Skylark Terrace were well maintained during the wet season and that infiltration of rainfall was maximized. The 34.14 inches of precipitation recorded for the season 1977-78 was the highest ever recorded for the City of Oceanside since their records began in 1892. Other comparatively wet years were 1965-66 and 1968-69, which followed completion of Skylark Terrace Subdivision.

During the landslide investigation, concern was voiced by homeowners in Skylark Terrace regarding the possible influence of subsurface and surface waters from the newly completed Heights Subdivision upslope of Skylark Terrace. An analysis of the hydrogeologic characteristics of the Heights completed by Geocon, Inc., dated June 29, 1979, concluded that there would be minimal impact on the Skylark Terrace landslides due to the development.

ENGINEERING ANALYSIS

METHOD OF SLOPE STABILITY ANALYSIS

Slope stability analyses were performed for both the active and ancient landslides using the ordinary method of slices which calculates factor of safety against failure for a specified shear surface.

SHEAR STRENGTH PARAMETERS

Shear strength parameters for the in-place materials were determined from 1) laboratory shear strength tests, and 2) stability analyses employing back-calculation techniques. Due to the limitations of presently available sampling and testing techniques, it is virtually impossible to obtain the shear strength of the failure plane at an incipient failure condition. Therefore, landslide analyses rely heavily on back-calculation techniques. Back-calculation was performed for the active slide mass illustrated in Cross-Section A-A' (Figure 3). By assuming a factor of safety of 1.0 (point of incipient failure), the strength parameters of the slide plane were computed.

Shear strength parameters utilized in our analyses, based on the above, can be summarized as follows:

a) Active and Ancient Slide Planes

Cohesion = 120 pounds per square foot
Friction Angle = 13 degrees

b) Ancient Slide Mass

Cohesion = 250 pounds per square foot
Friction Angle = 18 degrees

c) Existing Fill

Cohesion = 110 pounds per square foot
Friction Angle = 25 degrees

SLOPE STABILITY ANALYSES PERFORMED

Utilizing the above strength parameters, the stability of the active and ancient slides were analyzed for static conditions. The effect of surcharging the slide area was determined by calculating the stability of the slide with and without fill. Results of the stability analyses are summarized in Table 2. The effect of the fill loading is clearly demonstrated by a reduction in factor of safety from 1.8 to 1.1. The ancient landslide is shown to be presently stable with a factor of safety of 1.3.

TABLE 2. SUMMARY OF SLIDE ANALYSES

Case No.	Condition Analyzed	Static* Factor of Safety
1	Active Slide (with existing fill)	1.0
2	Active Slide** (without existing fill)	1.8
3	Ancient Slide (existing conditions)	1.3

*Analysis based on Cross-Section A-A'
**Site conditions prior to 1959 grading

RECOMMENDATIONS FOR CORRECTION OF DISTRESSED AREA I

Various methods have been considered and evaluated for correction of the active slide. The following alternates are considered most practical and suitable for the site conditions.

1) Removal and recompaction of the active landslide mass.

2) Re-grading of slope and construction of a butress fill.

Corrective methods such as piles of retaining walls or physico-chemical processes involving electro-osmosis, chemical grouting, etc., were discounted due to high cost or probably low effectiveness.

ALTERNATIVE 1 - REMOVAL AND RECOMPACTION

Advantages

1. By recompacting the distressed area the slide would be totally stabilized.

2. Buildable lots can be restored at top and bottom of slope for construction of new homes.

3. Subsurface drainage of general area would be improved.

Disadvantages

1. Houses located within slide area must be removed (at least temporarily).

2. Special safety provisions may be required to protect adjacent homes above slide, and Partridge Lane.

3. High costs are involved due to large volume of material moved.

ALTERNATIVE 2 - RE-GRADING SLOPE AND CONSTRUCTION OF BUTTRESS FILL

Advantages

1. Slide mass would be stabilized against further lateral movement.
2. Buildable lots can be restored at bottom of slope.
3. Subsurface drainage of slide area would be improved.
4. Cost is substantially lower than for Alternative 1.

Disadvantages

1. Integrity of slide mass is not substantially improved except within buttress area; i.e., upper slope soils are subject to continued settlement.
2. Houses can be built at top of re-graded slope but will require additional foundation design. Deep foundations may be required subject to further investigation.

CONCLUSIONS

The Skylark Landslide resulted from failure to recognize the adverse soil and geologic characteristics of the site, particularly the presence of ancient landslide terrain. Future prevention of similar disasters will depend upon the ability of geotechnical consultants to utilize modern engineering and engineering geologic procedures, particularly preliminary investigative techniques and in-grading geologic inspections. In addition, protection for the home owner can probably be best assured through adoption of at least the minimum grading code standards outlined in Chapter 70 of the Uniform Building Code.

SEA CLIFF RETREAT:

A CASE STUDY AT

OCEANSIDE, CALIFORNIA

by

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INTRODUCTION

This paper describes coastal bluff erosion of a 1-1/2 mile long strip that extends south from Ninth Street to Wisconsin Avenue, in Oceanside, California (Figure 1). The height of the bluff ranges from approximately 35 feet near Ninth Street to about 20 feet near Wisconsin Avenue. The face of the bluff varies in inclination; most of the upper part is essentially vertical, and the lower part is typically inclined 40° to 60° (Figure 2).

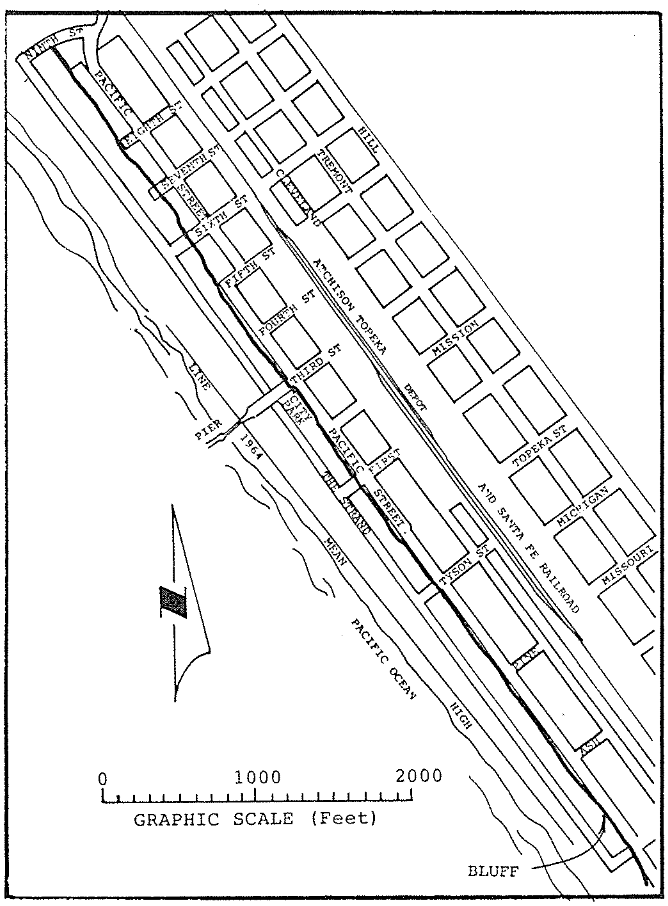

Figure 1 Location of Study Area in Oceanside

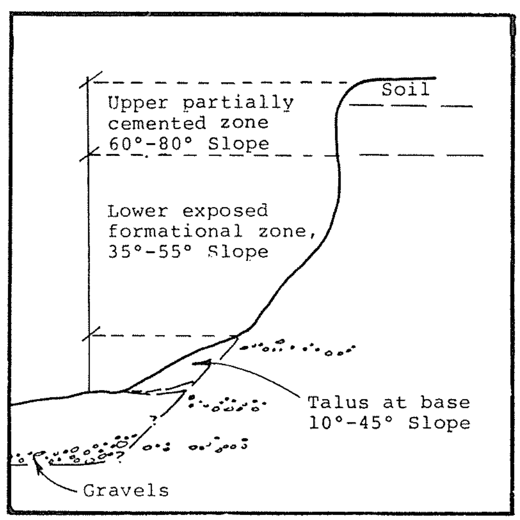

Figure 2 Typical Bluff Profile

The property between The Strand and the base of the bluff is relatively flat; about 75 percent of it is privately owned. Pacific Street runs along the top of the bluff between Wisconsin Avenue and Fifth Street.

A wide area between the bluff and the ocean was set aside for residential and commercial development, and a street, (The Strand) was constructed approximately 125 to 170 feet west of the bluff. This action effectively removed this segment of bluff from the active sea cliff cycle and the effects of storm waves eroding the toe and face of the bluff.

GEOLOGIC CONDITIONS

The geologic units along the bluff include a Pleistocene deposit, accumulations of talus, and contemporary beach deposits.

The Pleistocene deposit is composed of silty fine- to coarse-grained sandstone with conglomerate beds. In nearby areas, the unit varies from 30 to 50 feet thick. Along the bluff, the unit is uniform in bedding and physical characteristics, as seen in a photograph showing the geological conditions along a typical bluff segment (Figure 3). The upper part of these deposits are typically lightly cemented with iron oxides and capped by a thin, poorly formed topsoil. The surface of the topsoil is generally covered with "BB" to pea-size iron-oxide nodules (Figure 4). The topsoil generally consists of a two-foot thick layer of porous, light-brown silty sandstone containing iron-oxide nodules. The topsoils have a relatively high salt content and contain little or no organic matter. The cemented layer appears to vary from approximately five feet thick to as much as 16 feet thick; the layer is generally thicker in the northern part of the bluff. The cemented zone is underlain by a sequence of friable, gray, fine- to coarse- grained sandstone beds containing a few conglomeratic layers. Test borings indicate conglomerate layers are present from 22 to 24 feet below the top of the bluff. The conglomerate sequence may represent the base of the Pleistocene deposit. The unit has been deposited on the Tertiary Santiago Formation.

The talus materials at the base of the bluff consist of sand, gravel, silt, and small blocks of sandstone eroded from the bluff. The talus forms an angular wedge along the base of the bluff (Figure 2). The beach deposits in front of the bluff consist of wave-deposited sand and gravel along the flat coastal strand between the bluff and the ocean.

The beach deposits are underlain at a depth of about 12 feet by a basal gravel layer and sedimentary rocks similar to the Santiago Formation. Standing ground water is present about 6 to 8 feet below the flat beach surface.

BLUFF STABILITY

Presently, few bluff areas along The Strand are in a generally natural state. Most bluff areas have been over-excavated, filled over, and otherwise altered so that the original natural bluff configuration is no longer evident.

Figure 3 Geological conditions along a typical bluff segment viewed looking north from the proposed Tyson Street extension. Note the uniformity of the geologic units, slope inclinations and the general slope configuration.

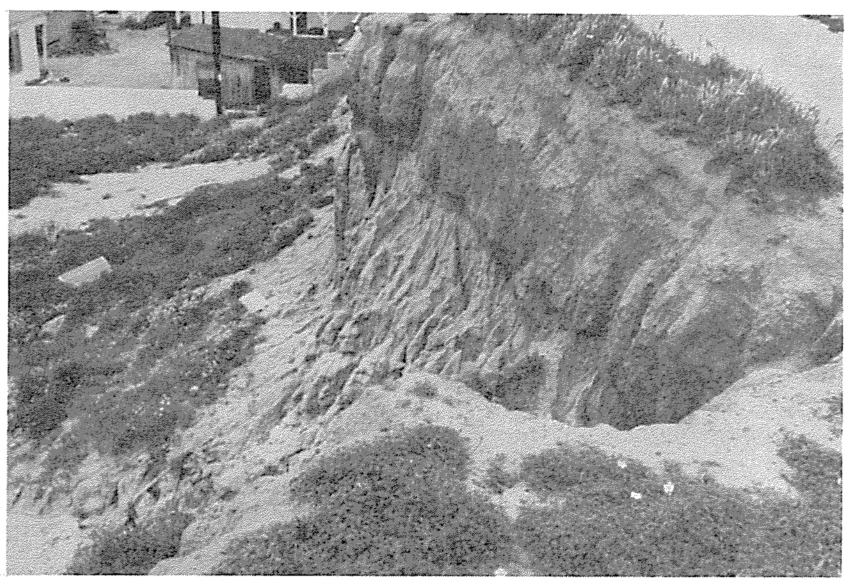

Figure 4 Poorly formed topsoil overlying the red-brown, slightly cemented horizon. Note the erosion gulley in foreground being used as a foot-trail

No specific areas of imminent bluff instability were identified in the area. It seems that typical failure modes have been in the form of relatively shallow (perhaps a few feet thick), rapid block falls, which may not give advance indications of slippage (Figure 5). The apparent continual removal of the talus at the base of the bluff by the property owners increases the potential for such continual falls.

Apparent tension cracking was observed at the top of the bluff along Pacific Street. Such cracks may indicate marginal stability. The cracks ar typically within about three feet of the top of the bluff. If the bluff failed at the tension cracks, material would likely fall against residential structures close to or built into the bluff below.

BLUFF RECESSION

Our investigation indicates that bluff recession is actively taking place at a rate comparable to sea cliffs along the San Diego County coastline that have similar geological and physical settings, even though this area is no longer subject to storm wave activity.

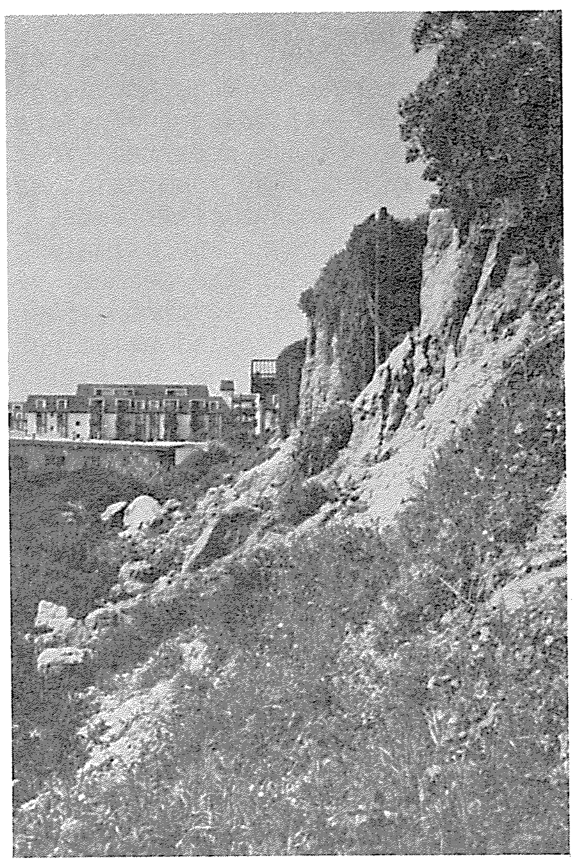

Figure 5

A section of bluff located to the north of the proposed extension of Eighth Street. Note the large blocks of failed bluff materials along the base of the high, near-vertical slope which varies in height from 8 to 12 feet.

Complete and accurate background data is not available to indicate where the original bluff was when the segment was removed from the active sea cliff cycle. Indirect evidence, such as recession measurements taken on both sides of a retaining wall or a hanging fence, or an exposed structure foundation, were used and compared with the exact or approximate year a structure was built. Along most segments of the bluff, up to about 36 inches of slope retreat can be observed and measured. Where conditions for relative measurement exist (Figure 6), 36 inches appears to be a good average for the entire bluff; however, in several areas up to 10 feet of recession may have occurred (Figure 7).

The average retreat of 36 inches has taken place over a 30- to 40- year time frame, which is an average of about 1 inch of recession per year. The areas of maximum retreat (Figure 7) calculate to approximately 3 to 4 inches of recession per year.

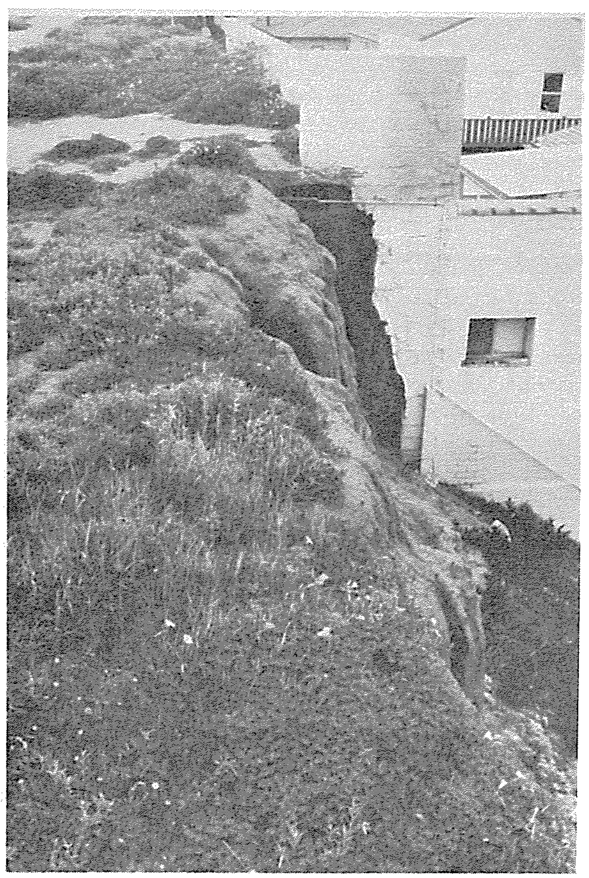

Figure 6

Two episodes of retreat are recorded in this photograph. The first episode of slope retreat has occurred since the building foundation was built up the cliff face, and averages approximately 36 inches. The second episode has occurred after installation and painting of the gas line; approximately 12 inches of unpainted pipe is exposed

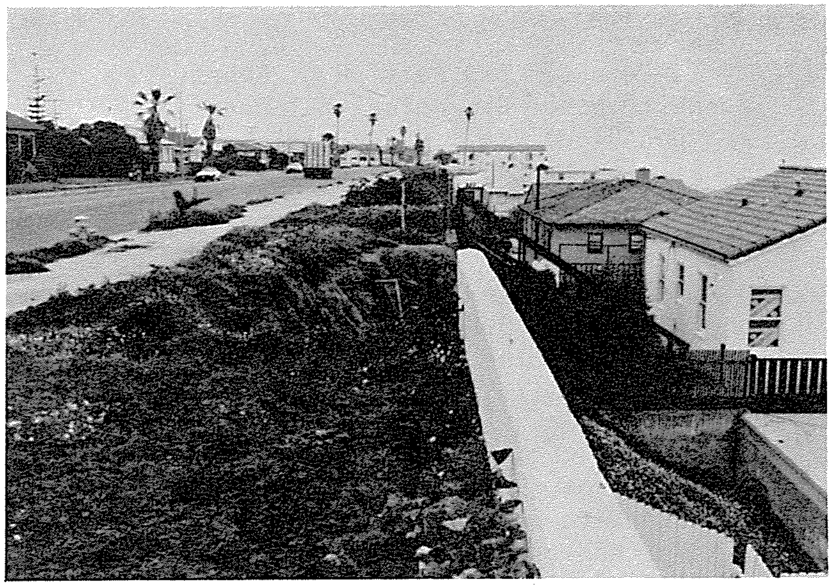

Figure 7 Ten feet of apparent slope retreat between two retaining wall structures. Eighteen inches of retreat are recorded after installation of gas pipeline.

CONCLUSION

It has been assumed that major storms and resultant wave action may be the main cause of cliff erosion. The bluffs in Oceanside, which are not subject to wave erosion, are receding at rates similar to recession rates of sea cliffs between Oceanside and San Diego that are subject to wave recession. We believe that the bluff recession in this area indicates that factors such as irrigation and saturation along the top of the cliff, foot traffic on slopes, and uncontrolled runoff including channeling and erosion are more important in the cliff recession process than previously assumed.

EARLY CENOZOIC TORRID CLIMATE, COASTAL SOUTHERN CALIFORNIA

by

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INTRODUCTION

Coastal Southern California and adjacent Baja California lie close to the boundary of two of the great prevailing wind belts of the world. To the north most of the states (excluding Alaska) lie in the westerlies. To the south are the tradewinds. As with any coastal area situated at this latitude (31-33°) on the western edge of a continent, the San Diego area climate is mild, semiarid and temperate. The average annual rainfall amounts to about 25 cm (10 inches) with most of the precipitation falling in the winter months. The average annual temperature is 16°C (61°F) with a small variation (5°C) between winter and summer. According to the Köppen climatic classification, the area is regarded as "hot steppe" in the coastal area to "hot summer Mediterranean" in the foothills and lower mountains to the east.

From latest Cretaceous to the present, the San Diego area has not changed latitude markedly and has always faced an open ocean to the west (Smith and Briden, 1977). Unless the climate of the world has changed markedly, the area might be expected to have much the same climate since Late Cretaceous time. Of course, the world climate has changed dramatically. Evidently during the maximum glacial advances of the Ice Ages the area had a climate more like that of a higher latitude coastal area. At the other extreme, in early Cenozoic time the world climate was markedly warmer (Torrid Ages of Peterson et al., 1979). At that time the Southern California coastal area was hot and humid (Figure 1) a climate much like that of the modern equatorial zone.

From Paleocene through early Middle Eocene time little or no stratigraphic units were deposited in the San Diego and adjacent areas. Instead, the area was evidently positive and this interval is recorded by a number of very well-developed soil profiles. These ancient soils (paleosols) formed in response to the prevalent climate and reflect that regime. The paleosols are usually found beneath the Middle to Late Eocene rocks and are developed on a variety of pre-Eocene rock units and on the early Middle Eocene Mt. Soledad Formation at Black's Beach.

	Average Annual Temperature	Average Annual Rainfall	Rainy Season
Present Climate	16°C	25 cm	Winter
Paleocene-Mid Eocene Climate	20-25°C	125 cm	Winter(?)

Figure 1. Comparison of the present climate and that of the Early Cenozoic for the San Diego coastal area (from Peterson and Abbott, 1979).

The purpose of this article is to summarize briefly the evidence for the early Cenozoic torrid climate which primarily involves description and interpretation of the paleosols. The descriptions are minimal since all have been previously detailed in the literature. Following the descriptions and interpretations is a brief account of some other lines of evidence from the California stratigraphic record which corroborate the local paleoclimate interpretation.

RANCHO DELICIAS PALEOSOL

Of all the known exposures of the sub-Eocene paleosols, the best crops out about 10 km south of Tijuana near Rancho Delicias (Flynn, 1970; Abbott et al., 1976). The paleosol is formed on mid-Cretaceous granodiorite and is overlain by mid-Eocene rocks of the Delicias Formation. The total weathering profile is approximately 30 m thick with the lower 16 m (C horizon) consisting of partially decomposed bedrock (grus) containing abundant spheroidal boulders in the lowermost portions (Figure 2).

The upper part (A and B horizons) of a paleosol is most important for paleoclimate interpretations. At Rancho Delicias, the preserved upper portion beneath the overlying erosion surface is approximately 14 meters thick. The basal 4 m (B horizon?) are reddish and gradational with the lower C horizon. The upper 10 m are white with mottled patches of red purple to moderate reddish brown, iron-oxide stain. Quartz (33%), kaolinite (66%) and iron oxides (< 1%) constitute the only minerals in this severely leached lower A horizon of the paleosol. Chemical analyses indicate that this portion is enriched in alumina, slightly leached of silica, moderately depleted in iron oxides and severely depleted in all soluble cations.

The unusual thickness of the Rancho Delicias paleosol, together with the quartz-kaolinite-iron oxide mineralogy and severely leached upper horizon, place it in the lateritic type of residual soil according to the criteria of Mohr and Van Baren (1954), or in the oxisolic type of soil in the "seventh approximation" classification (Soil Survey Staff, 1960). Similar modern soil profile thicknesses and mineralogy were reported by Harrison (1934) in British Guiana. Soils of this type result from severe weathering under long-lasting, humid tropical climatic conditions.

CARLSBAD PALEOSOL

A second excellent outcrop of the paleosol lies southeast of Carlsbad and immediately to the north of Palomar Airport. In the past this paleosol has been mined for kaolinite by the Pacific Clay Products Company but the excavations are currently inactive. The quarrying operations have provided excellent outcrops.

The Carlsbad paleosol locality is important for delimiting the age of severe weathering in the region. At almost all other localities, the paleosol is developed on basement rocks and is overlain by Middle and Late Eocene sedimentary rocks. However, at Carlsbad the paleosol is developed on the latest Cretaceous (Campanian-Maestrichtian) Point Loma and Cabrillo Formations (Peterson and Abbott, 1975). In general, the coarse and immature character of the Cretaceous rocks, the abundance of chemically complex clay minerals and the occurrence of red beds in non-marine sections all suggest at least a semiarid climate during Late Cretaceous time. Likewise, a semiarid climate is indicated for the later Eocene rocks (Pierce and Peterson, 1975; Peterson and Abbott, 1977, 1979). Thus the hot and humid weathering interval must have occurred within Paleocene through Middle Eocene time and coincides with the sub-La Jolla unconformity (Peterson and Nordstrom, 1970).

Natural outcrops of the Carlsbad paleosol are poor. The paleosol contains kaolinite of commercial quality and quantity and has been mined intermittently from the early 1900's to about 1960 (Cleveland in Weber, 1963). Two main quarrying areas have provided good outcrops. In the eastern quarry (or east pit) the kaolinite-rich, severely leached part of the profile is about 2 m thick and has a residual cap consisting largely of ironstone concretions and siliceous pebbles. The profile is developed on the Point Loma Formation.

Exposures of the upper leached horizon of the profile are best exposed in the west pit. Here the paleosol varies from bright white to moderate red to dark reddish brown to gray and grayish red mottled outcrops. Close inspection reveals that the leached horizon is here developed on conglomerates of the Cabrillo Formation. As in the east pit, there is a thin residual cap of ironstone concretions and siliceous pebbles. Maximum thickness of the exposed paleosol is about 3 meters.

Samples of the severely leached horizon were collected and analyzed. Even though the relict conglomerate texture is evident (Figure 3), only two minerals (quartz and kaolinite) plus a small amount of iron-oxide stain are present (Figure 4).

The Carlsbad paleosol is thinner than the Rancho Delicias paleosol but in all other respects is remarkedly similar. Such a selection of stable and non-varied mineralogy results from severe weathering under humid tropical conditions (Birkeland, 1974; Hunt, 1972).

OTHER PALEOSOL OUTCROPS

A number of other lateritic paleosol outcrops have been noted throughout the San Diego metropolitan area and still others are to be expected as growth of the City provides new road cuts and excavations for housing developments. In general, the paleosol appears beneath the Eocene rocks. The paleosol occurs in a variety of colors ranging from brick to red to pink to white with scattered red mottled blotches. The mineralogy is always dominated by quartz and kaolinite, at least in the uppermost leached part (A horizon) of the profile. The drastic change in color from outcrop to outcrop is due to the amount and distribution of iron oxide. Even a small amount of hematite acts as a strong coloring agent.

Several outcropping areas are of note. The outcrops which we observed were in fresh cuts and now are probably covered with ice plant or other ground covers, but new cuts within the area might be expected to provide additional exposures from time to time. One area occurs along the lower eastern edge of Fletcher Hills along Finch Street. The paleosol here is brick red and is overlain by the Eocene Friars Formation. A second locality is in the western portion of the Rancho Penasquitos housing development around the southern to southwestern flanks of Black Mountain. Here the paleosol ranges from pink-red to dark brick red and is overlain by the Eocene Mission Valley Formation.

A third, unique weathering profile occurs within the lower part of the Eocene stratigraphic sequence and crops out in the opening of Indian Trail Canyon that leads out onto Black's Beach in La Jolla. This weathering profile is developed on the Mount Soledad Formation (Peterson and Abbott, 1979). The

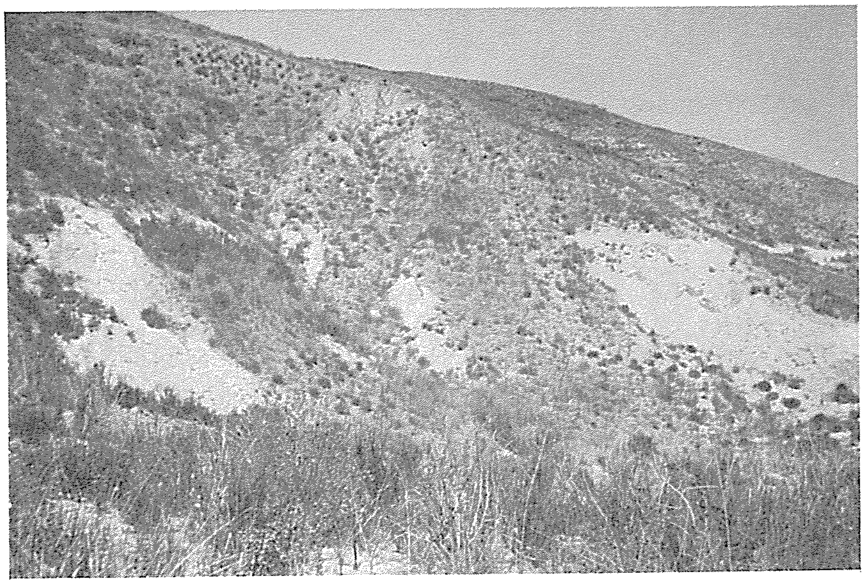

Figure 2. Eocene Delicias Formation resting on white kaolinite-dominated A horizon of Early Paleogene paleosol weathered on granodiorite. Photo taken on Rancho Delicias southeast of Tijuana.

Figure 3. Cabrillo Conglomerate exposure in west pit of Pacific Clay Products operation north of Palomar Airport. Conglomerate textures in photo are relict; all mineralogy is kaolinite.

Figure 4. Kaolinite in west pit of Pacific Clay Products operation north of Palomar Airport.

preserved upper horizons of the weathering profile consist of kaolinite and siliceous particles (quartz grains, quartzite and aplite clasts). Even the physically ultradurable Poway rhyolite clasts are reduced to kaolinite spheroids containing euhedral quartz phenocrysts. The upper profile contains a thin residual ironstone cap which is overlain by marine rocks. The severely leached portion of the profile is only about one meter thick (Figure 5). Most certainly this is not the same profile as those described from beneath the Eocene rocks, but it is of interest because it indicates that the severe leaching conditions which produced the sub-Eocene paleosols were still present as Middle Eocene deposition commenced. The later Eocene rocks indicate a semiarid climate (Peterson and Abbott, 1979).

CONCLUDING REMARKS

Paleosols are weathering profiles, not stratigraphic units, and as such are difficult to age date. In the San Diego area, the paleosols evidently lie between the latest Cretaceous rocks and the Middle Eocene rocks. We are interpreting this time interval to have been hot and humid, much like the modern equatorial belt.

Elsewhere in California, the early Cenozoic stratigraphic record is likewise characterized by paleoclimatic indicators that imply a similar conclusion. California is not endowed with coal in quantity or quality, but the coal that is present mostly appears to be of Paleocene through Middle Eocene age (Landis, p. 134-139 _in_ Albers, 1966). Coal is characteristic of humid climates with abundant vegetation and swampy conditions necessary for preservation.

Kaolinitic clay deposits, both residual and transported, are found in many parts of California (Kelley, p. 126-134 _in_ Albers, 1966). The best known deposits are from the Ione Formation of Middle Eocene age along the eastern edge of the Great Valley and the comparable Telsa Formation in Alameda County. Also well known are the Paleocene deposits of the Alberhill district of Riverside County and other deposits of similar age near Corona and the northern edge of the Santa Ana Mountains. Innumerable smaller deposits, such as those in the San Diego area, are probably of similar early Cenozoic age. Many of the clay deposits occur with bituminous coals. To form in appreciable quantities, kaolinitic clays (non-hydrothermal) require a long-lasting hot and humid climate.

Sandstones with a very high quartz content (silica sands or glass sands) are mined in California from a number of early Cenozoic formations (Goldman, p. 369-374 _in_ Albers, 1966). The sandstones consist essentially of quartz grains and kaolinitic clay. Their occurrence roughly parallels the kaolinitic clay deposits of commercial grade. Like the clays, they are a product of intense weathering wherein all minerals except the resistant quartz have been destroyed or converted to clays.

The physical paleoclimatic indicators in the stratigraphic record elsewhere in California confirm conclusions derived from the paleosols of the San Diego area. California was very hot and humid in early Cenozoic time. This type of climate at this latitude and on the western coast of a continent is unknown in the modern world. The hot and humid paleoclimate characteristic of the early Cenozoic represents an unusual time in earth history, just as unusual as the Glacial Ages of the recent past.

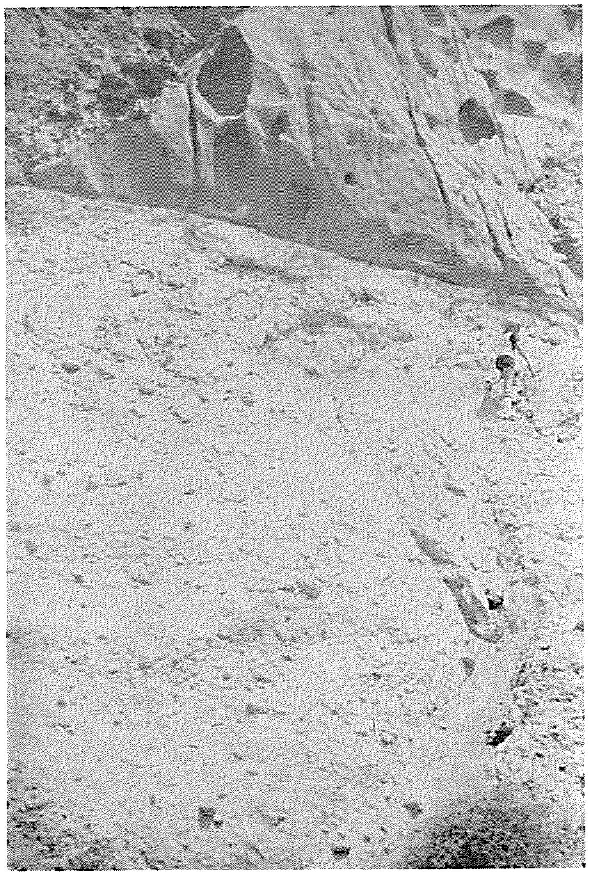

Figure 5. Severely weathered Mt. Soledad conglomerate on seacliff immediately south of Indian Trail Canyon at Black's Beach. Notice one meter thick, white kaolinitic A horizon above Deron's head.

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UPPER CRETACEOUS SEDIMENTARY ROCKS, NORTHWESTERN SAN DIEGO COUNTY

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INTRODUCTION

Upper Cretaceous sedimentary rocks assigned to the Lusardi, Point Loma and Cabrillo Formations (Kennedy 1975) are exposed at localities in La Jolla, Carlsbad and Olivenhain (Figure 1). These rocks record fluvial drainages that fed into marginal marine, shelf, slope and submarine canyon depositional environments.

LA JOLLA

The Cretaceous strata exposed in sea cliffs and outcrops on the flanks of Mt. Soledad are assigned to the Point Loma and Cabrillo Formations. Except for exposures south of La Jolla Beach and Tennis Club and localized road cuts on the north flank of Mt. Soledad, these rocks were deposited in inner- and mid-fan channels of a submarine fan (Nilsen and Abbott, 1981). The conglomerate units contain well rounded and poorly sorted clasts derived from the batholithic and pre-batholithic rocks of the Peninsular Ranges to the east (Peterson, 1970; Jones, 1973). Black dacite porphyry and black dacite aphanite constitute a high percentage of the clasts in the conglomerates (Table 1, Figure 2; Abbott, Kies and Bartling, 1981; Bartling, 1981, Kies; 1981). Some of the source terrane for the black dacites has been tentatively identified in northwestern Baja California (Bartling, 1981; Kies, 1981).

The strata exposed in the sea cliffs south of La Jolla Beach and Tennis Club are a transgressional sequence of Middle Campanian to Maestrichtian age (Sliter, 1968). The base of the sequence was deposited above wave base near a shoreline. These strata are succeed in order by approximately 200 meters of shelf, slope, basin plain and outer submarine fan deposits as the sea cliffs are followed south and then west to the Country Club fault.

CARLSBAD

Late Cretaceous rocks exposed in the Carlsbad area (Figure 1) record deposition in shallow marine and marginal marine environments. Liska (1964), Holden (1964), Sliter (1975) and other workers have described faunal assemblages typical of a protected marine embayment from mudstones collected in Letterbox Canyon and in the roadcuts along El Camino Real across from the Madonna Hill Guest Home just northeast of Palomar Airport. The sedimentary rocks are mostly green, fossiliferous mudstone layers interbedded with a few internally scoured sandstone beds. One amalgamated sandstone layer containing a high percentage of fragmental fossil debris constitutes a continuous horizon up to 3 feet thick that poured out onto the shallow shelf during a large flood event. Scour and fill channels trending S5^{o}W indicate high energy tidal transport toward the south of invertebrate megafossils, sands and rare boulders of San Marcos Gabbro up to one foot long. Sliter (1964) assigned these mudstones to the Middle Campanian, the same age as the shallow shelf deposits at La Jolla

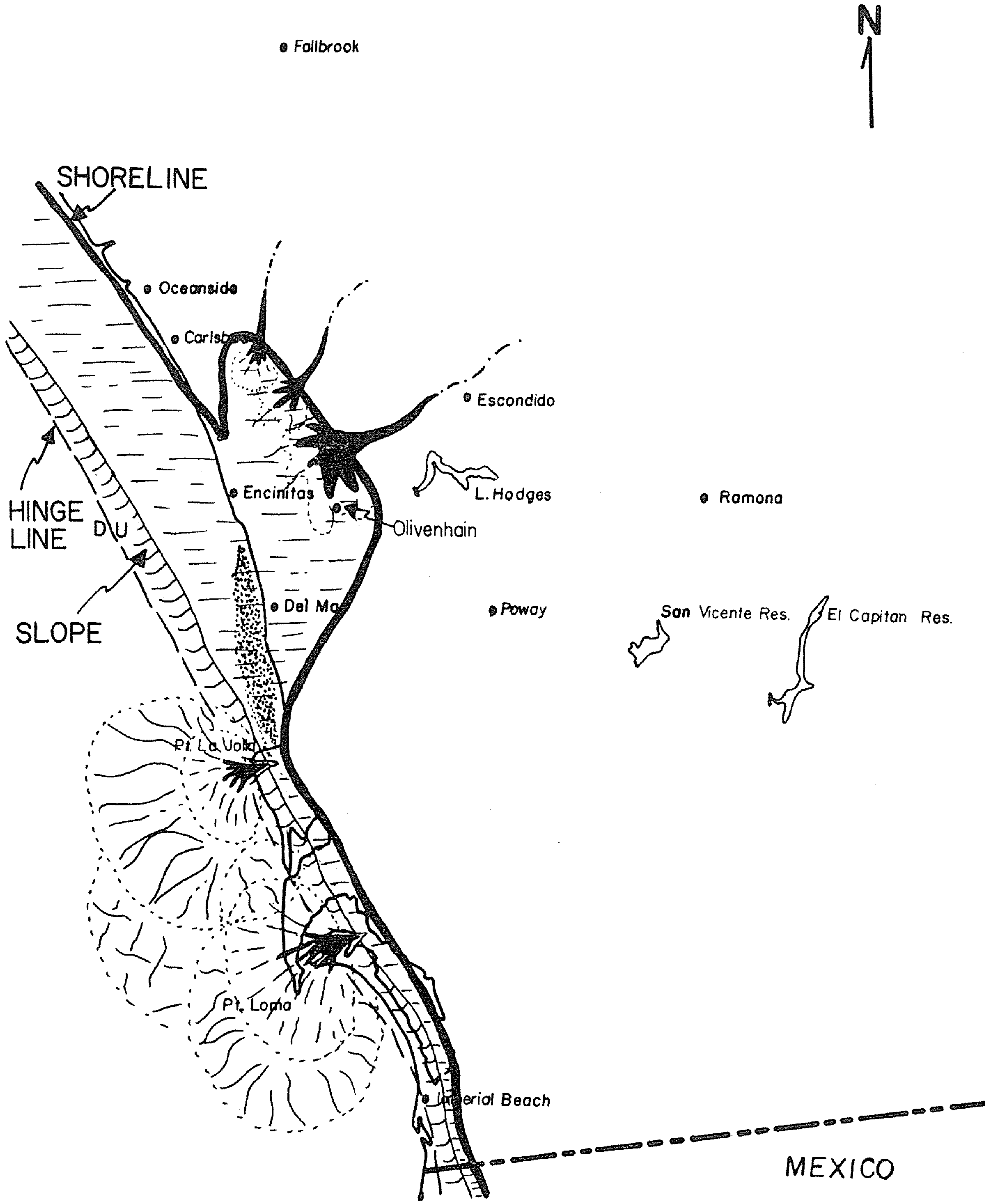

Figure 1 - Index map and Late Cretaceous paleogeography of west San Diego County indicating shelf, slope/hinge line and submarine fans. North arrow is present day.

just south of the La Jolla Beach and Tennis Club.

Northeast of the Madonna Hill Guest Home roadcut, near Cerro de la Calavera, is an exposure of well rounded, poorly sorted boulder conglomerate which has been intensely weathered. The lithologies of the clasts suggest an affinity to the Lusardi Formation (Figure 2). These conglomerates underlie unweathered conglomerate, cross-bedded sandstone and green, massive, unfossiliferous mudstone (Figure 3a). Within the upper, unweathered conglomerate are placer deposits and randomly dispersed pebbles of quartzite and ironstone soil nodules eroded from the weathering profiles (Figure 3b). The unweathered conglomerate, sandstone and mudstone are inferred to be Eocene. The lower weathered conglomerate is the remnant of a Cretaceous channel through which depositional pulses were funnelled toward the Madonna Hill Guest Home outcrops.

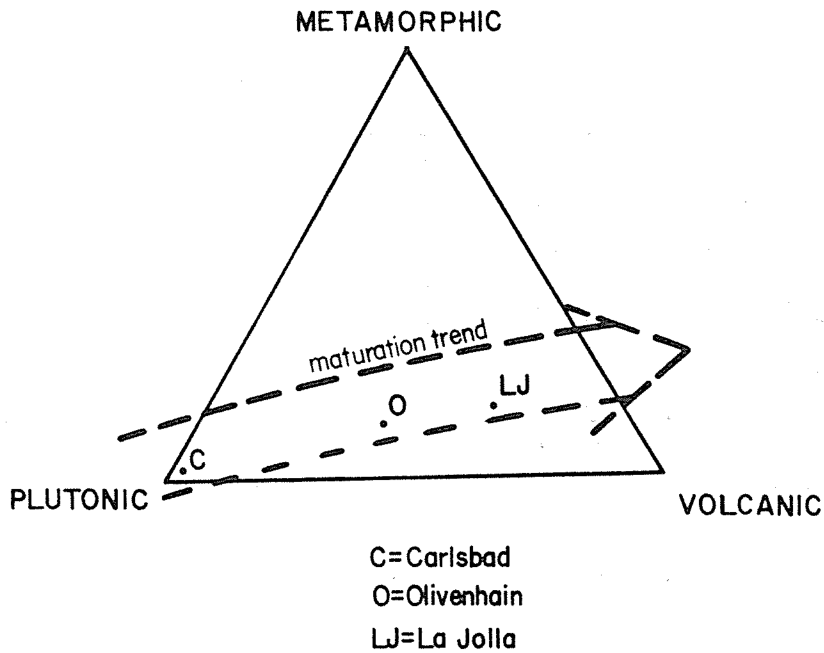

Figure 2 - Ternary diagram showing relationships of conglomerate compositions at Carlsbad, Olivenhain and La Jolla. Note that maturation trend moves toward abrasion- and weathering-resistant clast types.

OLIVENHAIN

A rounded cobble conglomerate containing distinctive black dacite porphyries and aphanites crops out in a road cut along South Point Road 1/8 mile southwest of El Camino del Norte in a recently graded set of house lots near Olivenhain. The conglomerate slopes to the south beneath the overlying Cretaceous submarine valley-fill sandstone beds (Figure 4). The Cretaceous sandstone is truncated by a Pleistocene (?) terrace deposit. The Cretaceous conglomerate shows crudely-expressed normal grading and overlies a shallow marine mudstone which contains *Baculites* sp. and conifer twigs with preserved strobili. The occurrence of an open marine species like *Baculites* sp. in association with delicately preserved

	LA JOLLA	CARLSBAD	OLIVENHAIN
PLUTONIC	25.0	92.6	45.1
METAMORPHIC	21.6	3.1	19.6
VOLCANIC	53.4	4.3	33.5
BLACK DACITES	26.7	0	17.1
OTHER	26.7	4.3	16.4

Values in percent excluding intraformational and unidentifiable clasts.

Table 1. Clast count analysis of conglomerate units.

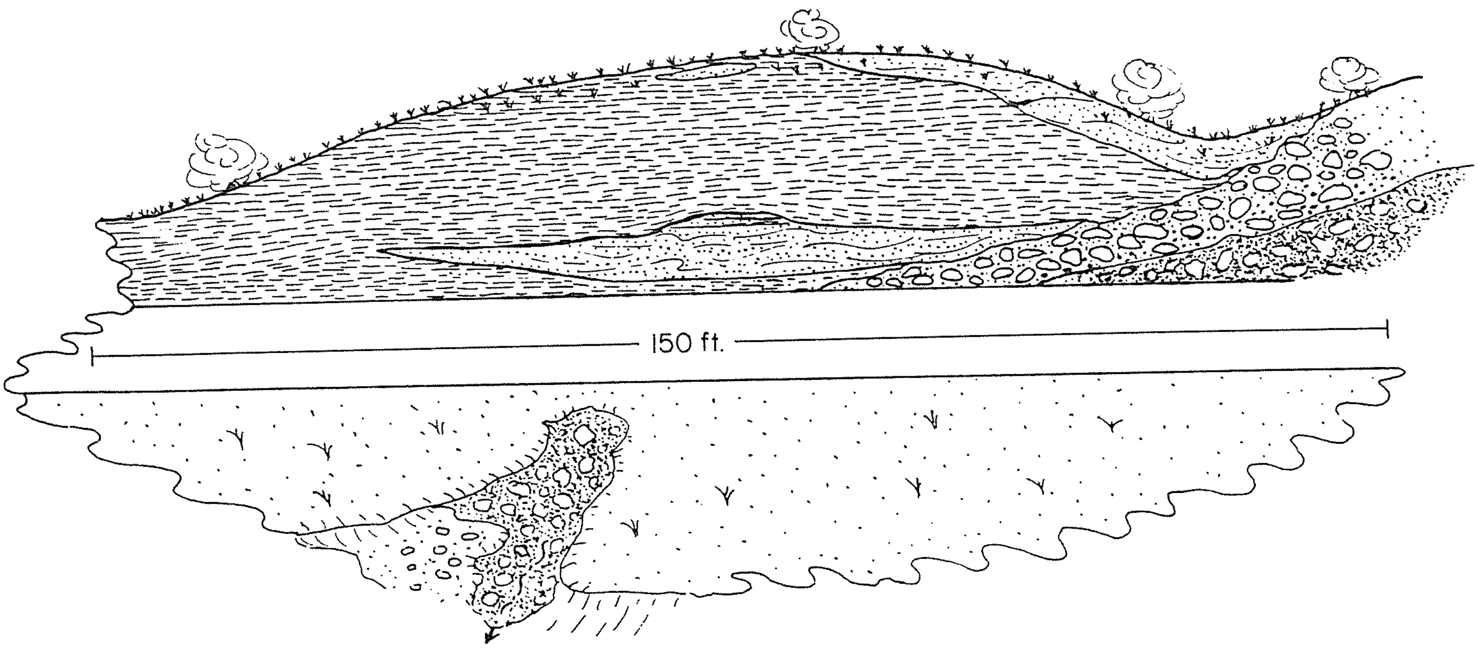

Figure 3a - Sketch of outcrop at Cerro de la Calavera near Carlsbad. Severely weathered, rounded boulder conglomerates (Lusardi Formation) overlain by unweathered plutonic boulder breccia, green mudstone and large sandstone lenses that contain kaolinitic laminae and iron-stone gravels eroded from the tropical-climate paleosol and redeposited probably during the Middle Paleogene. The older conglomerate probably was deposited in a drowned river mouth related to the Late Cretaceous shelf.

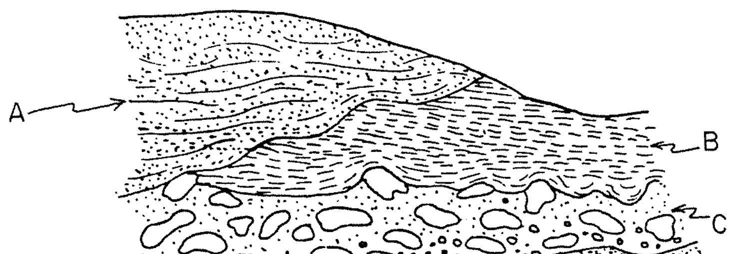

Figure 3b - Detail of Figure 3a. Lenticular sandstones (A) are channelized and co-mingled with un-weathered lagoonal mudstone (B). The medium to coarse sandstones exhibit planar and wavey laminations with intervening kaolinitic placers. Unweathered conglomerate (C) of subangular plutonic clasts has a sandy mudstone matrix with incorporated weathering-profile detritus. The material derived from the old weathered surface includes; well-rounded quartzite pebbles, ferruginous pebble-concretions and kaolinitic clay laminae. The weathered sub-angular plutonic-boulder conglomerate (D) exhibits matrix-supported grussified clasts in a kaolinitic sandy mudstone matrix.

flora is best explained by transport of Baculites into a quiet nearshore environment. This model is supported by the morphology of the conglomerate unit which suggests outbuilding of a conglomerate lobe into the shallow marine environment by way of debris flows.

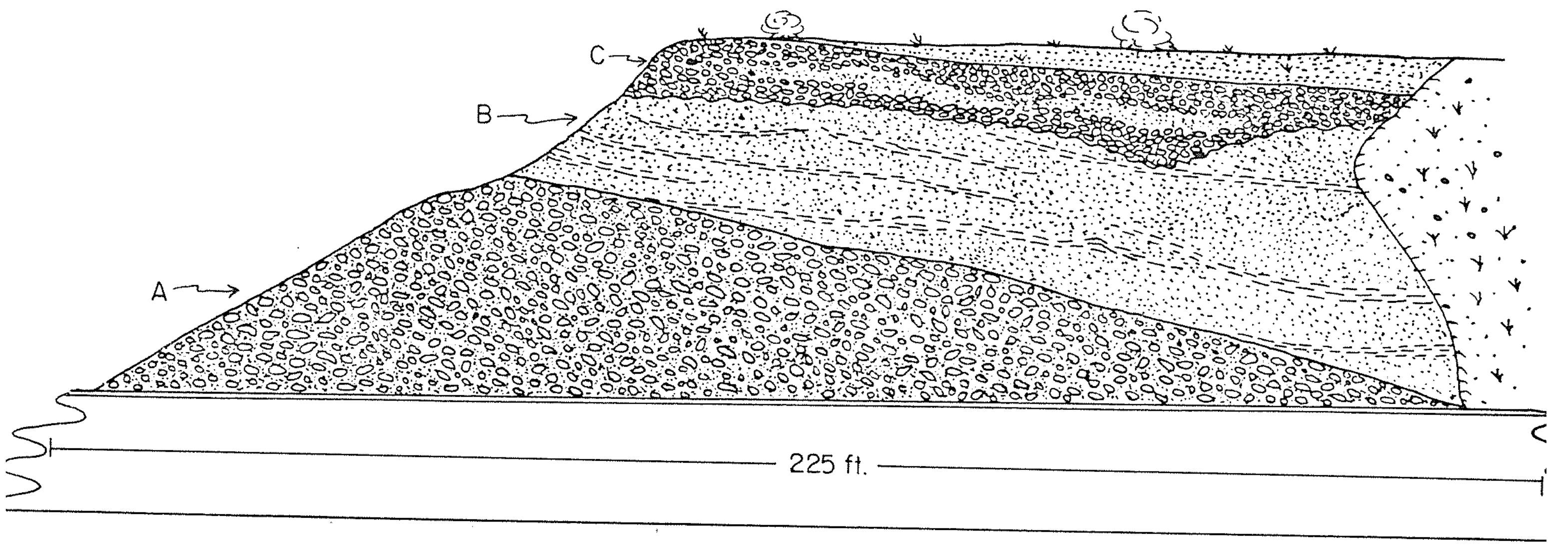

Figure 4 - Sketch of outcrop at Olivenhain. Disorganized to crude normally graded, sub-rounded cobble conglomerate (A) overlain by valley fill sandstone with thin mudstone beds (B). The contact between the conglomerate and sandstone has a slope of 13 degrees. The overlying sandstones and sparse mudstones were deposited against a sloping surface. These cobbles and sands in the lower conglomerate unit may represent outbuilding of a fluvial conglomerate lobe into a shallow marine environment. Younger, post-Eocene conglomerate and coarse sandstone (C) disconformably rest upon the Cretaceous deposits and probably represent recent terrace development.

FACIES RELATIONS

The Lusardi Formation was described by Nordstrom (1970) as a terrestrial deposit of massive cobble and boulder conglomerate with clasts ranging in size from less than an inch to over 30 feet in diameter deposited in mass-wasting and mud-flow events (i.e. typical alluvial fan deposition). The Cabrillo Formation (conglomerate) is typically a better sorted, more rounded conglomerate with a higher diversity of clast types deposited in an inner-fan channel of a submarine canyon.

An understanding of the relationships between these two formations can be achieved by envisioning a facies model in which an eastern highland of then recently exposed pre-batholithic and batholithic rocks were being eroded by a multitude of juvenile fluvial systems emptying onto a broad coastal plain as large alluvial fans. As time progressed, the Late Cretaceous transgression began (Vail et al, 1977) and individual streams eroded through more source rock types. The result of this was a migration eastward of both marine and non-marine deposition with the clast assemblages in the fluvial channels becoming more diverse and more mature. The greater maturity is shown by improved rounding and sorting and the increase in the percentage of abrasion- and weathering-resistant clast types (Figure 2, Table 1). To the west, shelf mudstone and incised conglomerate (Cabrillo facies) accumulated over an older deposit of non-marine, less mature conglomerate (Lusardi facies). The marine deposited conglomerate, due to the influence of reworking and winnowing by marine currents, became more mature with time.

Differences between Turonian, immature, localized alluvial fan deposits (Lusardi Formation) and Maestrichtian, mature, diverse submarine canyon conglomerates (Cabrillo Formation) are conspicuous. However, these represent the two end members of a continuous depositional system that progressively changed in source terrane, maturity, environment of deposition and stratigraphic position. Subsequent erosion and burial of most of the transitional phases of the sedimentary record confuse the relationships between the units. Thus, the transitional phases of this maturation process become a grey area in the stratigraphic nomenclature.

Based on depositional facies, it is appropriate to limit the term Lusardi Formation to those rocks deposited as immature conglomerates in a primarily non-marine environment and the Cabrillo Formation to the more mature, diverse, dominantly marine-deposited conglomerates.

TECTONICS

The three areas discussed show evidence of deposition of a complex array of intermingling fluvial and marine facies complicated by syndepositional tectonics (Figure 5). Kennedy (1975) suggested diagrammatically that the Lusardi, Point Loma and Cabrillo Formations were time transgressive facies of a single depositional system. Gastil (1966) suggested a hinge-line coast in Late Cretaceous time which controls the present day distribution of outcrops of the Rosario Group.

Comparison of Middle Campanian strata at Carlsbad and La Jolla show a drastic discordance in depth of deposition. At Carlsbad, mudstones and conglomerates of lagoonal affinity were subjected to intense sub-aerial weathering during Paleogene time (Peterson and Abbott, 1975). However, the same age strata of similar depth of deposition at La Jolla underlie a thick sequence of bathyal deposits which were unaffected by the subaerial weathering event. Tectonic downdropping along a hinge line located in the vicinity of the present day Rose Canyon Fault zone, in conjunction with eustatic sea level rise, created a basin into which submarine canyon deposits of Late Campanian and Maestrichtian age rapidly accumulated. As the submarine canyon system matured, larger volumes of coarser materials were funnelled into this basin. The alternative models of Campanian tectonic tilting or Paleogene uplift of the Carlsbad area are readily disputed by noting the extreme lack of deformation east of the proposed hinge line.

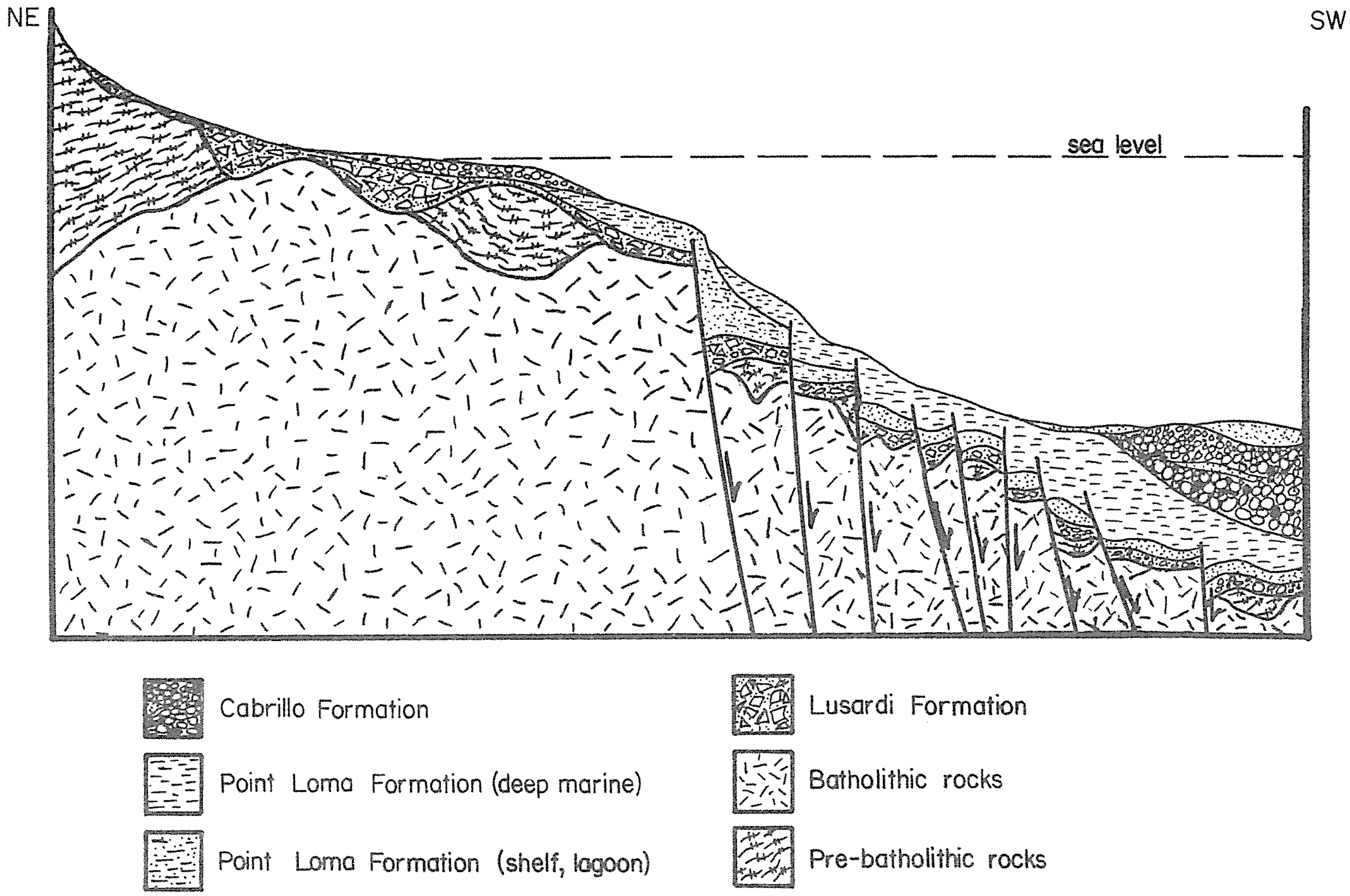

Figure 5 - Diagrammatic cross section from Carlsbad to La Jolla showing down dropping of basin via growth faults across postulated hinge line; downstream rounding of Lusardi Formation conglomerate, gradation from lagoonal mudstone to shelf sandstone and basin fill over Lusardi conglomerate and Point Loma shelf facies.

Paleogeographic reconstruction of Late Cretaceous San Diego County is displayed in Figure 1. Holden (1964) suggested that outcrops of pre-batholithic rocks now cropping out in a north-south fashion near Carlsbad served as a topographic high which sheltered this area from the wave and longshore reworking of sediments that is evident south of La Jolla Beach and Tennis Club.

CONCLUSIONS

It becomes clear after careful scrutinization of Upper Cretaceous sedimentary rocks in San Diego County that a simple layer cake model for deposition of these rocks does not provide an adequate explanation. Intermingled marine and non-marine deposition beginning in Turonian (?) time was tectonically complicated in Middle Campanian time by initiation of basin formation along a faulted hinge line. Subsequent deposition constituted early stages of shelf fill to the north around Carlsbad but matured into

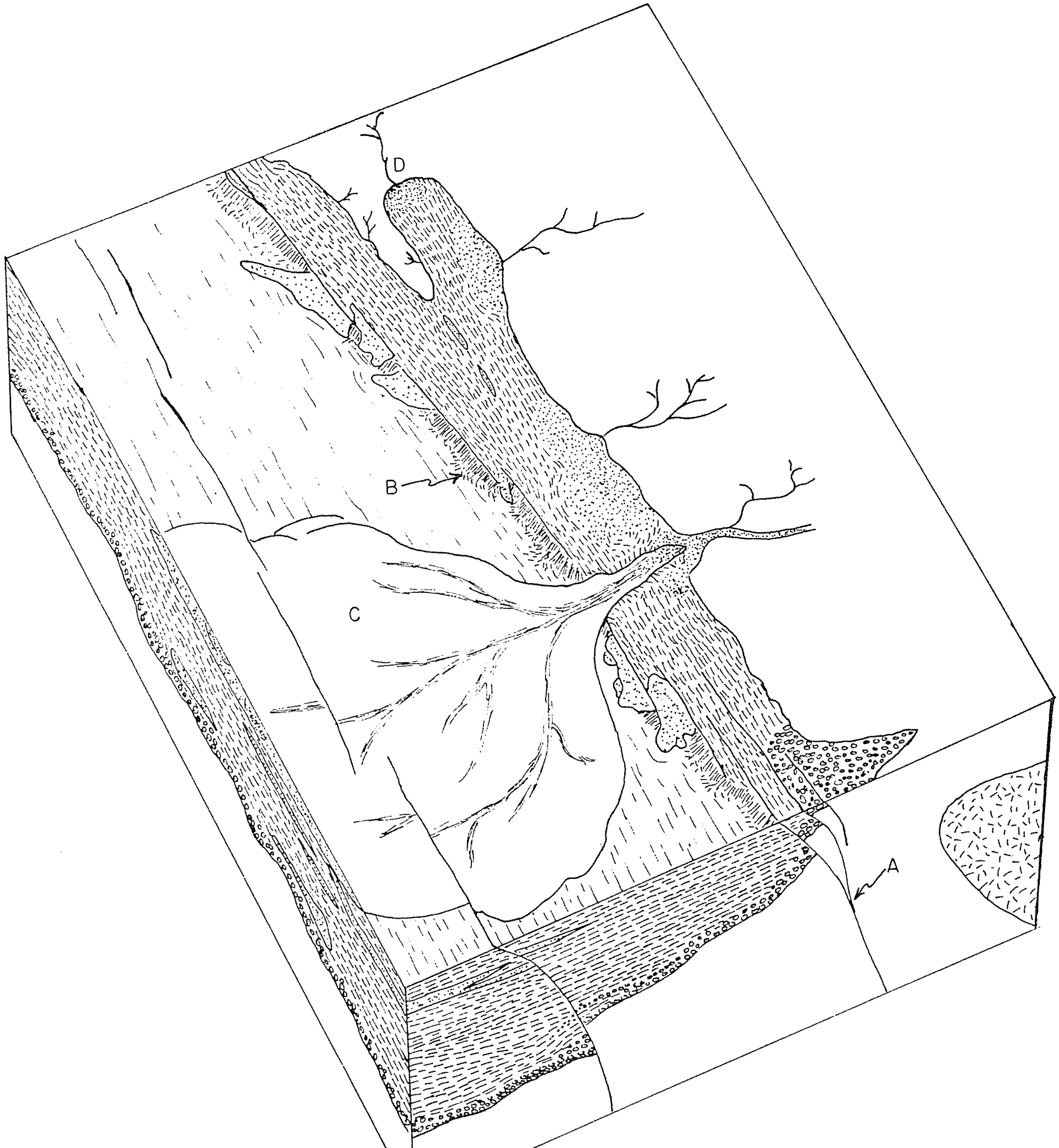

Figure 6 - Block diagram illustrating Late Cretaceous tectonics and geomorphology. Synchronous development of wrench faults (A) and sedimentation gave rise to a hinge line coincident with the shelf edge (B). Fault created topographic relief allowed a submarine fan depositional system (C) to generate. The Carlsbad area (D) remained on a stable shelf landward of these dextral slip faults.

rapid deposition in a submarine canyon complex to the south around La Jolla and Point Loma.

Recent work throughout the California Continental Borderland and within the Mesozoic Volcano-plutonic arc terranes, has revealed that the convergent boundary between the North American and Pacific plates had a significant amount of oblique motion during Middle Mesozoic and Early Paleogene time (Atwater, 1970; Saleeby, 1981). The result of this interaction included synchronous development of dextral wrench faults within the frontal arc basins. These faults undoubtedly would have controlled Mesozoic and Early Paleogene coastline configurations in the same manner as modern wrench faults associated with the San Andreas Fault System control present day shelf-basin topography (Figure 6). The vestiges of Mesozoic oblique subduction and resultant wrench-fault tectonics are seen as a preserved, fault-controlled shelf-basin topography. This morphotectonic feature is reflected by disparate depositional base levels of the Late Cretaceous marine strata of San Diego.

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A LATE CRETACEOUS AMMONITE FROM THE
OLIVENHAIN AREA, SAN DIEGO COUNTY, CALIFORNIA

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INTRODUCTION

A recently uncovered section interpreted to be the Cabrillo Formation has been found to be underlain by fossiliferous marine strata lithologically similar to the Point Loma Formation. The section is located in the small community of Olivenhain (Figure 1) and is within the area mapped by Nordstrom (1967). This report briefly reviews the present stratigraphic nomenclature of the Upper Cretaceous strata in the northern part of San Diego County, presents new paleontologic data, and discusses their implications.

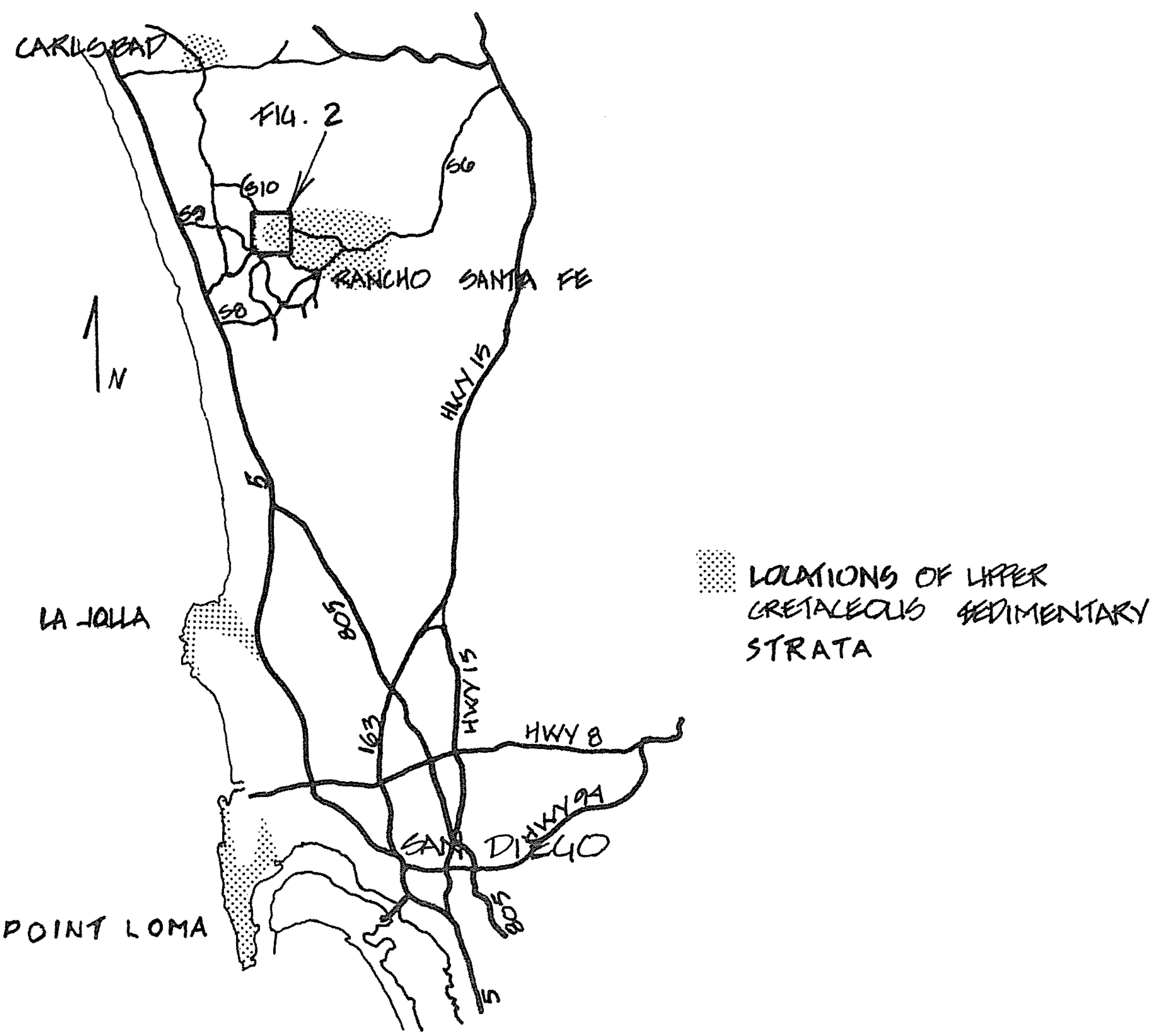


Figure 1. Location map showing part of the coastal area of San Diego County.

Nordstrom (1970) correlated the Lusardi Formation with the Turonian Trabuco Conglomerate (Popenoe, 1941) of the Santa Ana Mountains solely on the basis of its physical resemblance. At that time, no fossils had been found in the Lusardi nor were the prospects likely. Lithologically the Lusardi is non-marine conglomerate and sandstone containing clasts derived directly from adjacent pre-batholithic and batholithic rocks. Some of the clasts are exceedingly large, up to 10 meters in diameter, and the unit shows a decrease in grain size to the west (Nordstrom, 1967). In addition, it is thought to have been deposited directly on the eroded surface of the pre-batholithic and batholithic rocks (basement) on a high-relief unconformity (Peterson and Nordstrom, 1970).

The present stratigraphic nomenclature indicates that the Lusardi is the basal unit of the Upper Cretaceous Rosario Group (Kennedy and Moore, 1971a) and is unconformably overlain by the Point Loma and the Cabrillo Formations. However, no localities are presently known where all three units crop out. Hertlein and Grant (1939) reported a conglomeratic unit at depth in the subsurface in the northern part of Point Loma; Peterson and Nordstrom (1970) correlated the Lusardi Formation with this unit. In Carlsbad, the Lusardi appears to underlie the Point Loma Formation (Kennedy and Moore, 1971b; Wilson, 1972) which contains medial to late Campanian foraminifera (Sliter, 1968).

GEOLOGIC RELATIONSHIPS IN OLIVENHAIN

Figure 2 is a simplified geologic map of a small area in Olivenhain. This map is derived from an unpublished report (Shepardson and Sherrod, 1978) and was field checked by the author. A previous map (Nordstrom, 1967) showed that the Lusardi Formation unconformably overlies basement rocks and is unconformably overlain by the Eocene La Jolla Group just east of the area shown in Figure 2. In addition, no major faults are thought to occur here.

The four rock units that crop out in the Olivenhain area are: 1) Jurassic Santiago Peak Volcanics; 2) Upper Cretaceous Point Loma Formation; 3) Upper Cretaceous Cabrillo Formation (?); and 4) Quaternary terraces, colluvium and alluvium (Figure 3).

The Upper Cretaceous Point Loma Formation in this area is composed of mudstone, silty mudstone and local lenses of sandstone. The contact with the underlying basement rocks is obscured. The beds dip less than five degrees and appear to be unconformably overlain by conglomerates of the Cabrillo Formation (?) (Figure 3). The best exposures of the Point Loma are found near the center of the map (Figure 2) at the site of SDSU fossil locality 3235. Other exposures occur near the base of a ravine, 250 meters to the northwest. In addition to these outcrops, bore holes have penetrated this unit beneath the overlying conglomerates at depths up to 9 meters. There the hole bottomed out in clayey medium-grained sandstone to claystone (Ken Sherrod, 1980, personal comm.). Although no section is exposed well enough to measure, the topographic expression and the subsurface data suggest that the thickness of Point Loma Formation is about 30 meters. These rocks are lithologically similar to outcrops of the Point Loma Formation in roadcuts along El Camino Real, northeast of the Palomar Airport in Carlsbad, and those exposed at La Jolla Bay (Nilsen and Abbott, 1979).

Cobble conglomerate and sandstone of the Cabrillo Formation (?) lie in apparent angular unconformity on the Point Loma Formation in Olivenhain

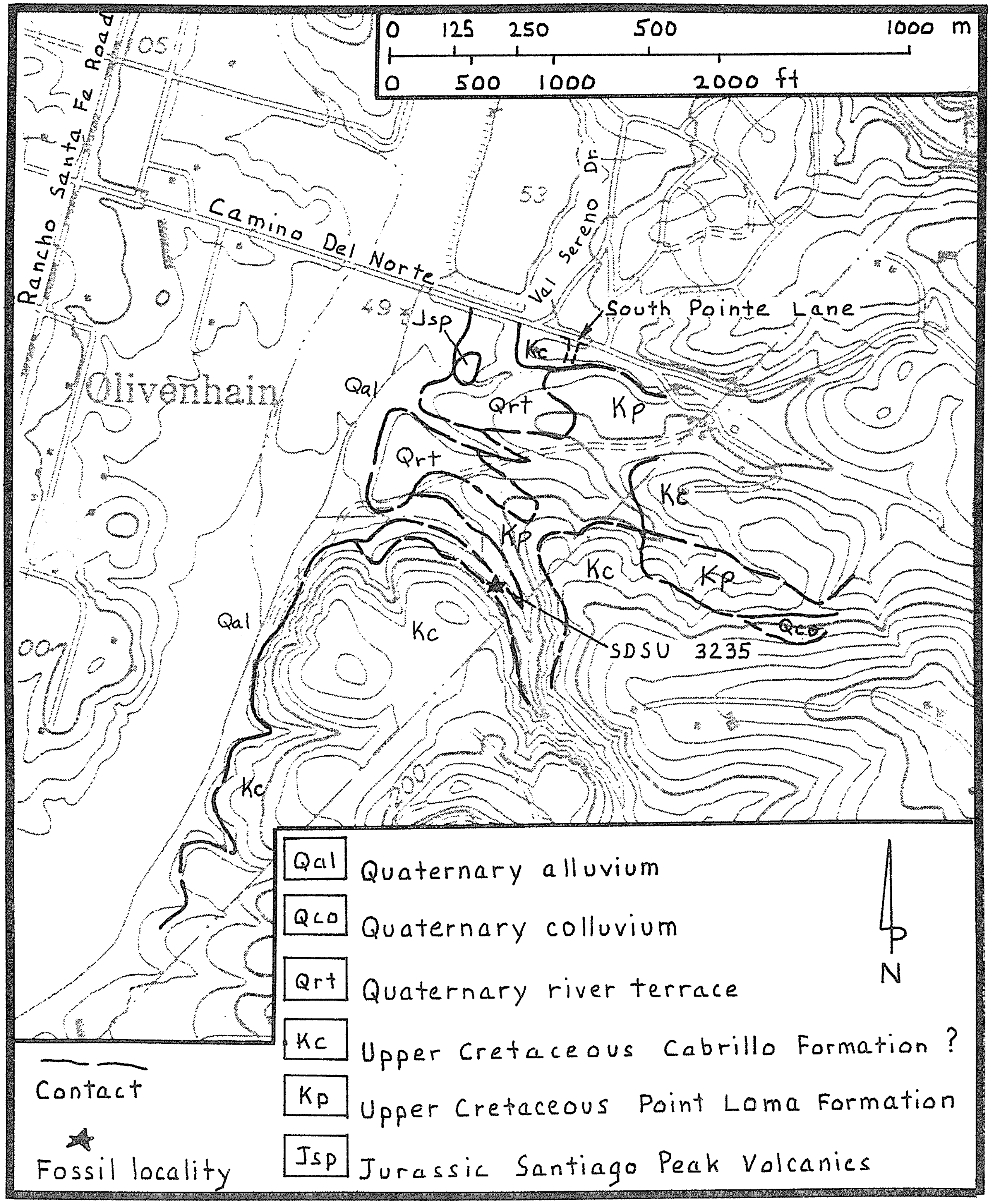


Figure 2. Generalized geologic map of a small area near Olivenhain, San Diego County. Base map is from the USGS Rancho Santa Fe 7.5 minute quadrangle 1968. Contour interval is 20 feet. Geology from Shepardson and Sherrod (1978, unpublished data).

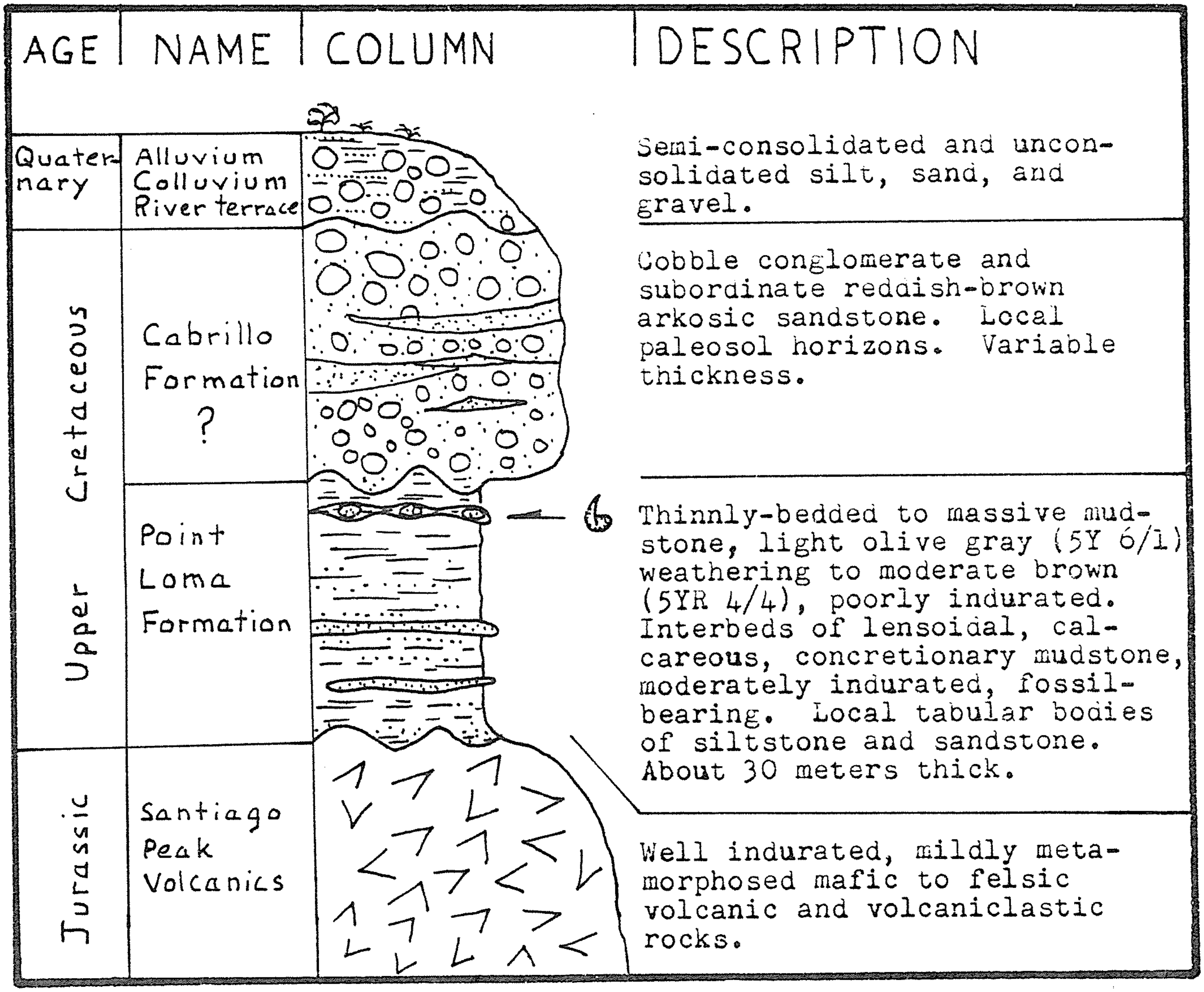


Figure 3. Stratigraphic column of rocks shown in geologic map.

(Figures 2 and 3). However, because of poor exposure, the nature of this unconformity is not known. The lithology of these conglomerates, previously termed the Lusardi Formation, is well described by previous workers (Nordstrom, 1967; Gastil and Higley, 1977). In a new roadcut along South Pointe Lane, approximately 120 meters west of SDSU locality 3235, the conglomerates are well exposed and occupy a position several meters stratigraphically higher than the underlying mudstones. In addition, one can traverse directly up section, in a southerly direction, from SDSU 3235 and find clasts of plutonic rocks consisting of the Peninsular Ranges suite. No Poway rhyolitic tuff clasts, which characterize Eocene and later conglomerates, are found.

Quaternary river terraces and alluvium occupy some of the lower areas and colluvium crops out locally (Figure 2).

FOSSILS

Identifiable fossils in this area are found near the upper part of the Point Loma Formation in Olivenhain. From the fragments available, Baculites anceps pacificus Matsumoto and Obata or B. lomaensis Anderson were identified (LouElla R. Saul and Peter Ward, 1981, personal comm.). They are considered late Campanian to early Maestrichtian in age (Matsumoto, 1960, Ward, 1978). The specimens, some of which are housed in the Allison Center at SDSU (location no. 3235, and some at UCLA (location no. 6893) are similar to those shown in Anderson (1958) and Matsumoto (1959). The shell appears to have been compressed and no sutures were found, but in several specimens, lobes and saddles that aid identification are evident. Some of the original shell material is also present (Plate 1).

Other fossils include several fragments of oyster shells, plant debris and a worm tube. No microfossils were found, precluding correlation with Carlsbad, La Jolla, and Point Loma localities where extensive micropaleontological work has been done (Bandy, 1951; Liska, 1964; Sliter, 1968, 1979).

Because of the limited fauna found in Olivenhain, and the lack of well-exposed diagnostic sedimentary structures, paleoenvironmental interpretations would be tenuous at best. The presence of Baculites may indicate moderate depths (L. R. Saul, 1981, personal comm.). However, oyster fragments are also present and oysters are thought to be typical of shallow-water environments. The fact that all fossils found thus far are broken suggest either transportation shortly after death or reworking of a previously formed deposit. This would account for both the ammonites and oysters occurring in the same bed.

Dawson (1978) reported B. lomaensis from the Cabrillo Formation in San Diego where trace fossils (Kern and Warme, 1974) and sedimentology (Nilsen and Abbott, 1979) indicate a deep-water, open marine environment. No such information is presently available for the Point Loma Formation of Olivenhain, therefore the present study can only suggest that it is marine and may have been deposited on the shelf as were the nearby Carlsbad strata.

DISCUSSION

The presence of fossiliferous marine strata underlying a section of conglomerates previously thought to be the Lusardi Formation raises many questions, some of which cannot be answered at the present time. The data suggest that the age of the conglomerates must postdate the lower Maestrichtian rocks underlying them and predate the Eocene rocks overlying them. One possibility is that the conglomeratic unit is correlative with the Upper Cretaceous Cabrillo Formation in San Diego. Both units have the same clast suite (Peninsular Ranges) and occupy the same relative stratigraphic position. In addition, in other areas thought to be underlain by the Lusardi Formation, similar conglomerates may be more closely allied to the Cabrillo Formation.

It seems unlikely that other outcrops, where the Upper Cretaceous conglomerates overlie marine strata, may be found in the Olivenhain-Rancho Santa Fe area because of poor exposures. As the Late Cretaceous alluvial fan complex was deposited, it is likely that some of the pre-existing Point Loma Formation may have been eroded, thus preserving only local sections such as the one in Olivenhain.

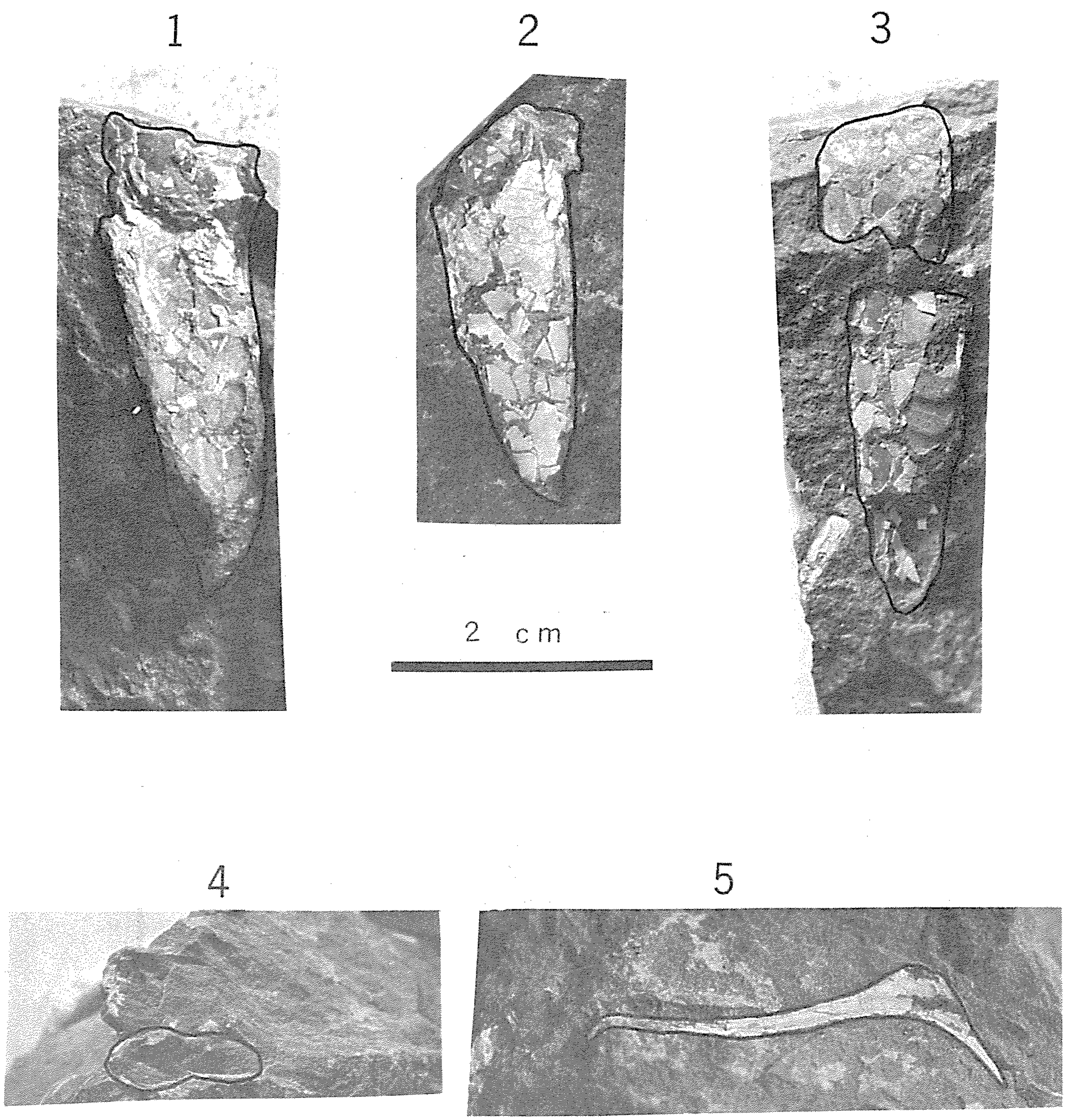
Another possibility is that the lithologies of the Point Loma Formation represent a tongue and the conglomerates were laid down in two intervals, somewhat analogous to the Eocene relationships in San Diego (Kennedy, 1975).

PLATE 1

Late Cretaceous fossils from the Point Loma Formation in Olivenhain.

Figs. 1-4. Fragments of *Baculites anceps pacificus* Matsumoto and Obata or *B. lomaensis* Anderson. Figures 1, 2 and 3 are lateral views. Figure 4 is a cross-sectional view. The original shell shape appears to have been altered by post-depositional compression.

Fig. 5. Fragment of an oyster shell.



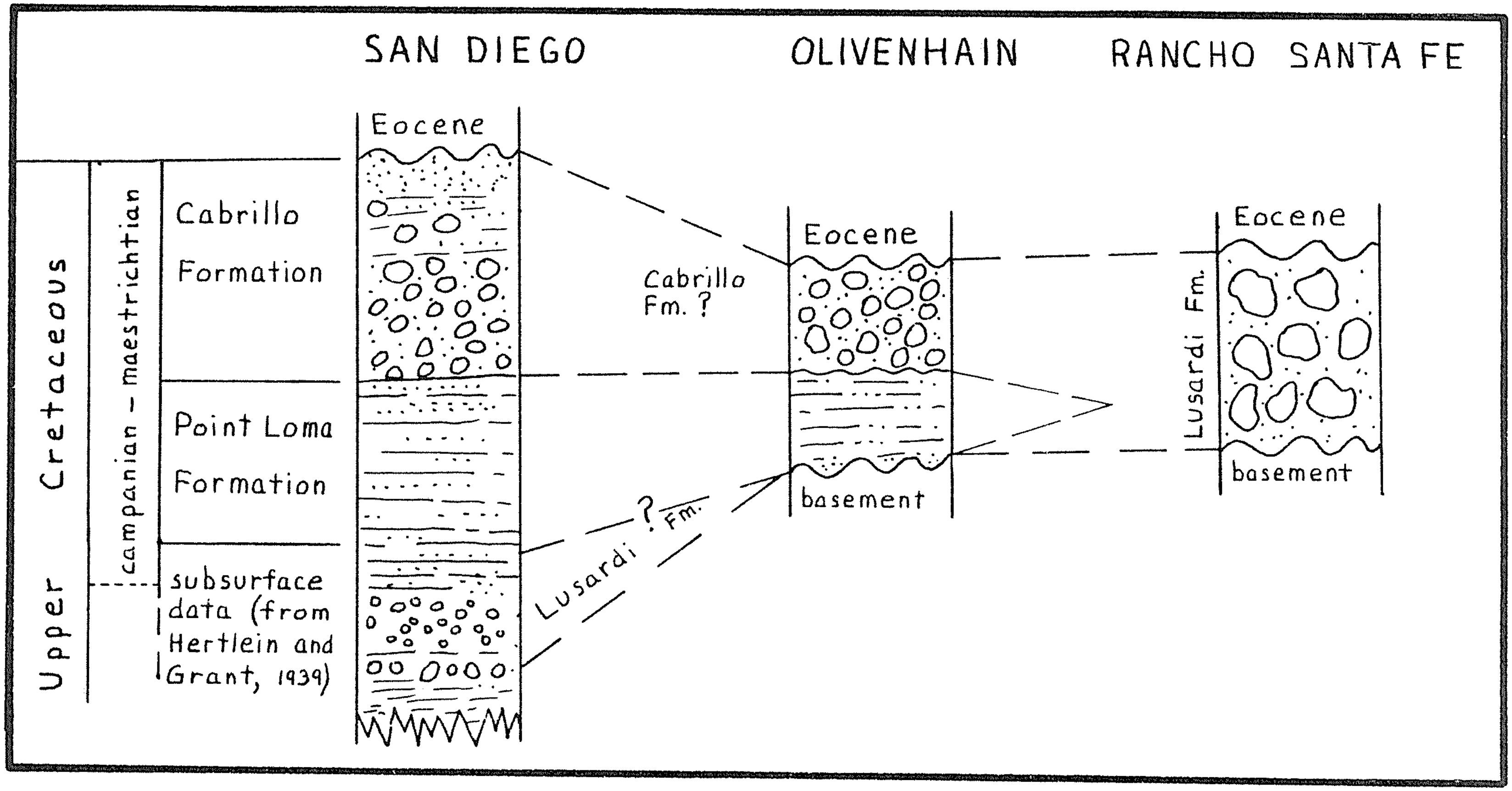


Figure 4. Proposed tentative correlations of Upper Cretaceous rocks in Olivenhain with related rocks in the San Diego and Rancho Santa Fe areas.

Non-marine and/or paralic deposition of the conglomerates may have occurred before and after deposition of the Point Loma Formation in northwestern San Diego County. Therefore, some of the conglomerates (Lusardi Formation) may correlate with the Trabuco Conglomerate, the Carlsbad outcrops, and the subsurface of San Diego as suggested by Nordstrom (1967, 1970), and some may correlate with the Cabrillo Formation. Figure 4 diagrammatically shows the tentative correlation proposed.

ACKNOWLEDGEMENTS

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LA COSTA STORAGE RESERVOIR
AND DAM

by
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INTRODUCTION

La Costa Storage Reservoir and Dam is a key element of the San Marcos County Water District Reclamation Project. The function of the reservoir is to provide temporary storage of treated sewage effluent for spray irrigation of open space. This paper describes the planning, design and construction of the earth dam with particular emphasis on the geological and geotechnical features.

PROJECT DESCRIPTION

The La Costa Storage Reservoir and Dam project is located just east of Rancho Santa Fe Road in the La Costa development area of Carlsbad, California. It consists of a zoned earth and rockfill dam, emergency spillway, outlet works, seepage control system and storage reservoir all located near the head of an unnamed tributary to Encinitas Creek.

The dam measures 80 feet high from the downstream toe to dam crest and 76 feet from toe to spillway crest. The reservoir is capable of storing 54,000,000 gallons or 166 ac-feet of water at spillway level. Because of its height and storage it falls under strict jurisdiction of the State of California Division of Safety of Dams. All design and construction must be reviewed by the Division and the owner is required to obtain a State permit for construction of the dam. The dam was constructed of materials available at the site and in nearby borrow areas. Graded filter material for construction of subsurface drains and the chimney drain were imported from aggregate plants in San Diego County. Concrete for structures was hauled in by ready mix trucks.

The emergency spillway is an ungated concrete-lined trapezoidal chute constructed through the ridge on the right abutment about 350 feet upstream of the right end of the dam. Since the reservoir is designed to store pumped-in treated sewage effluent it is unlikely the spillway will function often. If it does it will discharge under an access road through two arch culverts and into a valley that drains to the northeast.

The outlet works, consisting of an intake structure, an outlet conduit, and an outlet structure, will be used for filling the reservoir, discharging water for spray irrigation, and emptying the reservoir quickly, if necessary.

In addition to the dam and reservoir, the total project includes irrigation pipelines, a sewage treatment plant and various access roads.

Because the proposed dam and reservoir will serve as temporary storage for treated sewage effluent during rainy seasons, the reservoir will be empty or at low levels during about 9 months of the year.

SOIL AND GEOLOGICAL CONDITIONS

Physiography

The Storage Reservoir is located at the head end of an unnamed east to west trending tributary to Encinitas Creek. The topography on the south shore of the reservoir consists of a north-facing mountain, which has slope inclinations of approximately 2 horizontal to 1 vertical. The north side of the reservoir is formed by an east-west, elongated ridge that has south-facing slopes, of about 5 horizontal to 1 vertical slope. The spillway is located in this ridge. The drainage area above the dam encompasses about 26 acres and is covered by low chaparral, which is thicker and denser on the north-facing slopes. Precipitation in the area averages about 12 inches per year. Annual variations in precipitation are expected to range from a few inches to about 2 feet per year. Annual evaporation in the area is approximately 55 inches.

Field Explorations

Fifty-three exploratory excavations and borings were made at the dam site, onsite borrow area and offsite borrow area to investigate subsurface conditions. These explorations combined with previous test pits and engineering seismograph tests made during the feasibility phase provided the information needed to design the dam, evaluate quality of prospective construction materials and evaluate potential for foundation and abutment seepage.

Because the site is underlain essentially of metavolcanic and metasedimentary rocks with relatively shallow topsoil and alluvium heavy emphasis was placed on exploring with dozer trenches and backhoe test pits. Only three test borings were made along the axis of the dam to obtain rock cores and perform water pressure tests. One of the most valuable explorations was a continuous dozer trench excavated approximately along the dam axis from one end of the dam to the other. This trench provided proof that the material could be excavated by dozers and ripping below the depth of foundation preparation as well as visual evidence of the material that would be encountered beneath the dam. Test pits were excavated with various sizes of backhoe, namely John Deere Models 310, 410 and 510. Trenches were dug with a Kumatsu 155 dozer and an International Harvester TD15 dozer. Borings were made with a truck mounted Mobil B-53 drill rig using a Longyear HQ3 wireline triple tube diamond core barrel.

Materials obtained from the explorations consisted of alluvium, residual soils and rock in various degrees of weathering from completely-weathered to fresh rock. For purposes of establishing a consistent system for classifying the degree of rock weathering when dealing with construction contractors the following definitions were used:

a) "Fresh rock" shows no discoloration, loss of strength, or any other effects due to chemical or mechanical weathering.

b) "Slightly-weathered rock" is slightly discolored but not noticeably weaker than the fresh rock.

c) "Moderately-weathered rock" is discolored and noticeably weathered, but drilled cores or equal size fragments cannot be broken by applying pressure by hand across the rock fabric.

d) "Highly-weathered rock" is discolored and weakened to the degree that drilled cores or equal size fragments cannot be broken by applying pressure by hand across the rock fabric.

e) "Completely-weathered rock" is discolored and has entirely changed to soil consistency, but the original rock fabric is nearly preserved.

The above system was used in the construction specifications to define the depth of foundation preparation and the types of materials that could be used in various zones of the dam. The system worked well on this project to prevent conflicts between the contractor and the engineer. It has also been found useful on other projects especially in tunneling.

Soil samples were visually classified in the field and then tested in the laboratory to determine those properties which are pertinent in dam design. Such tests include compaction, shear strength and permeability as well as the basic classification tests - gradation and Atterberg limits. An offsite borrow area was considered as a possible supplementary source of impervious material. The material at the borrow site was Tertiary age sedimentary material consisting of unlithified, interbedded, gray, limonite-stained, fine, sandy silt and maroon to gray silty clay. Discontinuous gypsum interbeds and seams up to 1 inch thick were found at the contact of the clay beds with the overlying silt beds, and within the clay beds along planes of parting and fracturing. It was also expected that some finely-divided and disseminated gypsum would be found throughout the entire formational unit. Since gypsum is soluble by seeping water it would have been undesirable to have excessive amounts of gypsum in material placed in the dam. Tests made to determine the soluble salt content in accordance with the Saturated Soil Extract Test of the Department of Agriculture showed the soluble salt was 0.2 percent or less and the soil would be suitable for impervious embankment.

Water pressure tests were made in 2 borings to evaluate the permeability of the in situ bedrock. These tests indicated the fresh rock at depth was generally tight while the joint system in the slightly- and moderately-weathered rock would allow some water flow.

Site Geology

Metavolcanic and metasedimentary rocks of the Santiago Peak volcanics form the bedrock in the dam and reservoir areas. The rock varied from a highly-fractured, highly-weathered, brown, siliceous, meta-tuff breccia to a brown, fine-grained, highly-weathered meta-tuff. A number of interbeds of slightly weathered and slightly-fractured, dark blue-green, aphanitic, siliceous meta-tuff were present.

The Santiago Peak metavolcanic rock at the site is highly fractured with fracture spacing on the order of less than 1 inch to over 1 foot. The fractures dip steeply (60 to 90 degrees) and have omnidirectional trends. Shear zones were exposed in the long trench with trends northwest to southeast and dip from 50 to 72 degrees south. Though the zones are highly fractured they are hydrothermally altered and the fractures are tight and filled by highly-plastic, gray-brown clay. No zones were found in the dam foundation which would give concern for excessive leakage.

Sources of Materials

The exploratory program revealed that fine-grained material for constructing impervious zones of the dam were available within the dam foundation preparation area, in alluvial deposits immediately downstream of the dam, and from the topsoil, residual soil and highly-weathered and completely-weathered rock on the ridge downstream of the right abutment. As a reserve an offsite source of fine-grained borrow was found east of Rancho Santa Fe Road on the extension of La Costa Avenue.

Embankment shell material was available in the area north and west of the dam on the ridge west of the right abutment. This material was readily excavated with the aid of ripping and made excellent shell material. The rock broke up quite readily into rock sizes generally less than 12 inches. Where hard larger sizes were encountered they were, in accordance with the construction specifications, raked into the riprap zone.

Foundation Conditions

Below the topsoil, alluvium and completely- and highly-weathered rock at the dam site lies rock that is moderately and slightly weathered. It was obvious that with proper foundation preparation, involving the removal of the soils and completely and highly weathered rock, an earth dam could be constructed safely on the underlying moderately and slightly weathered rock. Likewise the outlet works and spillway could be founded safely in this material.

DAM DESIGN

Having determined that satisfactory foundation conditions existed and knowing the types of materials available for construction of a dam the embankment section shown in Fig. 1 was designed. The dam has a massive central impervious core (Zone 2) flanked upstream and downstream by relatively pervious random granular shells (Zone 1). A chimney drain of graded filter material covers the entire downstream face of the impervious core and is drained by a 6-inch diameter perforated asbestos concrete pipe at the bottom of the chimney (Zone 3). The perforated pipe is connected to two separate unperforated collector pipes that discharge into a concrete lined sump at the toe of the dam. The purpose of the chimney drain is to drain any water that seeps through the impervious core and collect it into the sump. Any water accumulated in the sump is pumped back into the reservoir.

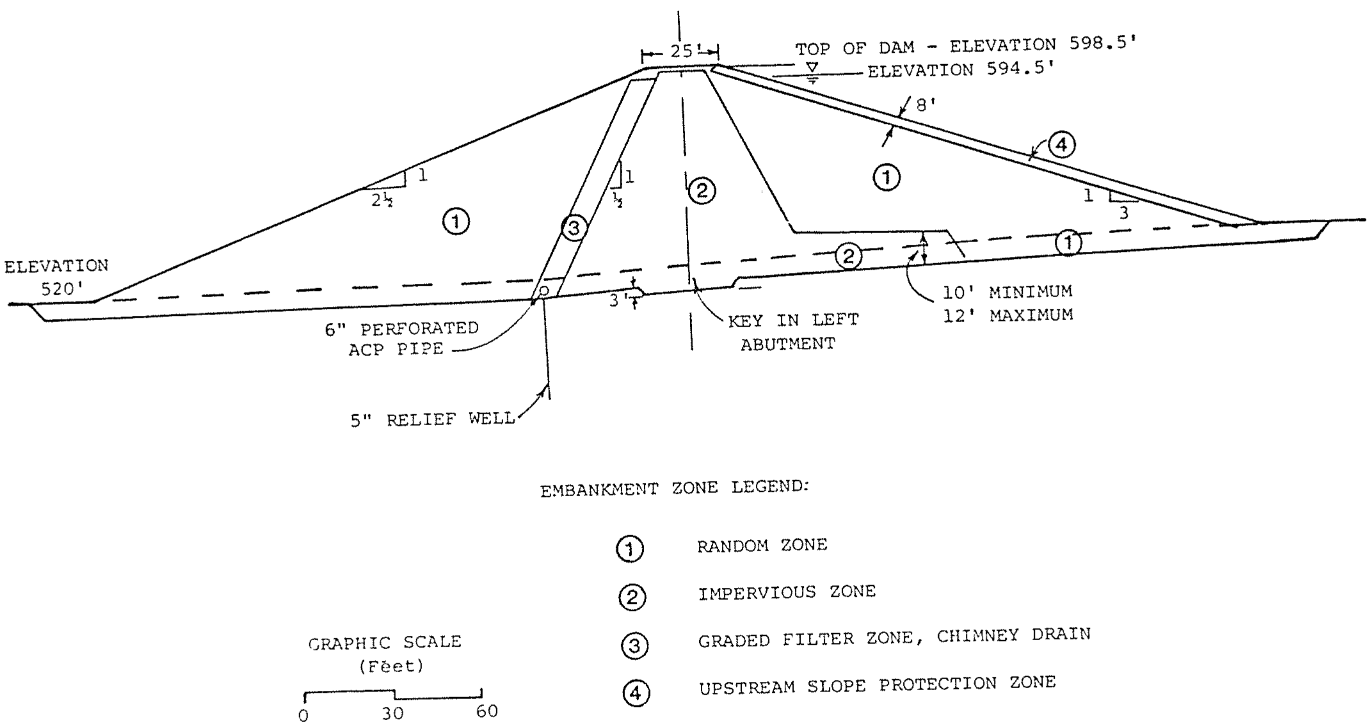

Figure 1
TYPICAL DAM SECTION

Protecting the upstream face of the dam against wave action is riprap (Zone 4). All hard rock for riprap at this dam was obtained on site by raking out the harder rock in borrow areas and depositing it in Zone 4.

Because it was expected there would be some seepage through fractures in the slightly- and moderately-weathered zones of the bed rock under the damm pressure relief wells were installed to a depth of 35 feet at the base of the chimney drain for most of the length of the dam. The purpose of such pressure relief wells is to intercept zones of any seepage under pressure and to relieve such water pressures before they create potential seepage problems at the toe of the dam. The seepage relief wells are 5-inch diameter holes 6 feet on centers filled with clean concrete sand. They discharge water under excess pressure into the chimney drain.

SPILLWAY

Though the watershed above the dam is small (26 acres) it was necessary to provide an emergency spillway. In this case the design of the spillway was based on the assumption the reservoir was full with 4 feet of free board when the heaviest probable rainfall occurred in the basin. Precipitation data from four stations in the region: Escondido Park Hill, Encinitas, Oceanside Pump Plant and Fallbrook were taken and extrapolated to determine the probable maximum flood. Our interpretation of the data indicated that a 5-min. probable maximum precipitation could amount to 1.17 inches of rainfall, corresponding to an equivalent rainfall intensity of 14 in/hr. This would result in a probable maximum flood equal to 310 cfs. This was a conservative approach to design of a spillway at this project.

The spillway is essentially a broad-crested weir 35 feet long with sloping sidewalls. It is concrete lined to prevent erosion of the underlying weathered rock.

OUTLET WORKS

Because of its use as an interim storage facility, design of the outlet works provided for efficient use as a storage reservoir as well as safety considerations for protection of the dam. The latter requires that the outlet works be capable of emptying at least one-half of the reservoir contents in 7 days, therefore an outlet pipe through the base at the dam is necessary.

In this case the outlet works is designed so a single outlet conduit serves as an inlet-outlet pipe and an outlet conduit for emptying the reservoir. At the upstream end an intake structure with trash rocks is provided to allow free inflow of water into the conduit. A hydraulically operated Armco slide gate was installed at the upstream end of the outlet conduit to permit closing the pipe at the upstream end. The outlet conduit is an 18-inch diameter asbestos concrete pipe encased in reinforced concrete embedded in an excavated trench in rock. Several cutoff collars were provided. Before encasing the pipe in concrete it was fully water pressure tested under a head substantially greater than full reservoir head.

At the downstream end the conduit connects to a T-section whereby a 12-inch diameter stub out with plug valve provides for connection to the pipeline from the sewage treatment plant and to the irrigation systems. At the downstream end of the 18-inch pipe is an 18-inch butterfly valve that allows for emptying the reservoir. The valves are housed in an outlet structure and control building. A pump for emptying the sump of seepage water is housed in this building along with the hydraulic pump for opening and closing the slide gate at the upstream end of the outlet pipe.

CONCLUSION

The La Costa Reservoir and Dam is a good example of adapting a dam to the geologic conditions of a site. Comprehensive and judicious investigations showed that the highly-weathered rock close to the surface would break down into fine grained impervious material suitable for an impervious core while the deeper highly-fractured material was suitable for relatively pervious random shells and the larger hard rock made excellent riprap material. Likewise the deeper less weathered material made an excellent foundation for the dam and the appurtenant structures.

ACKNOWLEDGMENTS

A substantial dam design project such as this one involves the efforts of a number of professionals. This project required the services of geologists, geotechnical engineers and civil engineers with skills in hydrology and hydraulic and structural engineering. Geologists involved in this project included Daryl Streiff, Charles G. Bemis, and Dorian Elder. Geotechnical and civil engineers involved in the planning and design studies included James E. Cavallin, Walter Crampton, Dr. Iraj Noorany, Carol Forrest and Buck Buchanan. Resident Engineer during construction was John Moossazadeh. The writer was Principal in Charge.

GEOLOGY OF THE MISSION GORGE PLUTONS
SAN DIEGO, CALIFORNIA

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ABSTRACT

The northwest-trending Mission Gorge plutonic complex is located in the northeast quarter of the La Mesa Quadrangle, San Diego, California. The complex is exposed over a combined area of approximately eight square kilometers and includes topographically prominent Cowles Mountain, Mission Gorge, and Fortuna Mountain.

Through field observations and petrographic analyses, three major intrusive rock types are recognized: granodiorite, quartz monzodiorite and adamellite intruded in that order, followed by aplite dikes. The adamellite has been interpreted as a tabular pluton. Zones of dark gabbroic inclusions possibly of synplutonic origin are found in the quartz monzodiorite and the adamellite.

These plutons were emplaced in the mid-Cretaceous by means of magmatic stoping at a depth of less than six kilometers. The adamellite has been potassium-argon dated at 101.8± 1.0 million years.

LOCATION AND REGIONAL SETTING

The purpose of this study was to add detail to the undifferentiated plutonic rocks mapped on the La Mesa 7.5 minute quadrangle by Kennedy (1975). These plutons are part of the Peninsular Ranges Batholith. They cover approximately eight square kilometers which includes Cowles Mountain, Mission Gorge, and Fortuna Mountain in the northeastern section of the City of San Diego. Two major roads traverse the area: Mission Gorge Road, with good roadcut exposures, and Fr. Junipero Serra Trail which follows the San Diego River through Mission Gorge.

The area is rugged, especially in Mission Gorge. The highest elevation is the summit of Cowles Mountain at 1,591 feet, and the total relief is about 1400 feet. Access on foot is good except for the northern areas which are densely overgrown with chaparral. Outcrops exist in most places, although the bedrock geology is obscured by dense vegetation and colluvium at lower elevations resulting in many approximately located contacts.

SURROUNDING ROCKS

The area of plutonic rocks is surrounded by both post-batholithic sedimentary and pre-batholithic volcaniclastic rocks. The sedimentary rocks, which bound 75% of the area, are in nonconformable contact with the plutons. They include the Eocene Friars, Mission Valley, and Stadium Formations.

The volcaniclastic rocks are the Late Jurassic Santiago Peak Volcanics (Fife, et al., 1967; Kennedy, 1975) which have been intruded by the younger plutons. The rocks are mildly metamorphosed and contain tuff breccia, highly silicified tuff, and dark hornfels of undetermined protolith. The Santiago Peak rocks were not differentiated during this study. These rocks were studied in the quarry just south of Mission Gorge by Russey (1979).

PLUTONIC ROCKS

Thin section analysis has determined the presence of three major intrusive rock types (Figure 1). These include a hornblende adamellite, biotite-hornblende quartz monzodiorite, and a hornblende-pyroxene granodiorite (Germinario, 1980). A minor phase of aplite dikes and zones of dark gabbroic inclusions were also present.

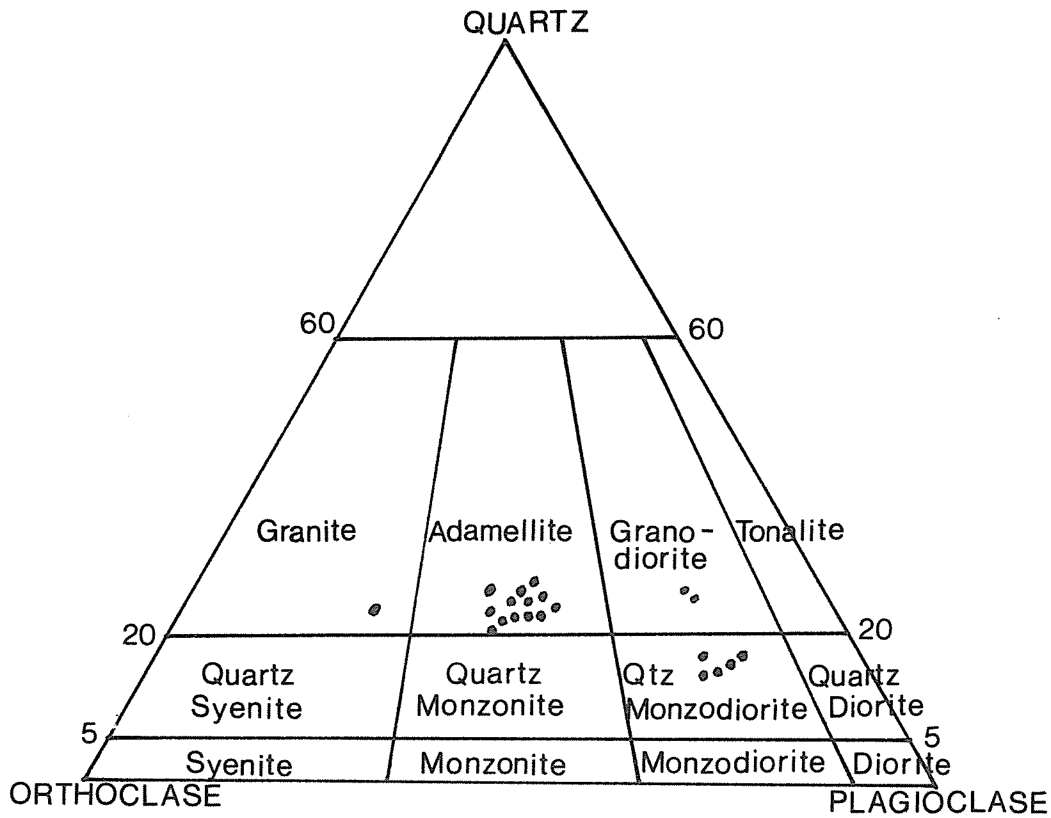


Figure 1: Plot of the thin-sectioned samples on the Plag-Or-Qtz diagram for plutonic rocks (Hyndman, 1972).

HORNBLENDE ADAMELLITE

Distribution, Outcrop, Weathering

This pluton comprises approximately 60% of the area (Figure 2). It forms all the topographic highs and is the most resistant rock type in the region. Outcrops are blocky, subangular, highly jointed boulders in the higher areas, forming cliffs and very steep slopes on the eastern side of Mission Gorge and Fortuna Mountain. The lower areas have subrounded boulders exhibiting spheroidal weathering. The weathered surface is medium tan to light reddish gray; the fresh surface is light to medium gray. The pluton has some miarolitic cavities and dark gabbroic inclusions that compose up to 50% of the rock. They are 2 to 65 cm in diameter and are found in zones and scattered randomly throughout the pluton.

Petrography

In thin section the average mineral composition is:

plagioclase	35%
orthoclase	36%
quartz	22%
hypersthene	1%
hornblende	5%
biotite	>1%
magnetite	1%
apatite	rare

This rock is medium-grained, hypidiomorphic, and contains granophyric textures and myrmekite. The plagioclase exhibits normal zoning and resorption patches. The An content determined by the Michel-Levy method (Kerr, 1977) ranges from An_{65} to An_{30} with an average of An_{42} (andesine). Corona textures of hornblende and biotite are also observed. There is no preferred orientation of any minerals.

BIOTITE-HORNBLENDE QUARTZ MONZODIORITE

Distribution, Outcrop, Weathering

This pluton comprises approximately 30% of the region (Figure 2) and is restricted to the low-lying areas. Its outcrops consist of subrounded boulders of various sizes. The weathered surface is brownish gray to dark gray. A fresh surface is medium to fine-grained and medium to dark gray. As in the adamellite, there are dark inclusions present with a similar type of distribution.

Petrography

In thin section the average mineral composition is:

plagioclase	50%
orthoclase	19%
quartz	12%
pyroxene	1%
hornblende	11%

biotite	6%
magnetite	1%
apatite	rare
sphene	rare

This rock is medium to fine-grained (microporphyritic) and hypidiomorphic. The plagioclase is normally zoned, with minor resorption patches. The An content ranges from An_{45} to An_{28}, with an average of An_{34} (andesine). The mafic minerals have corona textures. No preferred orientation of the minerals was observed.

HORNBLENDE-PYROXENE GRANODIORITE

Distribution, Outcrop, Weathering

This pluton is exposed over about 10% of the region (Figure 2) and is found in topographically low-lying areas. Its outcrop expression exhibits low relief and consists of small angular boulders with weathered surfaces which are a dark reddish brown in color. Fresh exposures of this rock are very dark gray.

Petrography

In thin section the average mineral composition is:

plagioclase	45%
orthoclase	11%
quartz	22%
hypersthene	14%
hornblende	6%
biotite	1%
magnetite	1%

This rock is medium-grained and hypidiomorphic-granular. The plagioclase is normally zoned with minor resorption patches. The An content ranges from An_{50} to An_{32} with an average of An_{42} (andesine). Some minor granophyric textures are present. There are some coronas of hornblende. No preferred orientation of minerals was observed.

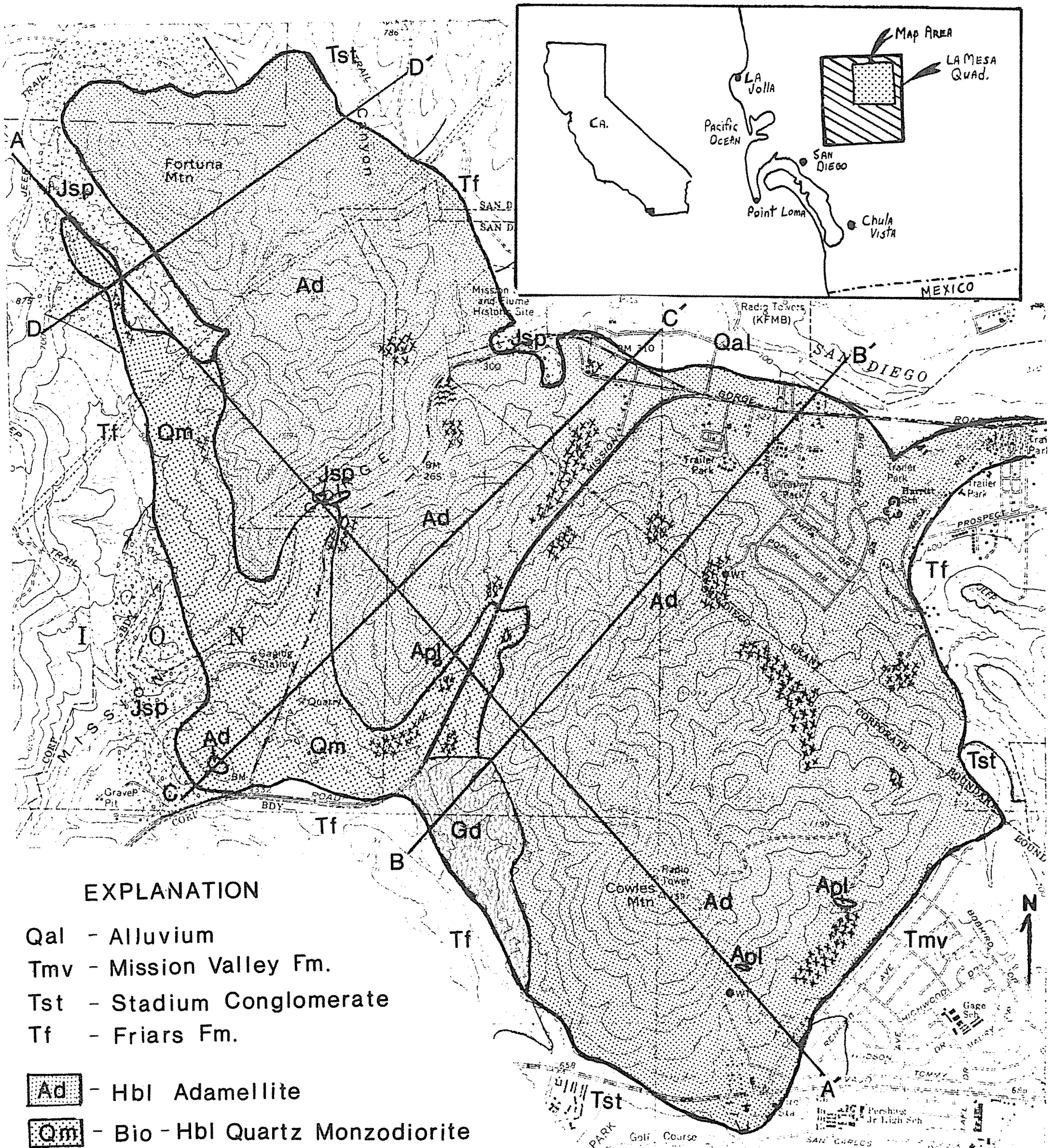
APLITE DIKES

The aplite dikes are a minor component found in all the plutons. They are found in greater abundance and larger outcrop in the adamellite where they range in width from one cm to approximately 35 m in the largest outcrop. They are a light tan on both fresh and weathered surfaces. The outcrop tends to be highly jointed, forming small angular blocks.

Petrography

The thin section sample has a mineral composition of:

plagioclase	16%
orthoclase	57%
quartz	23%
biotite	2%
magnetite	1%
muscovite	rare



EXPLANATION

Qal - Alluvium
Tmv - Mission Valley Fm.
Tst - Stadium Conglomerate
Tf - Friars Fm.

Ad - Hbl Adamellite
Qm - Bio - Hbl Quartz Monzodiorite
Gd - Hbl - Pyx Granodiorite
Jsp - Santiago Peak Volcanics
- Zone of dark gabbroic inclusions
- Fault zone
Apl - Aplite dike

SCALE

1 ½ 0 1 MILE
1 .5 0 1 KILOMETRE
CONTOUR INTERVAL 20 FEET

Fig. 2

This rock type is fine-grained, allotriomorphic-granular. Some of the orthoclase occurs as microcline. The average An content is An_{18} (oligoclase). Some granophyric textures were observed.

DARK INCLUSIONS

The adamellite and quartz monzodiorite plutons contain dark inclusions scattered randomly and also in wide zones where they compose 10 to 50% of the rock. These inclusions are subrounded to subangular and range from less than two cm to 65 cm in diameter. They show no preferred orientation or elongation. In different areas they show varying degrees of assimilation by the surrounding magma, and thus vary from medium to dark gray.

In thin section, the mineral composition is:

plagioclase	52%
orthoclase	7%
quartz	3%
hornblende	34%
biotite	2%
magnetite	1%
apatite	rare
sphene	rare

The sample is a fine-grained, hypidiomorphic-granular rock. The plagioclase is weakly normally zoned and has an average composition of An_{50} (andesine). The hornblende is observed as small prismatic crystals with some reaction rims forming biotite. The orthoclase and quartz are interstitial. These inclusions have a gabbroic composition similar to the inclusions in the Bonsall Tonalite of the Peninsular Ranges Batholith (Hurlbut, 1935).

In the areas immediately around the intrusive contact with the Santiago Peak Volcanics, the rocks have dark hornfelsic inclusions. These have been derived from the volcanic country rock and are not related to the dark gabbroic inclusions. These hornfelsic inclusions can be distinguished from the gabbroic inclusions where they are in close proximity.

ORIGIN OF THE DARK INCLUSIONS

There are several possible explanations for the presence of the gabbroic inclusions. It is possible that several small gabbro bodies or dikes associated with the batholith's older gabbro plutons were partially assimilated during the emplacement of these plutons. The composition of these inclusions and those of the Bonsall Tonalite are similar to the composition of the older gabbro plutons of the batholith (Hurlbut, 1935).

Another possibility is the occurrence of synplutonic gabbro dikes. These dikes would have intruded as the pluton was crystallizing and would then have been partially assimilated by the remaining melt. The lack of orientation, elongation of the inclusions, or flow structures tends to favor the synplutonic dikes. Inclusions related to synplutonic mafic dikes are found in several areas of the Batholith (Todd, V.R. and Shaw, S.E., 1979).

SEQUENCE OF INTRUSION AND AGE

Through the observation of the field relationships of these three rock types, it has been determined that there was three separate intrusions. The granodiorite was the first magma to be emplaced. It is found intruded by both the quartz monzodiorite and the adamellite in the northwest section of its exposure. The second magma was the quartz monzodiorite as it is found to be intruded by the adamellite in a well-exposed outcrop in a cut on the north side of Mission Gorge Road. Last pluton to be emplaced was the adamellite which was followed by late phase aplite dikes. The emplacement of the synplutonic gabbroic dikes occurred as a late stage in each of the respective plutons.

For the most part the older plutons were already crystallized when the next intrusion was emplaced. This is indicated by the sharp contacts and the presence of dikelets of the intruding rock (Larsen, 1951).

The age of emplacement of the adamellite pluton was determined to be 101.8± 1 million years using the potassium-argon dating method on hornblendes (Krummenacher et al., 1975). This is equivalent to middle Cretaceous time.

MODE AND DEPTH OF EMPLACEMENT

There are three basic methods of emplacement of a pluton; magmatic stoping, forceful injection, and metasomatic replacement (Billings, 1972). In these plutons, evidence of magmatic stoping is observed. In the areas of intrusive contact with the country rock, there are many stoped and partially assimilated inclusions. There is no evidence of forceful injection found. No flow structures, preferred orientation of minerals or elongation of inclusions are found anywhere in the plutons.

Coupled with the mode of emplacement, the depth of emplacement is divided into three zones, progressing in depth from epizone, to mesozone, to catazone (Buddington, 1959). These plutons suggest an emplacement in the epizone, crystallizing at a depth of less than 6 kilometers. This is based on the evidence of magmatic stoping, lack of foliation or lineation in the rocks, the miarolitic cavities, the low grade metamorphism of the country rock, and the granophyric textures (Hyndman, 1972). This follows closely with the previous work in which the western edge of the Peninsular Ranges Batholith was found to be composed of epizonal, shallow crustal intrusions (Gastil, 1975; Buddington, 1959).

GEOLOGIC STRUCTURE

These plutons do not exhibit any major structural features. A minor joint set of N55°W was found across the entire area but no major joint systems or petrofabrics were observed. There is a fault zone, approximately 60 m in width and striking N70°E, in the adamellite located in the roadcut on the northeast side of Mission Gorge. Fault gouge, clay seams and some slickensides are present.

Suggested interpretations of the internal structures of these plutons are exhibited in the geologic cross sections (Figure 3). The adamellite is a tabular intrusion that was emplaced over the quartz monzodiorite and granodiorite. This interpretation is based on several factors. The adamellite forms pronounced cliffs only in areas of contact with the other plutons. The character of this contact in the way it follows the topography, especially

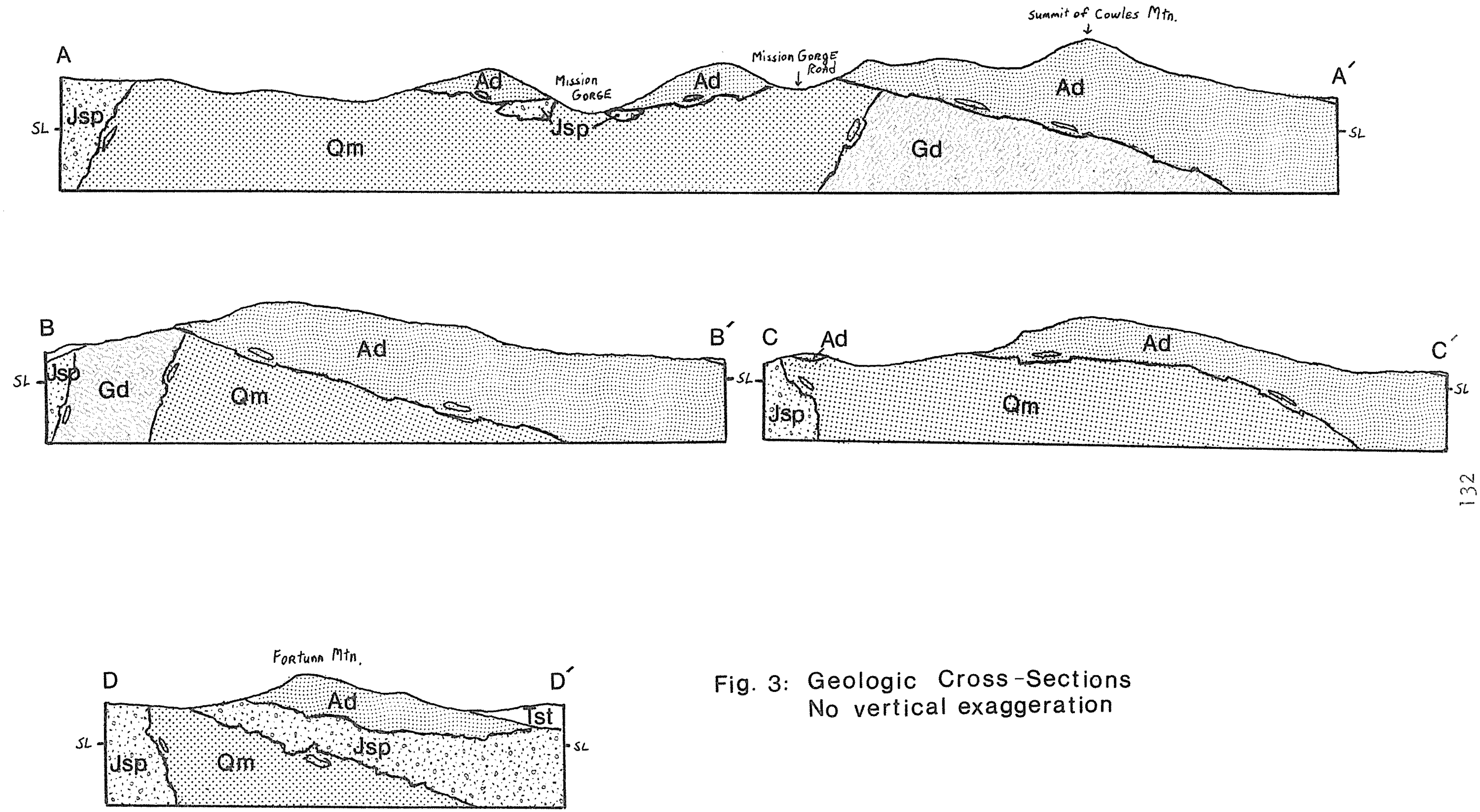


Fig. 3: Geologic Cross-Sections
No vertical exaggeration

through the Mission Gorge area, seems to indicate an almost horizontal base to the pluton (Figure 3, A-A, C-C). In the Fortuna Mountain area (Figure 3, D-D), the adamellite is separated from the quartz monzodiorite by a screen of Santiago Peak Volcanics. The western side of Cowles Mountain may represent the source area of the adamellite magma.

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SHELF SEDIMENT VOLUMES,
SAN DIEGO COUNTY, CALIFORNIA

by

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INTRODUCTION

California's shoreline is a major resource. However, the erosion of southern California beaches and sea-cliffs is rapidly reaching a critical stage. The loss of sand beaches is imminent (Inman, 1976) or has already taken place (e.g., Oceanside). Sea-cliff erosion in San Diego County was recently described by Kuhn and Shepard (1979), and the need for adequate coastal planning is only now becoming fully apparent. A potential resource of the continental shelf may provide at least a temporary solution to these problems.

Although marine aggregate or offshore sand and gravel deposits are intensively exploited in several European countries and in Japan, their utilization in the United States is insignificant. Southern California's shelf sands have been used for beach replenishment projects, but not as a source of construction aggregate.

This study was initiated to survey the potential sand and gravel resource of the southern California shelf from Point Conception to the international border with Mexico (Fig. 1). Although the study was designed to emphasize the beach replenishment aspects of these deposits, fluvial channel-fill deposits and other potential aggregate borrow sites were also identified. Sediment volumes were calculated for both the inner shelf (0 to 30 m) and the total shelf area to the 100 m+ isobath. A conservative estimate of the total volume of the recent (Holocene) silt, sand and gravel deposits of the San Diego County shelf is 3 km^3. Nearly one-third of this total volume lies within the 30 m depth contour, which is the present economic limit for dredging operations. However, based upon the studies of Osborne and others (1980 a and b and in progress, 1981) much of this sediment may be too fine-grained for beach replenishment use.

At present it is not possible to estimate the total volume of the older or Pleistocene age sediments, which locally underlie the Holocene veneer. These deposits are largely confined to ancient stream channel and terrace deposits. According to Spindt and Meade (1976) and Mokhtari-Saghafi and Osborne (1980) offshore sand and gravel deposits are not an economically viable source of aggregate today. But these deposits are important sources of beach replenishment material and may be important aggregate sources in the future.

DATA AND METHODS

INTRODUCTION

Seismic reflection profiles provided the major portion of the data used in this study. Geophysical surveys by our group (Marine Studies, CSUN)

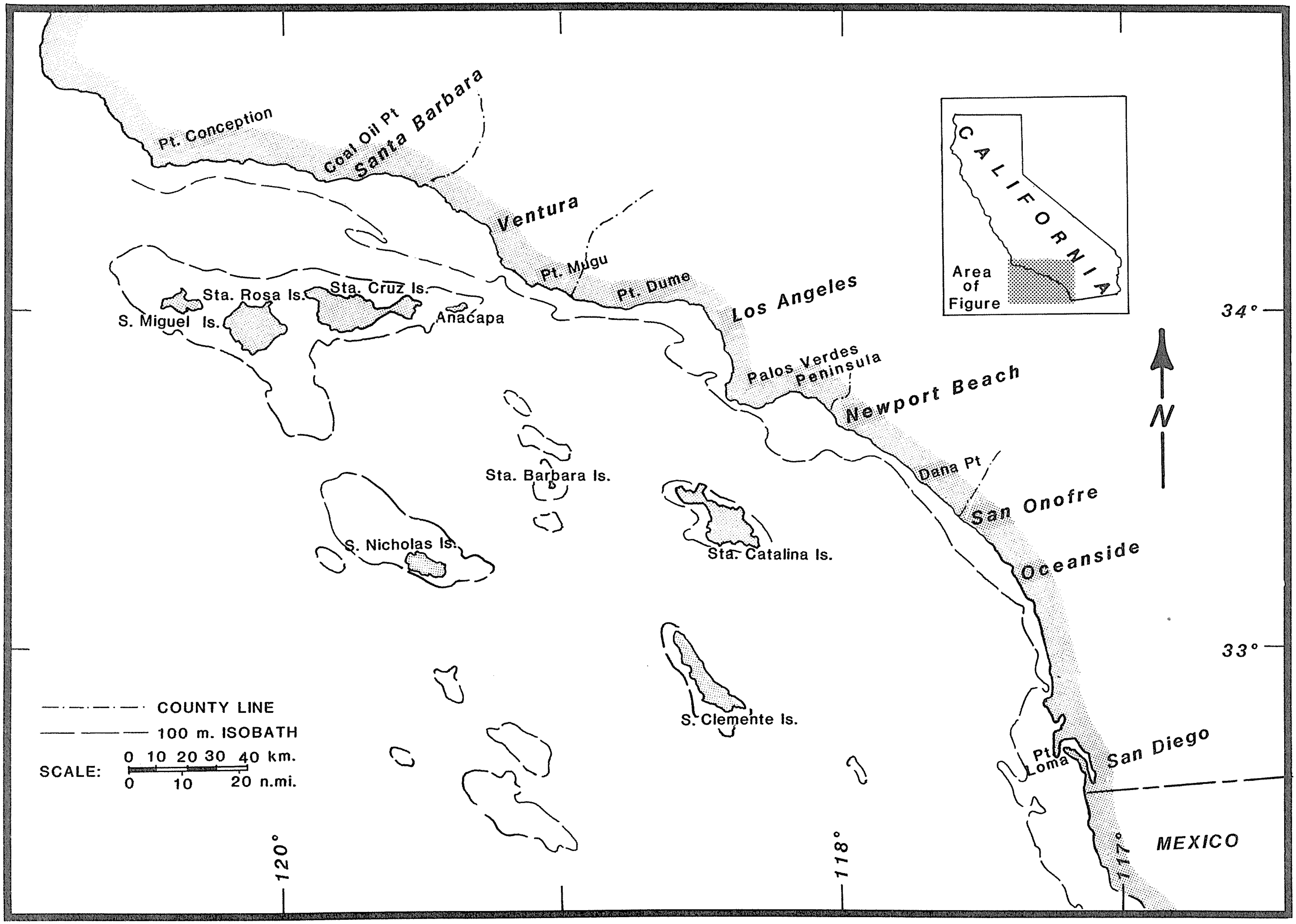

Figure 1. Index map, location of the study area.

and numerous other surveys by governmental agencies and industry provided the seismic reflection profiling data base, which includes: high resolution (3.5 kHz and 3.0 kHz-SONIA), UNIBOOM, air-gun, sparker and side-scan SONAR profiles. Table I lists the major sources of the data base by the types of seismic reflection data and total trackline coverage in kilometers (and miles).

The profiles were supplemented with Vibracore information from Coastal Engineering Research Center and Osborne and others (1980, and in progress).

MARINE STUDIES, CALIFORNIA STATE UNIVERSITY, NORTHRIDGE (MS-CSUN)/SAN DIEGO STATE UNIVERSITY (SDSU) SURVEYS

In the Orange-San Diego County areas of this study a major data set was collected by a combined Marine Studies CSUN and San Diego State University (SDSU) group. The data collected by Marine Studies (CSUN) and SDSU for this investigation consist of over 1400 km of 3.5 kHz high resolution seismic reflection profiles. A modified EDO Western Corp. model 515 profiling system with the 3.5 kHz transducer mounted in a ENVICOM "fish" was used for the 1976 to 1979 surveys. The resolution of the system is normally at least 0.5 m with a maximum depth of penetration in sediment of 50 m. Seismic surveys were conducted between 1972 and 1979, aboard the Southern California Ocean Studies Consortium's R/V Nautilus, the R/V Velero of University of Southern California, and the M/V Gianna of University of California, San Diego, Scripps Institution of Oceanography.

The pre-1976 Marine Studies surveys utilized a sled-mounted transducer which was towed an average speed of 6 knots. Shallow tow depths and instability inherent in this early system resulted in a reduction in data quality.

Surveys conducted between 1972 and 1976 were positioned by combining triangulation from two or three shore-based alidade stations, RADAR ranges and bearings and dead reckoning. This technique was compared with mini-radar positioning during surveys off San Diego County. An accuracy of ± 30 meters was recorded when visual contact was maintained with the shore or platform stations.

Subsequent cruises aboard the R/V Nautilus employed a precision rangefinding RADAR. An accuracy of ± 100 m was determined when this system was compared to locations determined by a Del Norte precision electronic navigation system (± 3 m). All final locations of MS-CSUN/SDSU seismic profiles were adjusted to bathymetry and structural features mapped and located by precision navigation.

SEISMIC REFLECTION DATA REDUCTION AND INTERPRETATION

Interpretation procedures for seismic reflection profiles are reviewed by several authors (Moore, 1969; Vedder and others, 1974; Greene and others, 1975; Sieck and Self, 1977; and Fischer, 1977). Seismic reflection profiles display density interfaces, which reflect the acoustic signal transmitted by the system. These interfaces represent a change in the acoustic impedance of the materials, which is a function of the density and bulk elasticity. Typical reflectors include: the seafloor, unconformities, bedding planes, faults, gas zones, and gas bubbles in the water

TABLE I

SUMMARY OF SEISMIC DATA

SOURCE	CRUISE (Vessel - Date)	SYSTEM	GRID (km)	SWEEP (sec)	PENETRATION (meters)	RESOLUTION (meters)	POWER (kj/kw)	FREQUENCY (kHz)	NAVIGATION (type-accuracy)
U.S.G.S.	R/V Polaris 1970	Uniboom	5-12	0.25	150	1.0	1 kj	1.3-.75	Shoran 10-100m
		Sparker	5-12	3.0	850	5.0	33 kj	0.31-1.6	Shoran 10-100m
	R/V Kelez 1973	Uniboom	1-5	0.25	100	0.75	5-6 kj	0.65-2.0	Raydist 30-100m
		Sparker	1-5	4.0	1400	20.0	90-120 kj	0.25-0.98	Raydist 30-100m
CSUN/ SDSU	M/Y Gianna 1975	Tuned transducer	1X2	0.25	40	0.5	2-10 kw	3.5	Precision Radar, 10-300m Alidade-Plane Table 10-100m
	- - - - - 1978	Tuned transducer	1	0.25	20	0.5	2-10 kw		
Nekton (South Coast)	R/V Seamark 1977	Uniboom	3.3	0.25-0.5	130	0.5-2.0	.65-.975 kj	-------	Mini-ranger ± 3m
		Archer	3.3	1.0	450	4.0	3-24 kj	-------	
Woodward-Clyde (CERC**)	- - - - - - 1979	Uniboom	1X1	0.25-0.5	75	0.5	.2-1.0 kj	-------.	NSI Mini-ranger ± 3m
Western Geophysical (SCE***)	- - - - - - 1971-1972	Aquapulse (single channel)	10	5.0	1100	5.0	120 kj	2.5	? ? ?
		CDP (1200% stack)	10	5.0	6000	20.0	120 kj	2.5	? ? ?

* San Diego State University - California State University, Northridge
** U.S. Army Corps of Engineers - Coastal Engineering Research Center
*** Southern California Edison

column. High frequency sources (e.g., 12 kHz) reflect only the seafloor. Lower frequency systems penetrate the seafloor and receive reflective energy from deeper interfaces. High resolution seismic profiles normally record reflections from the seafloor, one or more deeper reflectors, including the base of the sediment veneer or the bedrock surface and multiples of the seafloor (fig. 2).

Seismic reflectors may be displayed on graphical analog records as used in this study, or recorded digitally, processed and finally converted to a paper copy. Vertical scale of the record is 2-way travel time in milliseconds. Distance along the track line is displayed horizontally with the scale dependent on the speed of the ship and the recorder paper feed-rate. Typical records are vertically exaggerated 5 to 15 times.

To determine the thickness of sediment or bedrock units, the seismic velocity in the medium and the travel time to the interface must be known. Travel time is measured directly from the seismic profiles (fig. 2). Seismic velocities can be determined by laboratory tests, sonic logging techniques, refraction surveys or by correlating a known horizon penetrated by a core hole with the reflection of that horizon on a seismic profile.

Seismic velocities, based on sonic measurements, grain size and other physical properties of the unconsolidated sediment, have been determined for the southern California shelf (Hamilton, 1971 and 1980). Surface sediments of the study area range from coarse silt to very fine sand (Wimberly, 1964; Welday, 1975). Hamilton (1971) calculated velocities of 1677 m/sec to 1711 m/sec for shelf sediments near Pigeon Point. A seismic velocity of 1700 m/sec was determined from core hole data for Holocene/latest Pleistocene sediments from the outer San Pedro shelf (Fischer and others, 1977). The seismic velocity of 1700/sec of Fischer and others (1977) was selected as a representative seismic velocity for the upper Quaternary sediment of the southern California shelf. Errors introduced by using this constant velocity are minimal (for example, a velocity of 1600/sec would reduce the thickness of a 10 m thick sand body by (-)½ m).

The vertical resolution or minimum bed-thickness resolved by seismic reflection systems is a function of the seismic velocity and the frequency of the system. Typical resolution of the systems used for this study is one meter or less.

AERIAL PHOTOGRAPHY

In addition to the seismic reflection and core sample data, a study of historical (1929-1955) and recent (1976-1978) vertical aerial photography of the southern California coastal zone was completed. The photographs were used over the inner shelf to map rock outcrops on the sea floor and kelp beds, which are anchored to the rock bottom by their holdfasts. Since bedrock outcrops serve as attachments for the holdfasts of kelp plants (Emery, 1960, p. 162-164), the seaward extent of the kelp usually identifies the limits of the exposed bedrock and consequently the zero sediment edge of the inner shelf. Kelp, when present, is found in 3 m to 20 m of water over the study area (Emery, 1960, p. 162 and Hamilton,

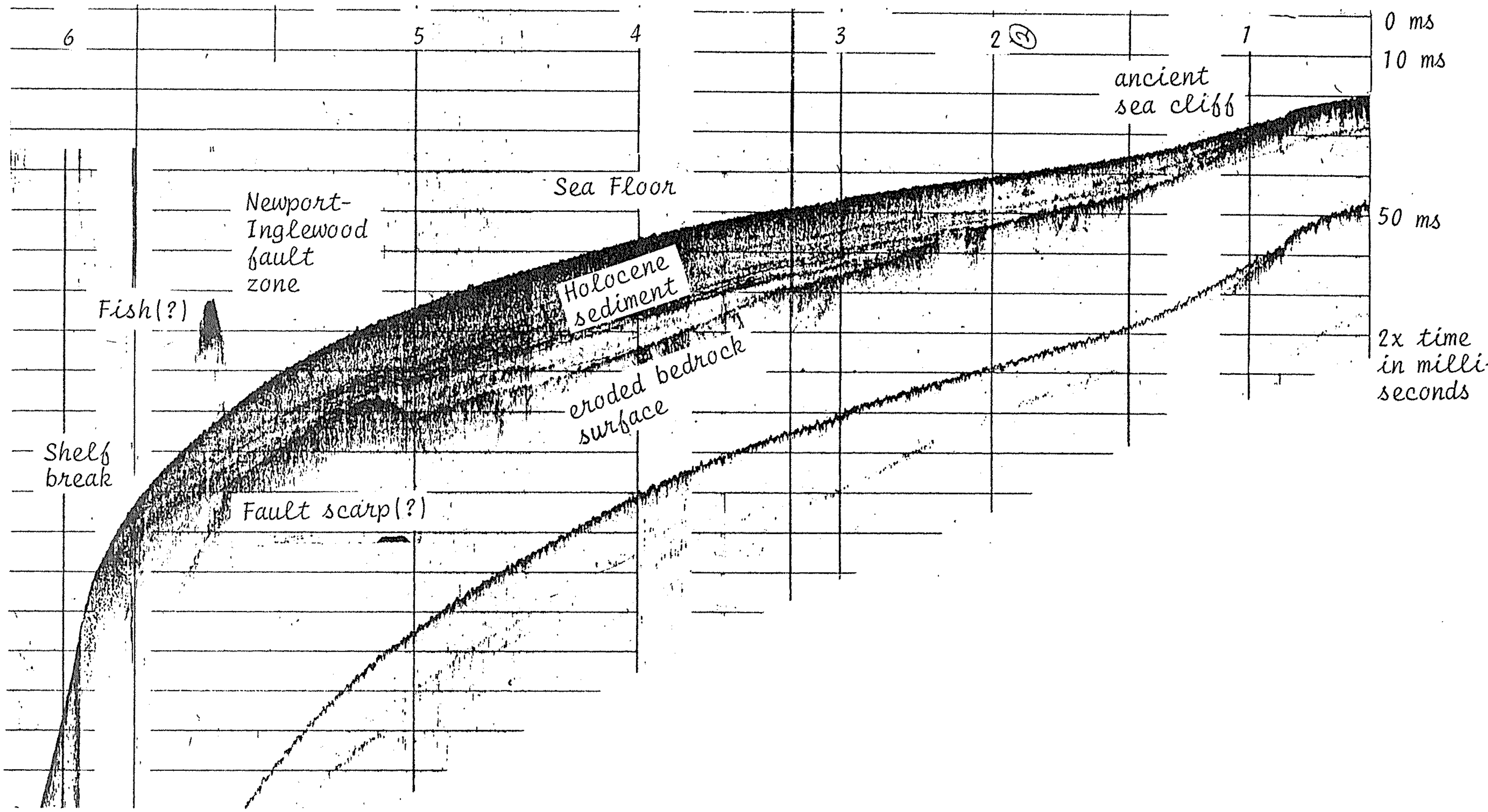

Figure 2. High resolution seismic reflection profile (3.5 kHz) CSUN-MS Line No. 4897.5 (1979). Location of profile is 2 k north of Dana Point, Orange County.

1980). The combined distribution of the kelp beds and rock outcrop areas was mapped using the maximum extent of the kelp as recorded by the 1950s and late 1970s photography. The seaward limit of kelp and rock areas as determined from aerial photography closely matches the "seismic zero" sediment edge of the inner shelf. In areas without seismic data coverage or inconclusive data the zero sediment edge was drawn near the seaward edge of the kelp or rock outcrop zone (fig. 3).

SHELF SEDIMENT DISTRIBUTION

INTRODUCTION

The San Diego shelf sediments generally form an elongated prism paralleling the coast and shelf break. The maximum thickness of the prism (10-30 m) usually occurs near mid-shelf. Bedrock outcrops occur along the inner shelf, at shelf break over topographic ridges, which are commonly associated with active faults and folds and off headlands (e.g., Dana Point and Point Loma).

In Orange and San Diego counties beach, sands generally extend seaward to the 3 m isobath, where exposed bedrock is documented by the kelp beds, rock outcrop patterns on the photography, and divers' observations (Hamilton, 1980, and Henry, 1977).

Areas of maximum sediment thickness coincide with the base of ancient buried sea cliffs, ancient stream channels or tectonically controlled depressions. Submarine terraces and sea-cliffs are best developed in northern San Diego County, but remnants of these features are mapped along the Silver Strand, which was the southern limit of the study area (fig. 4).

The grain size of surficial shelf sediments generally decreases seaward (Emery, 1960, Wimberly, 1964, Fischer and others, 1977). Local exceptions on the San Diego shelf are attributed to the presence of relict sediments (Emery, 1960). In vertical sequences the grain size of the deposits may vary from mud or even clay to gravel beds as is shown by the core hole samples and descriptions. However, the bulk of the Holocene shelf sediments are fine grained sands (based upon both core hole and seismic reflection data) and the typical vertical sequence "fines" upwards (Fischer and others, 1977).

Sediment volumes, when presented as bar graphs perpendicular to the coast, strikingly document the input of the river and stream systems, the loss of sediment to submarine canyons and near headlands, and the entrapment of sediment by estuaries or lagoons (fig. 5). These volumes may fluctuate over a short time span due to the variability of annual winter storms, and because of localized removal or erosion of the sediment in areas of energy concentration (e.g., headlands).

THE SOUTHERN MAINLAND SHELF

From Palos Verdes peninsula to the Mexican border the mainland shelf consists of three major segments: (fig. 5)

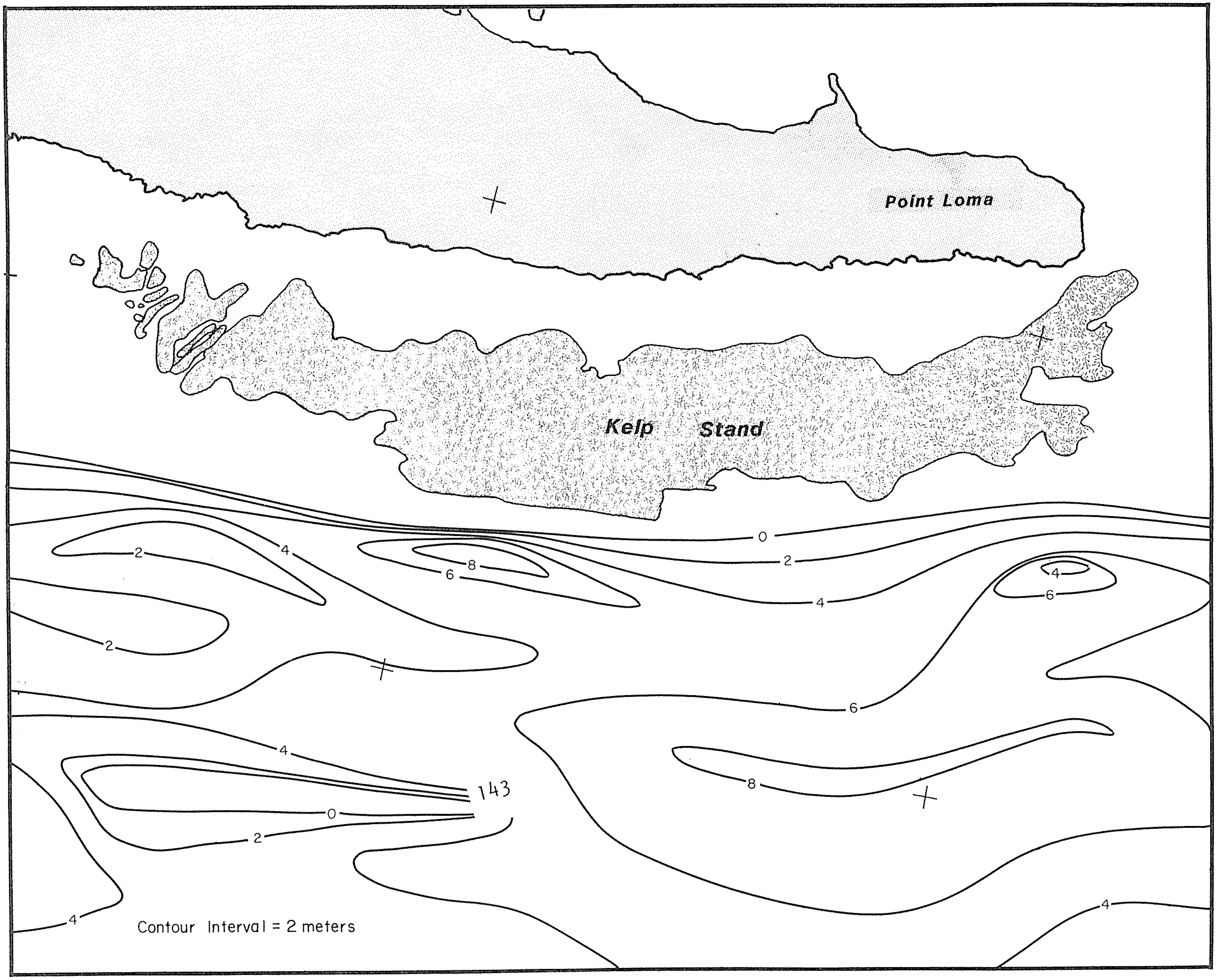

Figure 3. Kelp distribution and sediment thickness off Pt. Loma, San Diego County.

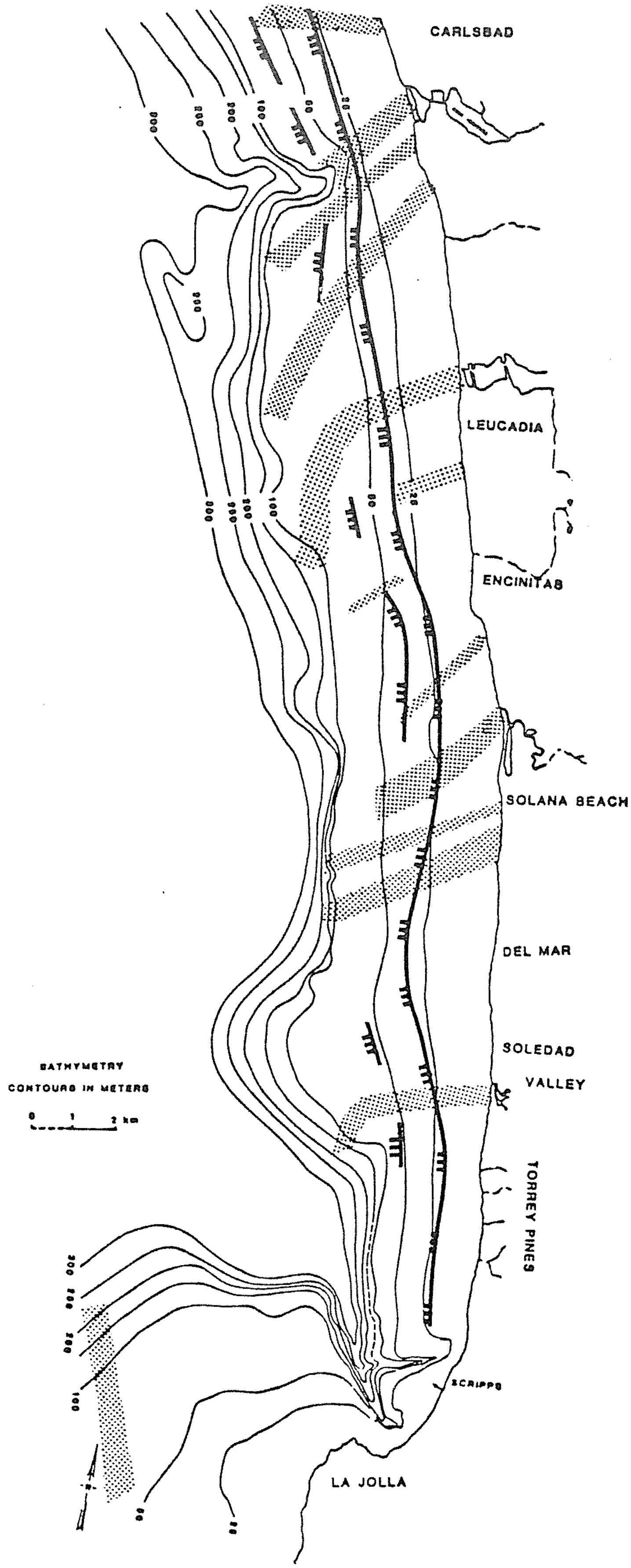

Figure 4. Ancient (late Pleistocene) stream channels and wave-cut terraces, central San Diego County (from Webb, in progress).

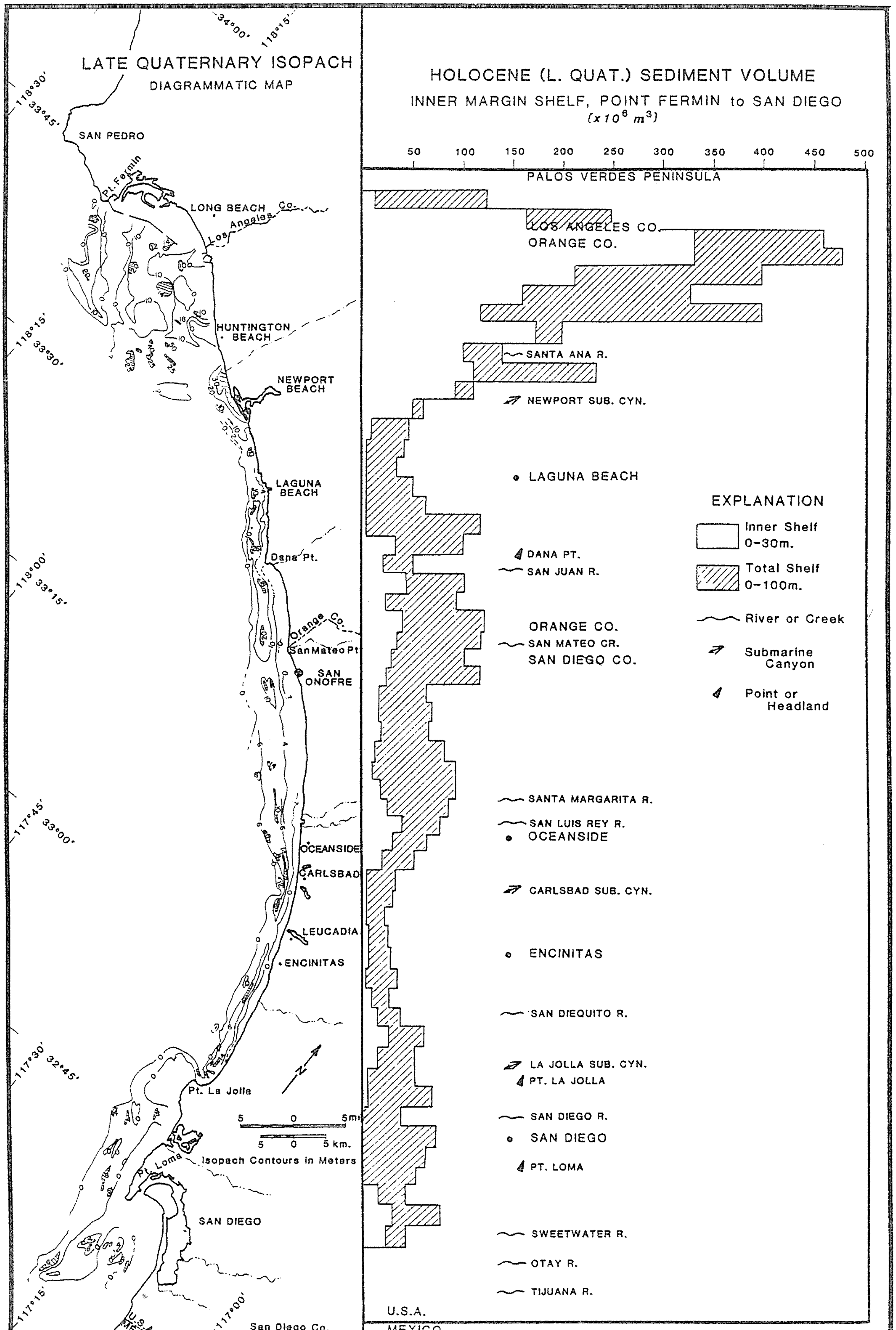

Figure 5. Shelf sediment volumes, Palos Verdes Peninsula, Los Angeles County, to the southern Silver Strand area, San Diego County.

1) the broad northern or San Pedro shelf,
2) the narrow central shelf from the Newport submarine canyon to the La Jolla submarine canyon (or Point Jolla), and
3) the broad southern or Point Loma-Silver Strand segment.

Of these three divisions, only the northern shelf of the San Pedro basin off southern Los Angeles county contains significant sediment volumes (fig. 5). Using the Quaternary stratigraphy established by Fischer and others (1977), and Rudat's (1980) isopach map of the Holocene sediment, we estimate a total sediment volume of 2,750 x 10^6 cu.m. for the San Pedro shelf. This exceeds the total volume (2600 x 10^6 cu.m.) of the remaining southern or Orange and San Diego counties shelf between Newport and Mexico. The major rivers that fed the San Pedro shelf (the Los Angeles, San Gabriel and Santa Ana Rivers) are unique to this portion of the southern California mainland shelf.

Between Newport and Point La Jolla the shelf is a narrow gentle concave arc. Holocene sediment volumes as shown by the bar graph (fig.5) increase gradually from Newport to the San Mateo Point-San Onofre area. From San Onofre to Oceanside volumes average 77 x 10^6 cu.m. per compartment and show an increase near the Santa Margarita River. But at Oceanside both total sediment volumes and especially inner shelf volumes begin to decrease sharply in response to the trapping of sediment by the estuaries between Carlsbad and Encinita. Near San Diequito Creek the volumes begin to increase slightly until the trapping effect of the La Jolla canyon occurs (fig. 5).

Off Point Loma the shelf becomes very broad (15 k) and the sediment veneer thins. On the inner shelf there is only patchy sediment. Within the reentrant south of Point Loma and west of North Island and the Silver Strand, shelf sediment volumes begin to increase, probably in response to the Tijuana River source (fig. 5).

DANA POINT TO CARLSBAD

The shelf off southern Orange County and northern San Diego County is nearly linear. It broadens from Dana Point (2.5 k) to a maximum width of 9 k south of San Onofre and narrows again near Carlsbad to 3 k. This shelf segment is an ancient (early Holocene) littoral compartment as defined by Emery (1960, fig. 28) and formally named by Inman and Frautschy (1966). As shown by the shelf sediment volumes on the bar graph, the maximum sediment volumes exceed 100 x 10^6 cu.m. north of San Onofre and a minimum volume of 25 x 10^6 cu.m. occurs south of Carlsbad near the small submarine canyon.

Along this shelf segment the Holocene sediment package forms a broad band with thicker accumulations localized against submarine sea-cliffs (figs. 6 and 7). Older Quaternary shelf deposits underly the Holocene unit and display steep seaward faces that are thought to be wave-cut cliffs (figs. 6 and 7). These deposits are tentatively correlated with late Pleistocene oxygen isotopic stages 3 to 5e.

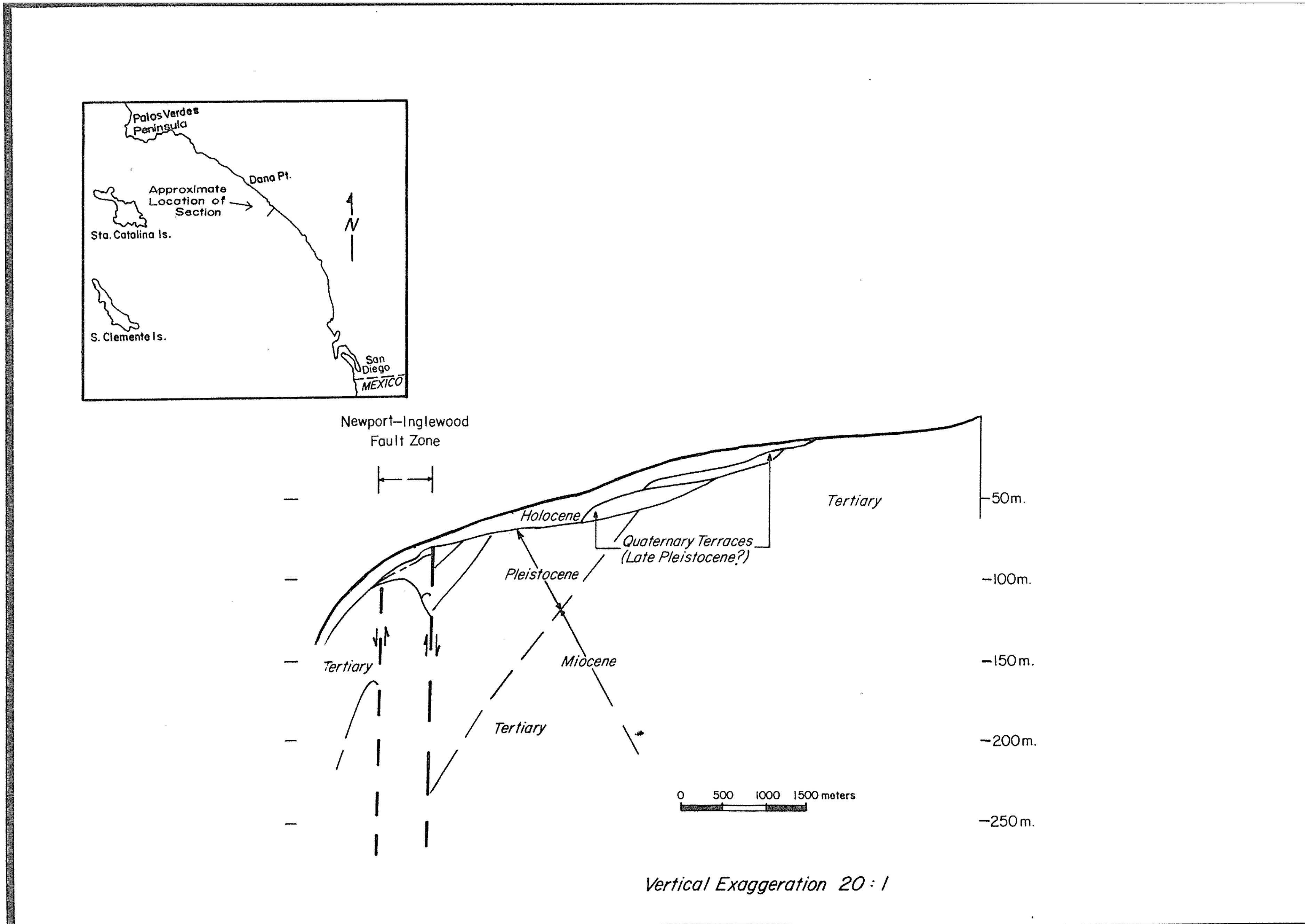

Figure 6. Geologic cross-section IV south of San Onofre, northern San Diego County. A thick wedge of Lower(?) Pleistocene sediment was cut and folded(?) by the Newport-Inglewood fault zone (N-1). Note slight thinning of Holocene sediment over inner N-1 splay. Two well developed Pleistocene terrace deposits are preserved beneath the Holocene veneer.

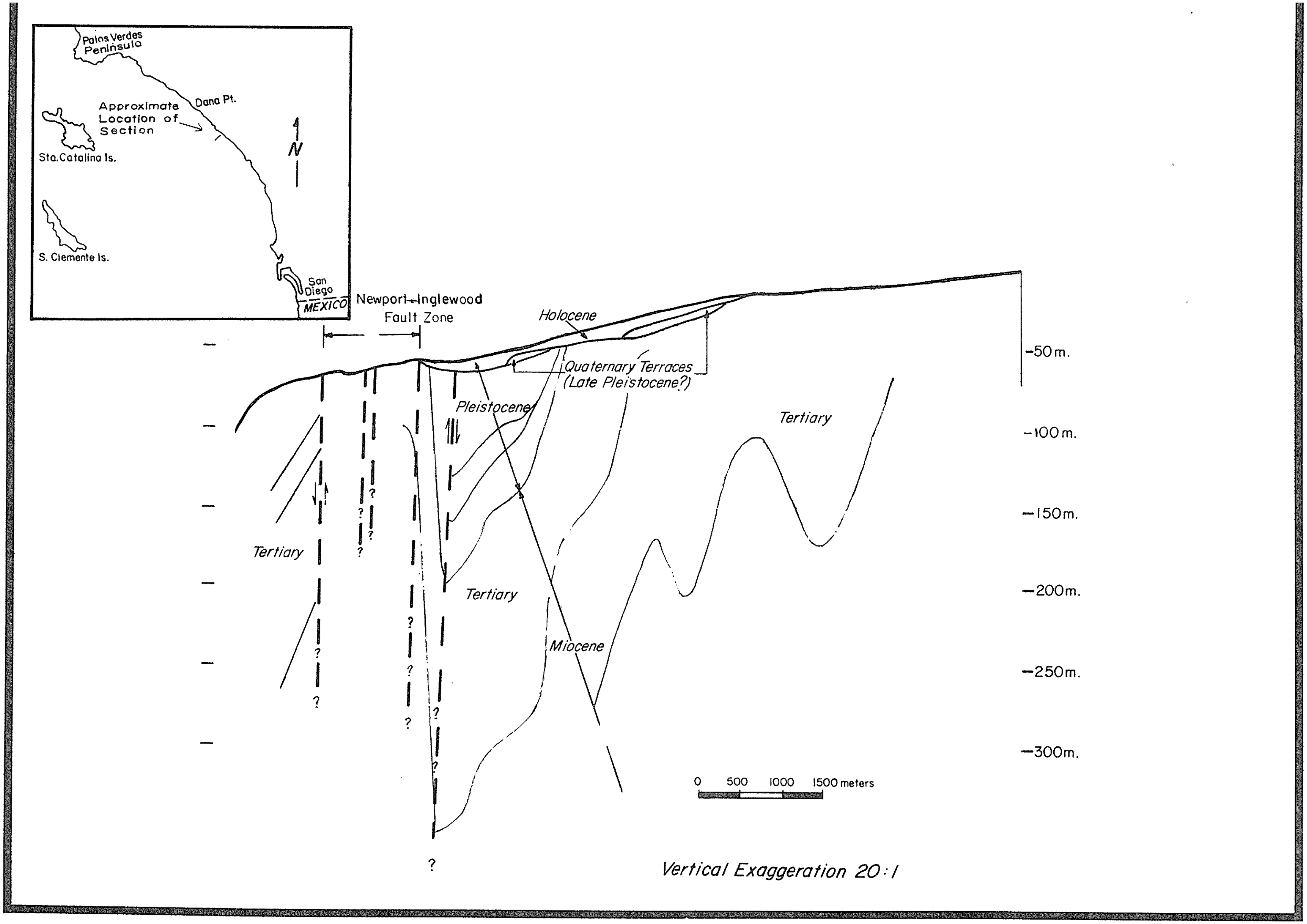

Figure 7. Geologic cross-section V off San Onofre, northern San Diego County. Note absence of Holocene sediment over and ponding of the sediment package behind the active Newport-Inglewood fault zone. Two Pleistocene terrace deposits are preserved below the Holocene veneer.

CARLSBAD TO POINT LA JOLLA

Ranging in width from 4 to 6 kilometers the shelf between Carlsbad and Point La Jolla is 36 kilometers in length. The shelf surface tilts gently seaward from one to two degrees from the shoreline to shelf-break, which is near the 100 m isobath. This inner margin segment is interrupted by two deeply incised submarine canyons. To the north the presently inactive Carlsbad canyon and to the south the active La Jolla-Scripps submarine canyon system played major roles during the Quaternary evolution of this shelf segment.

The Holocene shelf sediment package of this area is generally lenticular in shape, convex upward at the top and overlies the irregular surface of older bedrock units. The sediment package thins to zero (0) meters both shoreward and seaward. Its shoreward limit generally parallels the 15 meter isobath, while seaward the sediment lens pinches-out near the shelf-break.

Thickness of the sediment is controlled by structural and topographic barriers, paleo-submarine terraces,proximity to source and to active submarine canyons.

The internal reflective response of the unit as viewed on 3.5 kHz-HRP lines appears to be featureless and acoustically transparent. However, the unit displays continuous, moderate to high amplitude thickly layered reflectors when seen on the uniboom profiles of Woodward-Clyde (CERC) and Nekton surveys.

At the northern end of the study area off Carlsbad the sediment veneer ranges from 0 meters inshore at the shelf-break, to 10-14 meters thick along the mid shelf area (fig. 8). The Holocene isopach shown on Figure 5 indicates a north-south trend, which coincides with the structural grain and paleo-terraces.

From Leucadia southward, the isopach (fig. 5) indicates a general thinning of the sediment package. The maximum section is only 8 meters thick over a ancient terrace. The unit becomes sharply lenticular and thickens towards shore while toward the shelf-break, the sediment veneer abruptly thins and is tectonically dammed (figs. 8 and 9).

A dramatic example from the high resolution profiles is shown by Figure 9. Here the familiar lenticular and acoustically translucent Holocene unit is abruptly dammed by a horst-like feature and then continues seaward as a patchy, thin veneer.

At the southern end of the area in La Jolla Bay, the inner margin shelf is dissected by the active La Jolla and Scripps submarine canyons. On the shelf adjacent to the canyons, the Holocene section thickens to 16 meters north of Scripps Canyon, to 24 meters between the canyons and to 10 meters on the shelf west of La Jolla Canyon (Byrd, and others, 1975).

In the submarine canyons, the Holocene(?) display an altogether different seismic signature. Here the unit appears as a hummocky, chaotic and disrupted group of reflectors.

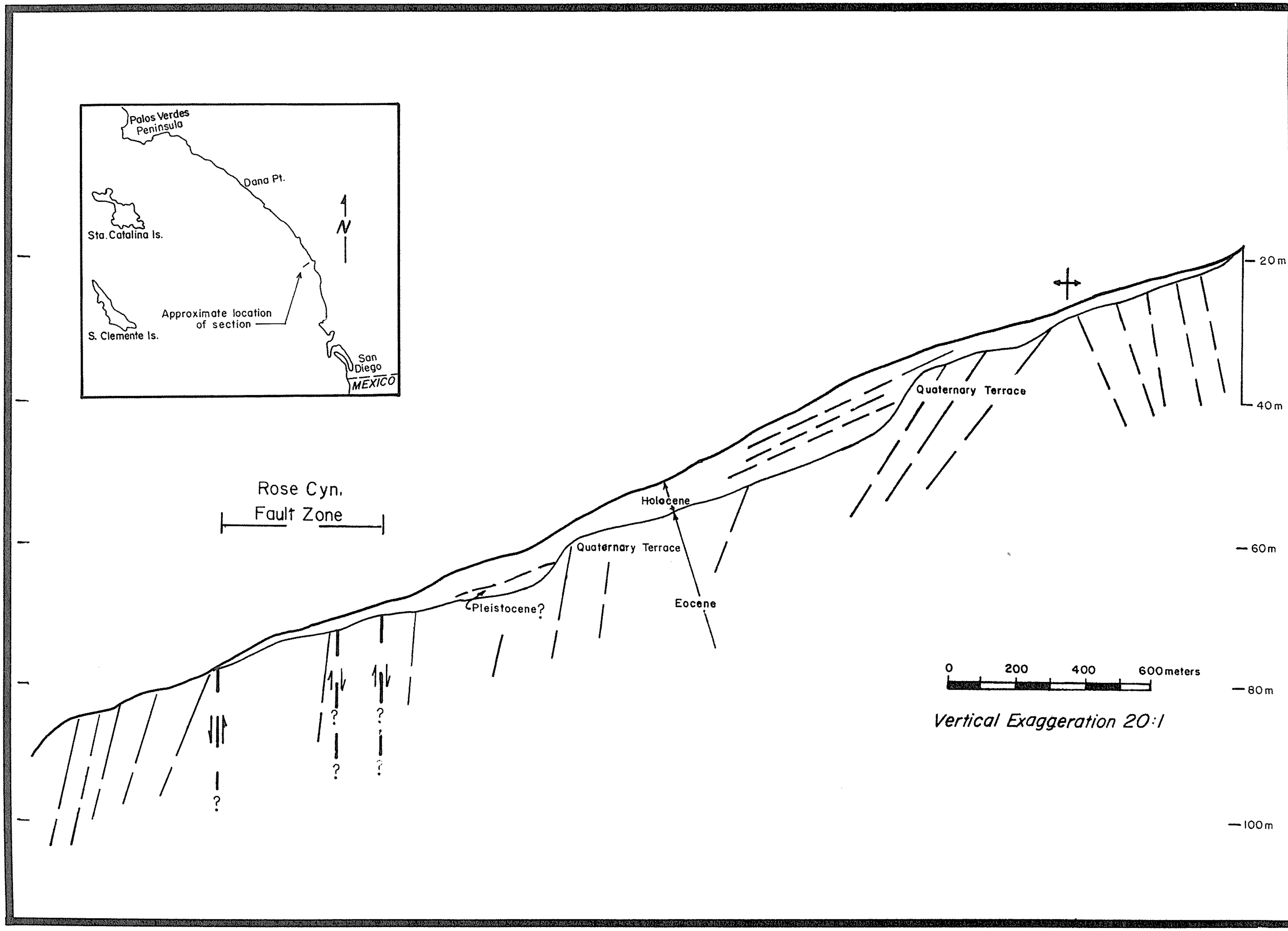

Figure 8. Geologic cross-section III south of Carlsbad, central San Diego County. The Holocene sediment veneer off San Diego County is most typically shown by this section. The thickest portion of the sediment wedge is controlled by a bedrock scarp, which is probably an ancient wave-cut cliff.

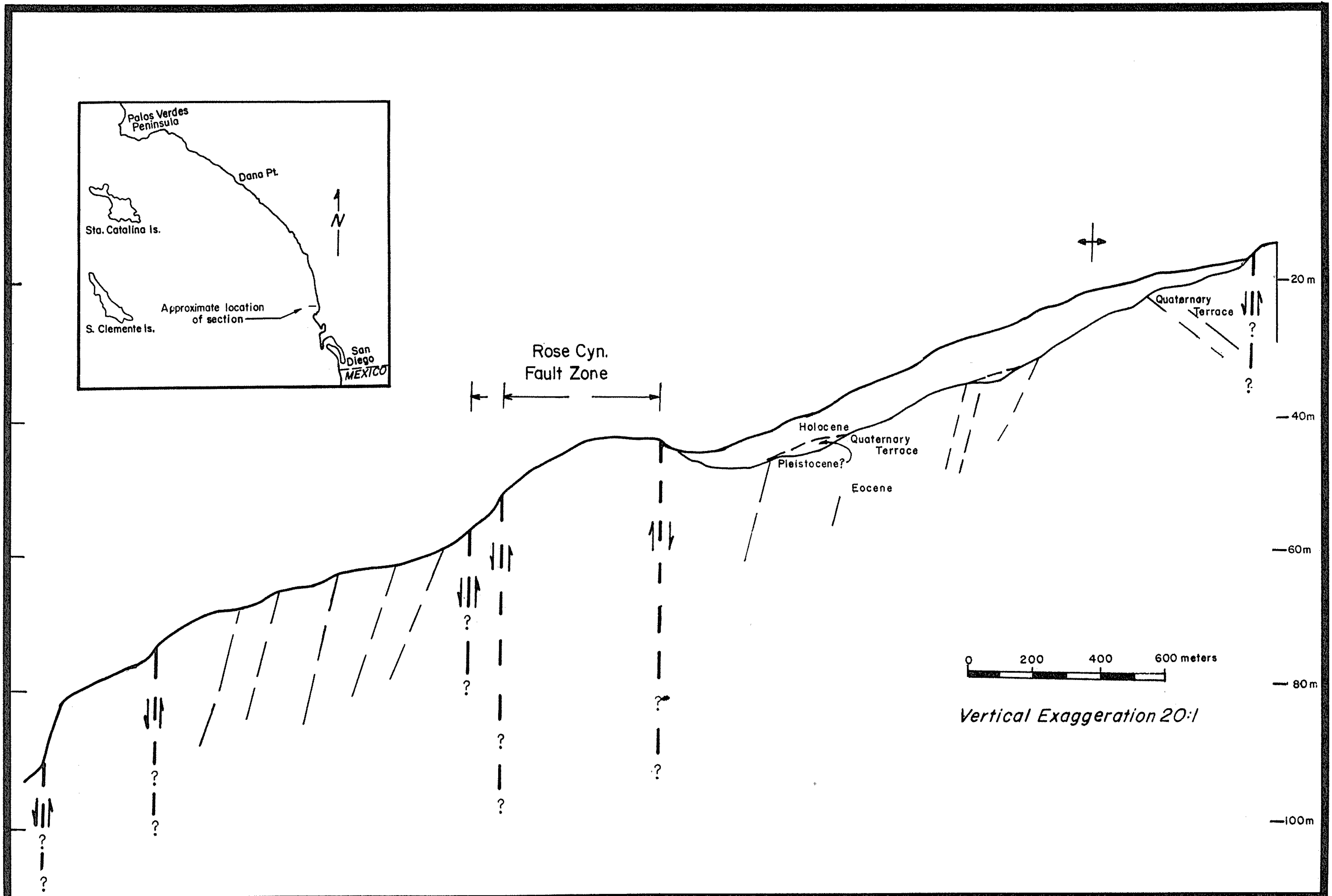

Figure 9. Geologic cross-section II north of LaJolla, south central San Diego County. The high topographic ridge over the active(?) Rose Canyon fault zone has ponded the Holocene sediment wedge behind the fault.

In summary, the shelf between the Carlsbad and La Jolla submarine canyons contains the lowest sediment volumes of the southern mainland shelf (fig. 5). Typical volumes are 25 x 10^6 cu.m. per shelf compartment or less north of the San Diequito River mouth. At this point the total shelf volumes double and inner shelf sediment volumes become significant. The lack of sediment in this ancient littoral compartment may be attributed to an interplay of several factors:

1. the narrow shelf,
2. interception of littoral drift during early-mid(?) Holocene time by the Carlsbad canyon,
3. coastal lagoons, which trap sediment behind barrier beaches (Inman, 1976), and
4. the effectiveness of the southern sediment sink--the La Jolla canyon.

Although the Del Mar to Oceanside studies of cliff erosion by Kuhn and Shepard (1979) attest to rapid or even catastrophic periods of cliff retreat related to severe winter storms and attendant high waves, the total contribution of this material over longer time spans is relatively small. The localization of severe cliff retreat to this area may also be related to the minimal inner and total shelf sediment supply. Beach sand protection of the cliffs is essentially non-existant.

LA JOLLA - TIJUANA RIVER

Sediment distribution patterns over the broad shelf (6 to 14k) from Point La Jolla along Point Loma to the Tijuana River are unique. From Point La Jolla to the southern tip of Point Loma a linear sediment trend is developed along the mid-outer shelf. The inner shelf consists of exposed bedrock, kelp stands and very thin, patchy sediment pockets. This outer trend continues beyond Point Loma to at least the international border with Mexico. Between Point Loma and the Silver Strand a second and nearly separate sediment accumulation is present (fig. 5). This second or inner shelf deposit coincides very closely with the "final sink for sand in this littoral cell" described by Chamberlain and others (1958) (fig. 5). The northerly littoral drift and a unique wave refraction pattern described by Inman (1976, p. 45-46) for the inner shelf between the Tijuana River and North Island explain the mechanism responsible for this deposit.

Sediment volumes for this southernmost shelf segment may be divided into:

1) the outer trend off Point Loma and over the mid-outer shelf south of the point - 450 x 10^6 cu.m., and
2) the inner trend off North Island and the Silver Strand - 60 x 10^6 cu.m.

The inner deposit off the Silver Strand is of interest for beach replenishment along the cell. Inman (1976) has described beach erosion areas near Coronado and Imperial Beach which could benefit from the material contained in this deposit.

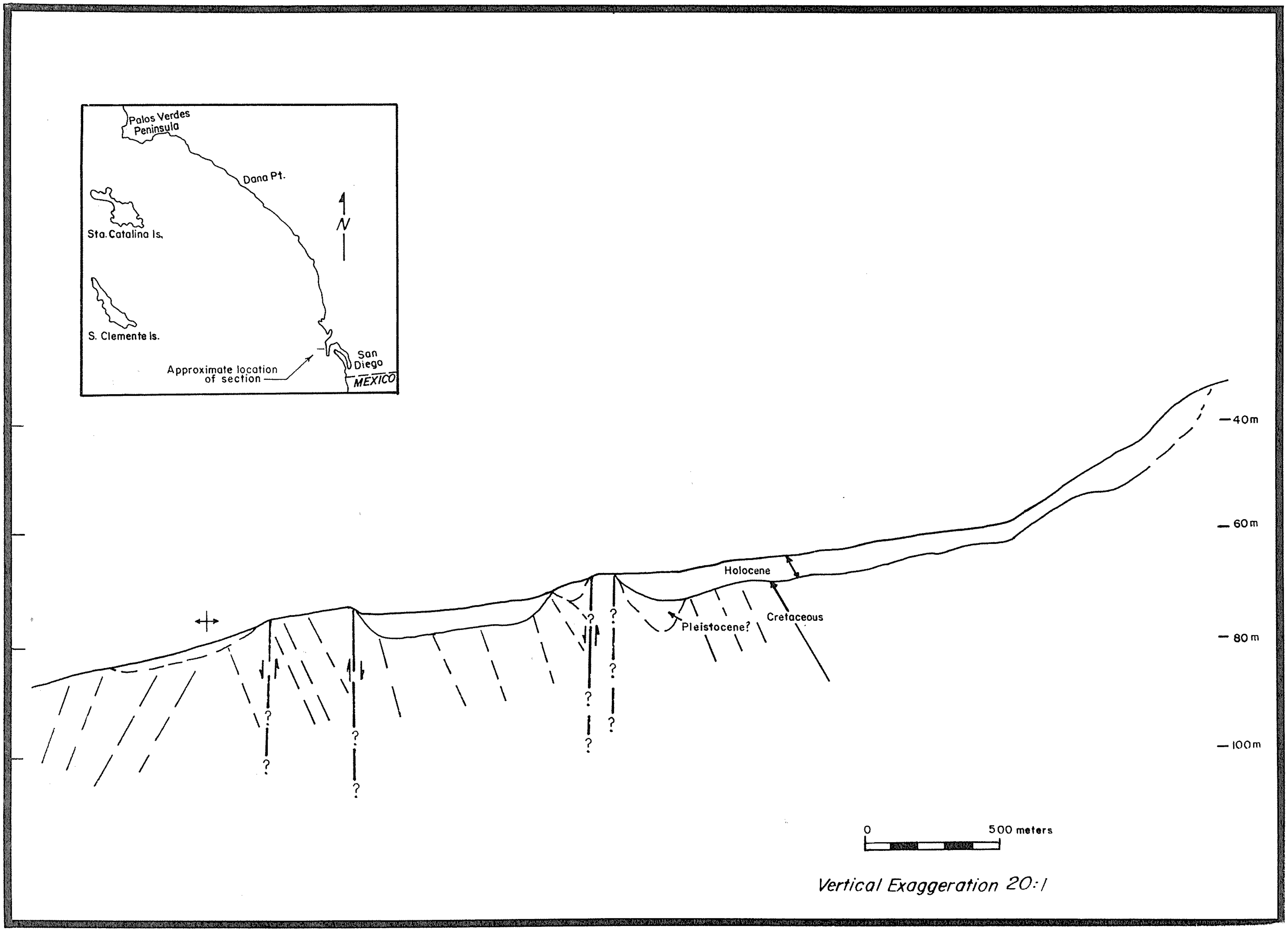

Figure 10. Cross-section I, off the southern tip of Point Loma, southern San Diego County. Ponding and irregular distribution of the Holocene sediment veneer was controlled by topographic fault-bounded ridges.

SUMMARY AND CONCLUSIONS

Since the sediment veneer of the shelf was deposited over the last 18,000 years, an understanding of its genesis and distribution must include an assessment of the shelf environment during this period of rising sea level. Estimates of the 18,000 year B.P. low-stand of sea level range from (-)85 to (-)110 m below present mean sea level. During this last low-stand the major rivers and streams maintained flood plains, formed deltas and cut and filled distributary channels across what is today's shelf surface. The larger channels initiated during these times became submarine canyons as the shelf was submerged and if their sediment supply was maintained. Many canyons were beheaded--or cut off from the long-shore drift system by submergence or changes in coastal geomorphology. These inactive canyons today include the Newport, Dana Point and Carlsbad canyons. The only active canyon of the southern shelf is the La Jolla-Scripps system which today traps the southerly flowing littoral drift and funnels sand and mud into the San Diego trough.

Littoral cells for the southern California shelf were defined but not named by Emery in 1960 (fig. 5). Inman and Frautsche (1966) named the littoral cells between Point Conception and the Mexican border and more recently Inman (1976) briefly described and figured the cells. A littoral cell involves a sediment source, in the southern California continental borderland rivers are the dominant source of shelf sediments, net littoral drift (normally south and east) and a sediment sink or loss point (a submarine canyon). Although Inman and Frautsche described modern littoral cells between the Palos Verdes peninsula and the Mexican border, Emery (1960) indicated an additional inactive cell which terminated at the Carlsbad canyon. If sea-level were to be lowered (-)50 m below present sea-level (BPSL) the additional late Pleistocene or ancient littoral cells of Emery can be recognized (fig. 2).

The modern Oceanside cell (Inman & Frautsche, 1966) may be divided into a northern Newport-Carlsbad canyon cell and a southern Carlsbad to La Jolla canyon cell. These inactive cells will be termed the Carlsbad and La Jolla cells respectively.

Such ancient cells essentially extended from the termination of one cell to the next or simply between the submarine canyons. Unlike the modern cells of Inman (1976), there were no major areas of sea-cliffs south of the canyons during the late Pleistocene-Holocene transgression (18,000 - 5,000 yrs. B.P.). Leakage of sediment from the cell to the north (or west), erosion of shelf material and intermittent drainages that were more important during the higher rainfall of Pleistocene (glacial) time developed a continuous littoral transport system from cell to cell.

The concepts discussed above describe what we believe to be the genesis of the "Holocene" shelf sediment package. Additional evidence from core holes on the inner San Diego shelf and the outer shelf and upper slope of the southeastern Pedro basin margin and seismic stratigraphic correlations provide regional lithologic predictions. At shelf-break the basal Holocene consists of fine sand with abundant shell fragments (Fischer and others, 1977). The middle and upper Holocene units become very fine sand to silt in an upward-fining sequence. These units are recognizable on high resolution seismic profiles and may be correlated over the shelf. One obvious conclusion is that the upper Holocene, both from core and seismic reflection evidence as well as logic, should be finer grained sediment than the basal Holocene (unit C of Fischer and others, 1977). This implies that typical shallow (2 to 4 m) vibracore samples will not provide an adequate sample of the Holocene section nor a true assessment of the sand and gravel potential of these deposits.

If a study of the shelf sediment is initiated, coring operations should be designed to core areas where the upper Holocene has been removed (by scour, etc.)--only then a complete section can be described and an accurate resource assessment made.

ACKNOWLEDGMENTS

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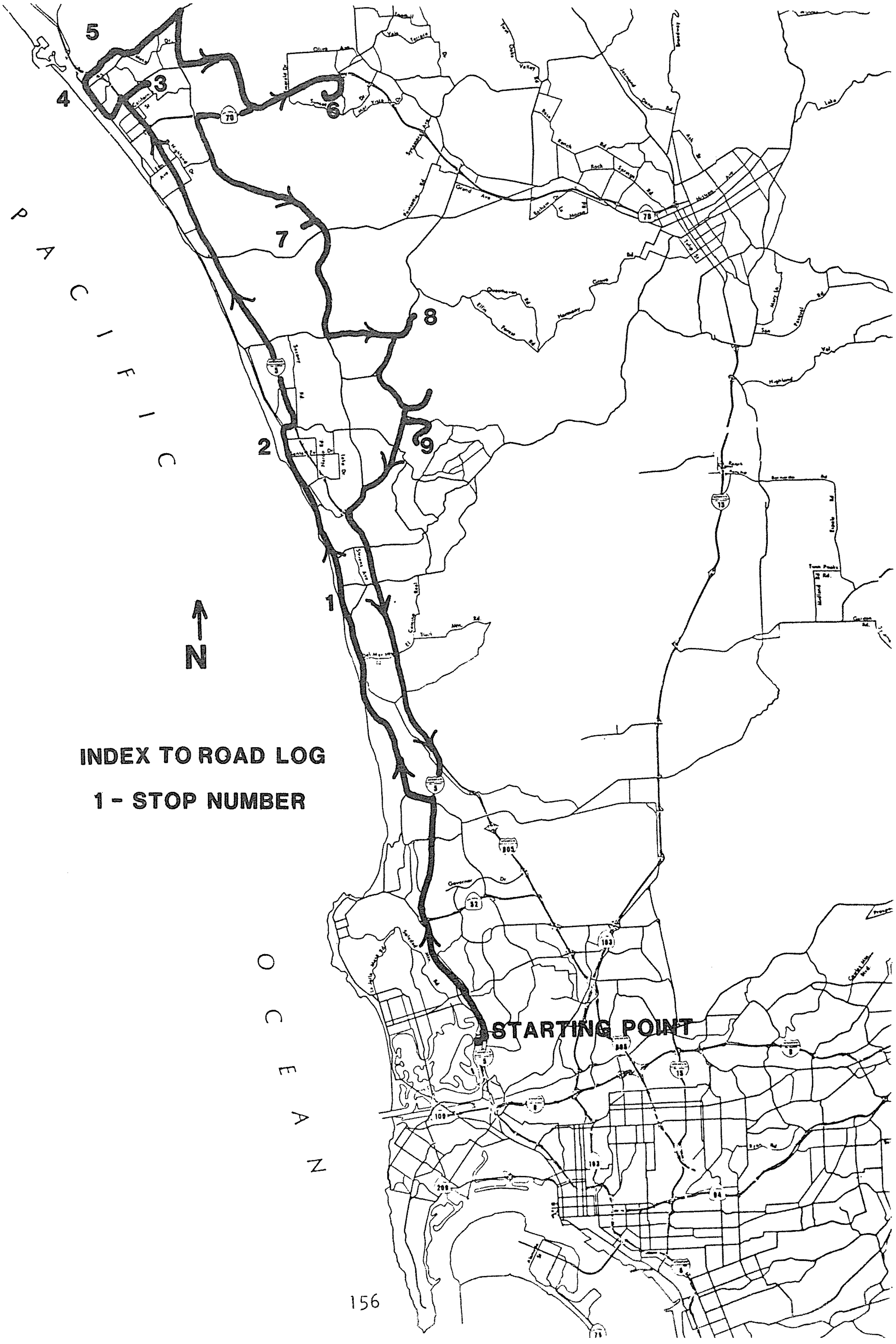
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FIELD TRIP GUIDE TO GEOLOGIC FEATURES IN NORTH-COASTAL SAN DIEGO COUNTY, CALIFORNIA

by

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3467 Kurtz Street
San Diego, CA 92110

The starting point for this field trip is the large parking lot located at the intersection of East Mission Bay and Clairemont Drives just north of the Mission Bay Visitor Information Center on Interstate 5. Mission Bay (formerly known as False Bay) is a natural lagoon that was enlarged in the late 1950's by dredging to form the existing water-recreation area. The dredged material was used to build the shoreline and to augment island areas within the bay. The main stream channels to the bay are Rose Canyon Creek entering from the north and Tecolote Creek from the east. The bay formed at the axis of the northwest-trending Pacific Beach Syncline, which extends from the west side of Mount Soledad to the southern edge of the bay.

Mileage

0.0 Thomas Bros. 52E5 — Start of trip. Parking lot, Mission Bay Visitors Center. Take Clairemont Drive on-ramp to Interstate 5 and proceed north.

1.3 — As we enter Rose Canyon, note on the left the southerly-dipping, out-of-slope bedding of the Eocene Ardath Shale. For many years, these beds were exposed in a steeply-inclined, south-facing cut slope. Recent site regrading has buttressed the lower portion and flattened the upper portions of the slope.

The northwest-trending Rose Canyon and Mount Soledad Faults approximately follow the axis of Rose Canyon. Mount Soledad, on the left, has been interpreted to have been uplifted approximately 350 feet higher than Linda Vista Mesa on the right, based on correlations of the Pleistocene Lindavista Formation on both sides of the canyon. For information on local stratigraphy, see Kennedy (1975); for articles on local faulting, see SDAG guidebook edited by Abbott and Elliott (1979).

2.4 — To the left, the site of the 1961 Mount Soledad landslide is immediately west of the cantilevered houses. As reported by Farrand and Elliott (1979), eight houses were destroyed during construction by failure of an oversteepened cut in faulted and jointed siltstones and claystones of the Ardath Shale. The homesites were subsequently regraded and buttressed, and new homes have been built.

This failure proved to be a significant factor in having the City of San Diego contract with the California Division of Mines and Geology to fund the work by Kennedy (1975).

2.8 To the right, note the Budweiser plant and other commercial structures. The Rose Canyon Fault is mapped by Kennedy (1975) as crossing the canyon in the vicinity of these structures. Trenches excavated prior to site development indicated unfaulted alluvium to a depth of at least 18 feet; the results of these studies are reported by Farrand _et al._ (1981).

4.6 To the right, note the gentle south-facing slopes and the steep north-facing slopes of San Clemente Canyon. This asymmetry has been described by Gary Peterson in classes at SDSU for two decades.

5.9 Take Genesee Avenue offramp and proceed west. As we cross the freeway, observe probable ancient landslide in Ardath Shale on grass-covered hillside to the north.

7.4 Turn right onto Torrey Pines Road. We are travelling approximately along the axis of a Pleistocene beach ridge formed on the Lindavista Formation.

7.7 Red-brown pebbles along roadway to right are "ironstone concretions" described by Emery (1950). These concretions are quite common in the Lindavista Formation (see paper by Abbott, this volume).

8.0 Torrey Pines Golf Course on left.

8.7 The pine trees in this area are Torrey Pines (!), a species that is indigenous to this area and Santa Rosa Island as a relict from the Ice Ages.

8.9 Cut on left shows Lindavista Formation overlying crossbedded Eocene Torrey Sandstone.

9.2 Cut on left shows Carmel Valley Fault of Kennedy (1975).

10.0 Torrey Pines State Beach; mouth of Sorrento Valley.

10.8 On the right, note the locally named "Railroad" fault offsetting both Quaternary terrace sandstones and the Torrey sandstone.

11.3 Entering the City of Del Mar.

12.3 Horizontally stratified, fossiliferous claystones and siltstones of the Eocene Delmar Formation are exposed in cut slope to right.

12.6 Turn left on Court Street; then immediately right on 22nd Street. Turn right on Oceanfront (12.7) and proceed north to 27th Street.

STOP 1
12.9 Thomas Bros. 34A1 Longard tube. The Longard tube was installed late in 1980 along approximately 600 feet of coastline in this area by local property owners in an effort to halt sand erosion and resultant structural damage from loss of sand to cushion wave attack. As of this writing, the tube, which has proven successful in other parts of the world, has performed well under several periods of large waves. This erosion control device may well prove to be an effective and relatively low-cost alternative to groin jetties and offshore rock barriers.

12.9 Return to Pacific Highway and proceed north.

13.2 Crossing the San Dieguito River Valley; Del Mar Racetrack is on the right.

13.3 To the left, the bluff on the north side of the tidal channel is the site of the "Del Mar Man" skull discovery. The skull was dated by amino acid racemization to be approximately 50,000 years old.

13.4 Entering Solana Beach.

15.1 Crossing San Elijo Lagoon.

16.4 On the right, cut slopes exposed along railroad tracks are in Quaternary terrace deposits.

17.0 Self Realization Fellowship complex on left. A temple is described by Kuhn and Shepard (1979) as having fallen off the bluff top as a result of terrace sand failure during a storm in 1941. To date, this is the only occurrence of a structure having fallen off the sea cliff along the North County coastline as a result of sea cliff failure. Block falls below the complex have been described by Maloney (1981).

17.4 Entering Cardiff-by-the-Sea.

18.1 Turn left on Encinitas Boulevard; left again on Third Street (18.2); turn right on "C" Street (18.3) and right into gravel parking lot.

<u>STOP 2</u>

Coffee break

18.3 Thomas Bros. 24D4 — Moonlight State Beach. Considerable controversy has been generated at this locality between engineering geologists and environmentalists concerning the amount of sea-cliff and/or beach sand retreat that has occurred since the Encinitas Town Plot map was filed in 1883. Gerry Kuhn of Scripps Institute of Oceanography presented maps in 1975 that were interpreted by governing agencies and others as indicating that as much as 800± feet of sea cliff had eroded at Moonlight State Beach between 1883 and 1894. A more detailed account is presented by Kuhn and Shepard (1979).

18.3 Retrace route to Encinitas Boulevard; proceed east to I-5.

18.7 Exposed in cut slope to right are Quaternary terrace deposits overlying Torrey Sandstone.

19.0 Turn left onto I-5; proceed north.

20.9 On left, the Leucadia Village subdivision is situated in the bottom of a topographically anomalous amphitheater. As shown on topographic maps, the feature is approximately 1,000 feet in diameter and nearly circular. The feature exposes Quaternary terrace sandstones and is thought to be the result of spring sapping during the Pleistocene. The available evidence does not support other possible geomorphic features, such as ancient landslides, river meander, ancient current erosion from Batiquitos lagoon, or meteor impact crater (half-astrobleme).

21.2 La Costa Avenue; proceed north. A well-expressed fault exposure is present in the road cut along La Costa Avenue, approximately 0.25 miles east of the freeway. This feature is more fully described by Adams and Frost in this volume.

21.6 Batiquitos Lagoon. Batiquitos Lagoon represents the approximate boundary between correlative Eocene formations of the La Jolla Group to the south and the Santiago Formation to the north. Much of the North County coastal strip was mapped and described by Wilson (1972).

22.9 Well exposed Pleistocene beach ridges are present on both sides of the freeway.

23.5 Sewage treatment plant under construction on left.

24.8 San Diego Gas & Electric Company Encinas fossil fuel power plant on left.

25.5 Crossing Agua Hedionda Lagoon; entering Carlsbad.

27.5 Crossing Loma Alta Creek.

28.8 Take Oceanside Boulevard offramp; proceed east on Oceanside Boulevard.

29.2 On left, Pleistocene lagoonal siltstones and claystones containing numerous articulated pelecypods were encountered during site grading for Best Plaza.

29.5 Turn right on Crouch Street, cross creek, then turn left on Downs Street.

29.8 On right, note the westerly-dipping, interbedded sandstones and claystones of the Santiago Formation.

30.0 Turn left on Skylark Drive. Proceed east to Partridge Lane, turn right, and park.

STOP 3

30.1 Thomas Bros. 9F6 Skylark Landslide. The Skylark Terrace Subdivision was constructed in the late 1950's prior to a City of Oceanside grading ordinance. Studies described by Hannan (this guidebook) and Hart (1979) indicate that the failure occurred in poorly prepared and compacted fill soils placed upon previously unrecognized ancient landslides.

Proceed south on Partridge Lane to Sarbonne Drive (30.3), turn right, and retrace route back to Oceanside Boulevard.

31.0 Turn left on Oceanside Boulevard and proceed to coast.

31.7 We are approximately crossing the Eocene-Miocene boundary; canyon to right is underlain by the Upper Miocene San Onofre Breccia. Bedding in the Tertiary units in this portion of Oceanside is dipping approximately 10° toward the northwest.

31.9 Cut on right is composed of slopewash soils, Pleistocene lagoonal deposits, and the San Onofre Breccia. Fault traces exposed are interpreted to be in San Onofre Breccia (Dowlen, in prep.), and are part of the postulated onshore extension of the Rose Canyon Fault of Euge et al. (1973).

32.1 Roadcuts to right and left near top of hill contain rounded boulders and display minor ground-water seepage. This zone is interpreted to be the contact between the San Onofre Breccia and the Pleistocene terrace deposits that cap the mesa.

32.2 Hill Street intersection; continue west to Pacific.

32.5 Turn right on Pacific and proceed north. Turn left on Wisconsin Street (32.8), then right on Strand (32.9). Proceed north along beach to First Street.

STOP 4

33.4 Oceanside Main Beach. Prior to 1945, the City of Oceanside had a thriving tourist industry because of its wide and expansive beaches. This was apparently disrupted during World War II with the construction of the Del Mar Basin and associated jetties to the north by the U.S. Marine Corps. The resulting loss of beach sand has caused considerable damage to oceanfront properties in this area, and methods for replenishing the sand are still being argued. Rudin (1976) presented an unpublished history of the problem for the Oceanside mayor's office.

The present 100± foot-wide beach was recently constructed with dredge soil from Oceanside Harbor.

Bluff retreat in this area is described by Artim (this guidebook).

Turn right on First Street.

33.4 Turn left on Pacific; then right on Third Street (33.6) and proceed east. Turn left on Horne Street (34.1), then right on Fourth Street.

34.2 We are crossing a Pleistocene beach ridge.

34.3 Turn left on McNeil Street and proceed down canyon to gate. Pliocene San Mateo Formation is exposed in cut slope on right.

STOP 5 Thomas Bros. 9C5

Lawrence Canyon Sand and Gravel Pit. This area was mined for concrete aggregate and fill soil during the 1950's and early 1960's, with the aggregate being produced from clasts within the San Onofre Breccia (see Stuart, 1975). For the most part, over 100 feet of hillside was extracted until the sand beds along the east side of the pit were encountered and the pit closed.

The sand beds have proven to be extremely fossiliferous sediments of the Pliocene San Mateo Formation, with the primary fossils being birds, marine mammals, and other vertebrates (see article by Barnes et al. in this guidebook).

Separating the San Mateo Formation from the underlying San Onofre Breccia is a north-striking normal fault that dips approximately 60°E. Borings excavated east of the fault. Trace and mapping in the general area indicate that approximately 450 feet of vertical slip has occurred since Late Pliocene time. Warped Pleistocene terrace deposits are present adjacent to the fault in the southern portion of the pit, and may indicate that Quaternary faulting has occurred as well.

35.0 Turn left on Third Street; proceed east to San Diego Street (35.5). Turn right on San Diego Street, then left on Mission Avenue (35.6).

35.8 On right, very thin Quaternary terrace deposits appear to overlie the westerly-dipping San Onofre Breccia. Fault traces exposed in cut are in San Onofre Breccia.

36.0 On right, contact between the San Onofre Breccia and the Santiago Formation.

On the left, across the San Luis Rey River Valley, the chaparral-covered hillsides are composed primarily of Miocene sedimentary rocks whereas the underlying Eocene sedimentary rocks form the grass-covered hillsides.

36.5 On right, numerous ancient landslides are present on the north- and west-facing hillsides, due primarily to failure along bedding planes in the northwesterly-dipping strata.

36.7 Turn right on El Camino Real; proceed south.

39.0 Turn left on Oceanside Boulevard.

40.5 Massive grading operations in this area are part of the specialty sand production by the Crystal Silica Company (Weber, 1963).

40.7 Fault trace in the Santiago Formation in cut on left. Many of the fault traces that are exposed along roadways in the Oceanside-Carlsbad area have been noted by Hannan (1975).

41.3 On right, note the large ancient landslide abutting the subdivision. Numerous slide stabilization methods were utilized during grading.

41.7 Turn right on College Avenue; proceed south to Highway 78.

43.4 Turn left onto Highway 78; proceed east.

44.8 Road cut excavated in granitic rocks of the Cretaceous Peninsular Ranges Batholith.

45.8 Take Melrose Drive offramp; proceed south.

46.4 Veer to right on Melrose Way; proceed west. Turn right on Pomelo Drive (47.0) and proceed to end (47.1).

STOP 6 — Thomas Bros. 15A1

Proceed up unpaved driveway at end of Pomelo Dr. A highly weathered profile with "multiple" interpretations can be observed in the hillsides to the north!

Return to Highway 78 (48.6) and proceed west.

48.9 In cut to left, note the gabbroic boulders within the fractured, deeply weathered, decomposed granitic sandstones. Boulders such as these are typical of the high velocity "floater" blips encountered during shallow refraction seismograph surveys.

50.7 Streuter's Quarry on left. This quarry is a major North County source of crushed aggregate for asphaltic concrete. The material being mined is the Jurassic Santiago Peak Volcanics.

52.3 Take El Camino Real offramp; proceed south on El Camino Real.

54.0 Westerly-dipping sandstones and claystones of the Santiago Formation are exposed in cut slopes.

55.2 On left, observe the eroded volcanic neck of Cerro de la Calavera. Cerro de la Calavera is a dacite plug which intruded the Eocene Santiago Formation.

55.9 We are approaching one of the uncommon North County localities of Cretaceous age sedimentary rocks. On the left, forming the highlands are Cretaceous batholithic rocks overlain near the creek by sandstones and siltstones of the Point Loma Formation. On the right, the Point Loma Formation comprises Letterbox Canyon. Cretaceous marine fossils from the canyon have been described by Bandy (1951), Liska (1964) and Holden (1964).

56.5 Cut slopes near top of hill are in Point Loma Formation. Boulder conglomerates of the Lusardi Formation form the canyon slopes to left.

57.1 Turn right onto dirt road near top of hill and proceed west across mesa.

STOP 7
57.8 Thomas Bros. 19F1 Pacific Clay Products pits. Early Paleogene lateritic paleosol is exposed in west clay pit (see paper by Peterson and Abbott in this volume). For years, brick producers used this site because of the abundance of kaolinite. The clays were interpreted by Peterson and Abbott to have formed on the Point Loma and Cabrillo Formations as residual products of intense tropical weathering.

Return to El Camino Real and turn right.

58.7 Palomar Airport Road. Continue south on El Camino Real.

62.0 La Costa Avenue. Turn left and proceed through development to Rancho Santa Fe Road.

Green mudstones of Delmar Formation are present in both newly graded slopes to right.

64.0 Turn left on Rancho Santa Fe Road, proceed northeast.

STOP 8
65.0 Thomas Bros. 20E5 La Costa Dam-Reclaimed water storage reservoir. Turn right on gravel road and proceed to gate (65.3).

The storage reservoir dam, which will be used to intermittently store varying volumes of treated sewage effluent for spray irrigation, is a zoned earthfill embankment founded in the Santiago Peak Volcanics. The embankment, which measures 80 feet from the downstream toe to dam crest and 76 feet from toe to spillway crest, was constructed with materials from nearby borrow areas. Graded filter materials and concrete aggregate were imported from local aggregate plants (see paper by Gizensky in this volume).

Rock quarry to northeast is in Santiago Peak Volcanics and was used to supply rip-rap for Dana Point Marina in Orange County.

Return to Rancho Santa Fe Road (65.5), turn left.

67.5 Turn left onto Rancho Santa Fe Road at Olivenhain Water District headquarters. Sedimentary rocks in hillsides to left are in Delmar Formation.

67.8 In cut slope to right are typically weak claystones of the Delmar Formation.

68.5 Weak claystones of the Delmar Formation exposed in cut to left.

68.7 On hillsides across drainage to left, note recent natural landslides and reactivated ancient landslides. The slides occurred in the Delmar Formation.

68.8 Turn left on Lone Jack Road.

70.3 On hillside to north, note recent grading. Reactivation of a shallow ancient landslide approximately 1-1/2 years ago required the construction of an earth buttress. Larger recent failures are present over the ridge of the hill.

Local engineering geologists who are familiar with this area predict that many more slope failures may be imminent, as the County of San Diego does not generally require detailed geologic reports prior to development in this area. This is partially due to the local zoning, which specifies relatively large lots and generally minimal site grading. Further compounding the problem is the general lack of sewer facilities, necessitating the use of leach lines and seepage pits.

Turn around and proceed back to Rancho Santa Fe Road.

71.8 Turn left on Rancho Santa Fe Road; then left on El Camino Del Norte (71.9).

72.5 Turn right on South Pointe Lane; proceed south to cut slopes containing conglomerates (72.8).

STOP 9
72.8
Thomas Bros. 25D5

Exposed in cut slope are conglomerates interpreted to be either Lusardi or Cabrillo Formations. Fossils, including *Baculites*, have been found in Point Loma Formation underlying conglomerate (see articles by Zlotnik, and Bartling *et al*. in this guidebook).

Return to Rancho Santa Fe Road (74.0) and turn left.

74.3 Downtown Olivenhain.

74.8 Encinitas Boulevard. Cross intersection and proceed west on Manchester Avenue.

76.3 Turn left at El Camino Real and proceed to freeway.

77.7 Take Interstate 5 south to Mission Bay Visitors Center.

98.2 Mission Bay Visitors Center; end of trip.

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