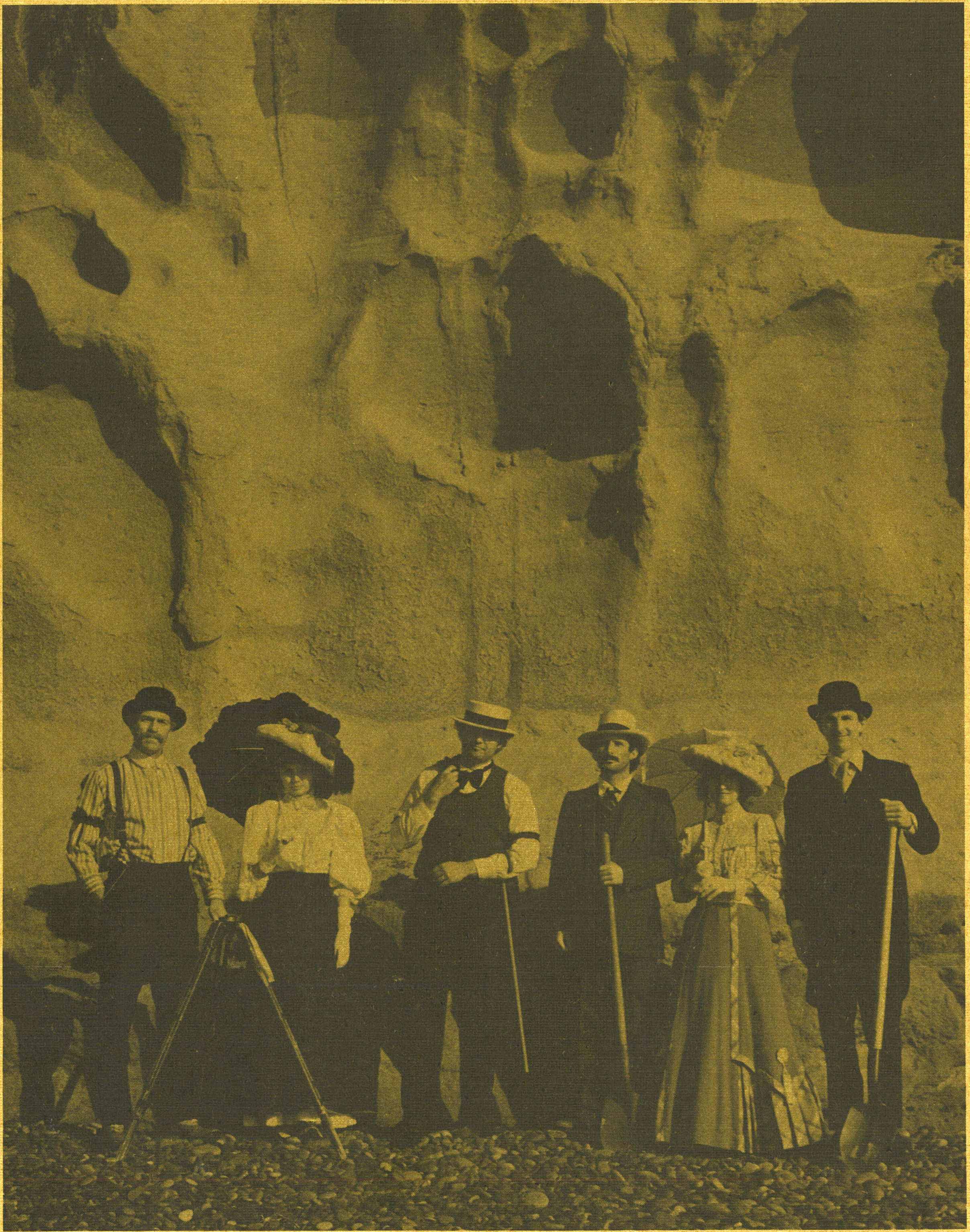
ON THE MANNER OF DEPOSITION OF THE EOCENE STRATA IN NORTHERN SAN DIEGO COUNTY



SAN DIEGO ASSOCIATION OF GEOLOGISTS GUIDEBOOK

Edited by PATRICK L. ABBOTT

ON THE MANNER OF DEPOSITION
OF THE
EOCENE STRATA IN NORTHERN SAN DIEGO COUNTY

Editor

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SAN DIEGO ASSOCIATION OF GEOLOGISTS

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San Diego Association of Geologists

You could almost be the perfect one, one that never touches yet leaves an indelible mark, a subliminal suggestion of love, scars more deeply than the act itself. Ah, perhaps I am the fool and I should miss the love of a lifetime.

D'Alexandra Saville

Acknowledgements

KATHY JESSUP and PIA PARRISH-LINCOLN were instrumental in bringing this book into existence. They prepared camera-ready copy and helped lay-out manuscripts in a positive and cheerful style. Their beauty in Victorian dress also adds immensely to the enjoyability of this volume.

JOE CORONES was the photographer deserving credit for the interesting pictures.

SCOTT FENBY drafted several of the inked figures.

For copies of this guidebook and maps write to:
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SUBMARINE-CANYON SYSTEM OF THE EOCENE SAN DIEGO EMBAYMENT

Jeffrey A. May
Denver Research Center, Marathon Oil Company, P.O. Box 269, Littleton, Colorado 80160

ABSTRACT

A well-integrated Eocene submarine-canyon complex dissected coeval slope, shelf, and nearshore deposits of the San Diego Embayment. Multiple cross-cutting channels on a multitude of scales and with widely diverse lithofacies compose the canyon system. Individual channels range up to 100 m deep by 600 m wide. Four modes of fill occur: (1) mudstone, (2) interbedded mudstone and sandstone, (3) mudstone-draped and sandstone-plugged, and (4) fining- and thinning-upward.

Overall, the canyon complex fines upward; formation and fill were in response to global sea-level changes. Subaerial inception occurred during a late Early Eocene eustatic lowstand. During the following sea-level rise, the canyon first eroded headward; filling then began as tributaries became detached from nearshore sediment sources. A slight eustatic drop during the Middle Eocene rejuvenated canyon transport; the tributaries tapped coarse-grained detritus, which flushed basinward. Mudstones next backfilled the complex during the late Middle Eocene eustatic rise. Finally, prograding nearshore and alluvial materials capped the canyon in response to a eustatic highstand.

Two field localities are described in detail. The canyon system was named the Torrey Submarine Canyon for spectacular exposures at Locality I. Coastal outcrops display an irregular, erosive, canyon floor cutting across paralic and lagoonal deposits. The overlying fill is tripartite and fines upward. A basal, amalgamated, pebbly sandstone grades to a fine-grained, horizontal- and convolute-laminated sandstone. Capping the sequence is an intensely channelized mudstone interval. Farther inland, at Locality II, channels are (1) draped-and-plugged and (2) fine upward. The canyon incises into shelf deposits. The shallow-marine units include hummocky cross-stratified sandstones and turbidites.

INTRODUCTION

Cretaceous and Cenozoic deposition in the San Diego region took place along the narrow, steep, coastal plain and continental margin of a forearc basin. The eastern limit, and source terrane of most of the detrital material shed into this complex, is the northwest-trending pre-batholithic Jurassic volcanics and Cretaceous batholith system of the Peninsular Ranges. K-Ar dates from granitic plutons in the Peninsular Ranges decrease eastward, from 112 to 75 million years (Nilsen, 1977), indicating the progressive shut-down of active forearc magmatism.

Eocene units formed within a broad embayment and consist of intertonguing, eastward-thinning strata deposited during two major transgressive-regressive events (Kennedy and Moore, 1971). An integrated fan-delta/submarine-fan system dominated the paleogeography (Howell and Link, 1979; Link et al, 1979). A fluvial valley, the Ballena Channel, cut across the low-lying Peninsular Ranges and debouched westward onto a large alluvial fan (Minch, 1973, 1979). The alluvial deposits graded laterally into coastal-plain units and downdip into lagoonal and shoreline environments. A large submarine canyon - the Torrey Submarine Canyon (May et al., 1983) - was incised across the shelf, heading eastward into the nearshore zone. This system provided a conduit for moving coarse-grained material out onto the adjacent submarine fan. The east-west trending drainage was later disrupted by post-Oligocene oblique slip (Yeats, 1979). The sedimentary-source terrane is now located in the Sonoran region to the southeast, and coeval submarine-fan facies crop out to the northwest on the Channel Islands of the Southern California Borderland (Abbott and Smith, 1978; Howell and Link, 1979; Minch, 1979; Kies and Abbott, 1983).

This paper concentrates upon some features of the Eocene submarine-canyon system exposed in the San Diego region. Lohmar and Warme (1978, 1979) and Lohmar et al. (1979) previously provided an overview of the canyon units as they relate to other shelf-edge deposits along a beach-cliff transect north of San Diego. Coverage herein includes the (1) variety of lithofacies present in the canyon complex, (2) timing of and mechanisms responsible for canyon formation and fill, and (3) areal distribution of outcropping canyon units. Finally, two easily accessible field localities are discussed in detail.

CANYON-FILL MONTAGE

The canyon complex north of San Diego was named the Torrey Submarine Canyon (May et al., 1983), after outcroppings along sea cliffs in the Torrey Pines State Reserve. Many more exposures are present throughout the Del Mar and La Jolla Quadrangles (Figure 1). This submarine-canyon system is composed of multiple cross-cutting channels on a multitude of scales and with widely diverse lithofacies. Individual channels range from 100 m deep by 600 m wide, to only subtly scouring and a few meters wide.

Parts of the Ardath Shale, Scripps Formation, and the Torrey Sandstone (Figure 2) variably comprise the submarine-canyon materials. Four modes of fill typify these deposits (Figure 3). The predominant channel facies consists of laminated to bioturbated, light- to medium-gray, silty mudstone - the Ardath Shale (Figure 3 and 4a). Carbonaceous flecks and micaceous laminae are common. Minute, thin-shelled, whole and broken molluscs are scattered throughout. Trace fossils include <u>Planolites</u>, <u>Helmintoida</u>, and <u>Chondrites</u>. Benthonic foraminifera indicate deposition ranging from neritic to bathyal (shelf to slope) depths.

These mud-plugged channels range from some of the deepest and largest (Figure 4b) to only slightly downcutting and unobvious (Figure 4c). Clearly originally formed by active erosion, the conduits are now pervaded by materials of later passive

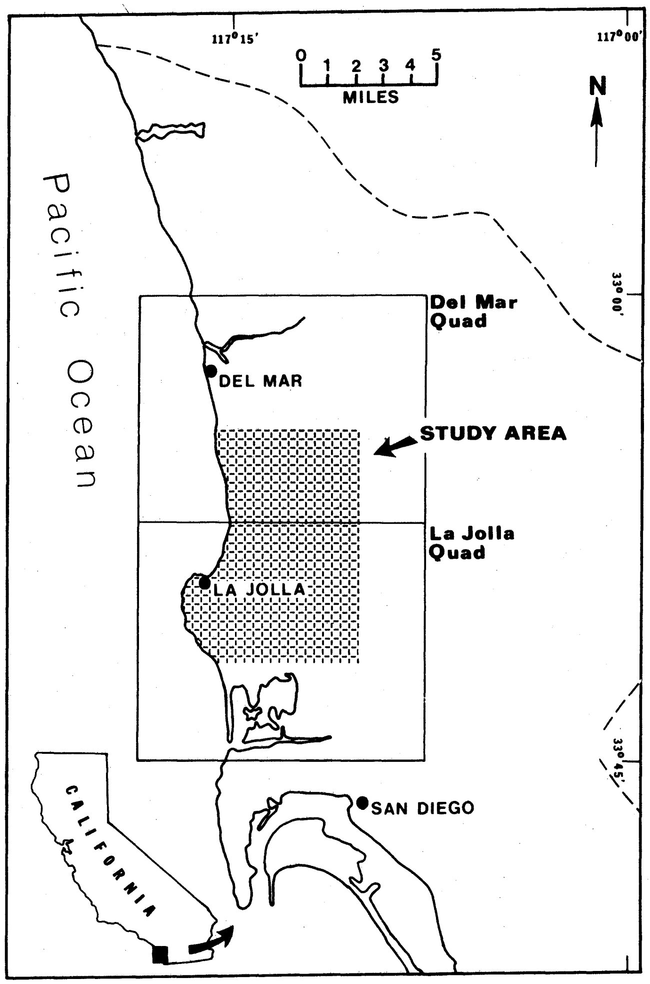


Figure 1. Index map showing area of study in San Diego County. The eastern limit of the San Diego Embayment is represented by the dashed line.

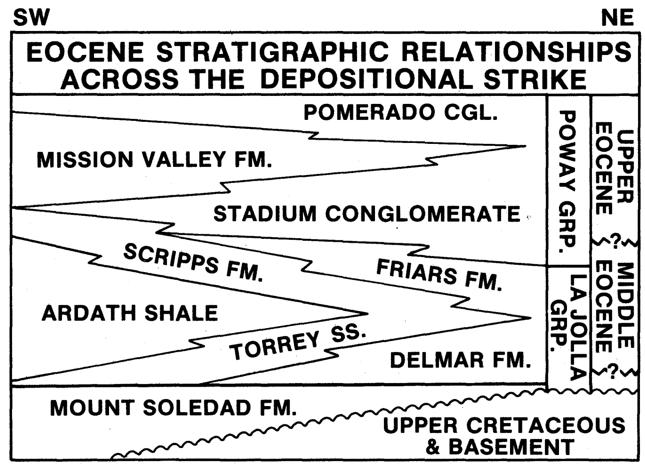


Figure 2. Regional stratigraphic relationships of the Eocene units across the San Diego Embayment (from Kennedy and Moore, 1971).

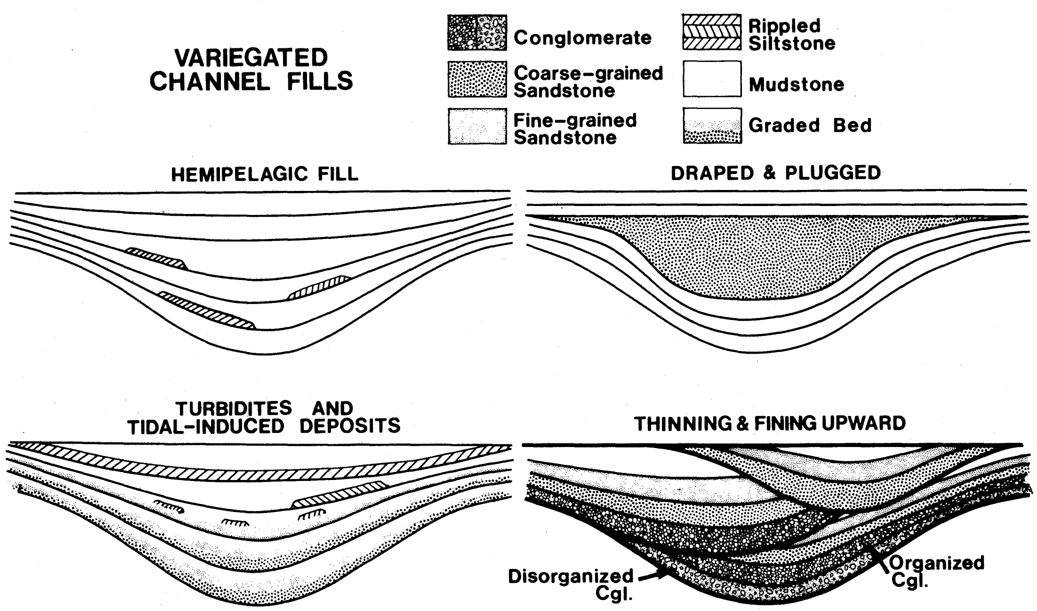


Figure 3. Lithologically varied channels characterize the Eocene Torrey Submarine Canyon exposed north of San Diego. Channel fills include those (a) dominated by fine-grained suspensate fallout, (b) containing graded (turbidite) and bidirectionally rippled (tidally influenced) sandstone and siltstone, (c) draped with mudstone and plugged by sandstone, and (d) with multiple cross-cutting, fining- and thinning-upward sequences.

deposition. Meandering currents probably originally evacuated successive, cross-cutting channels. The channels, in turn, were filled with both muddy, low-velocity (low-concentration) turbidites and by hemipelagic detritus, which fell out of suspension. Numerous other ancient submarine-canyon complexes are likewise dominated by fine-grained fills. The buried Yoakum Canyon in the Texas Gulf Coast is almost uniformly silty shale (Hoyt, 1959), as is the Early Cretaceous Gevaram Canyon of Israel (Cohen, 1976). The buried Tertiary canyons of southern Sacramento Valley, California - Martinez, Meganos, and Markley Canyons - are also predominantly filled by mudstone, with some interbedded sandstone and siltstone in the shallowest portions (Dickas and Payne, 1967; Almgren, 1978).

Many of the mudstone channels of the Torrey Submarine Canyon are punctuated by an assortment of coarser grained units. These variations give rise to two other modes of fill - channels composed of interbedded mudstone and sandstone and channels first draped by mudstone, then filled by sandstone (Figure 3). The coarse-grained layers display a variety of internal configurations. The range includes cross-beds, small-scale cross-laminae, and horizontal laminae, to completely lacking in sedimentary structures. Two processes, density flows and tidal currents, dominated the sand deposition.

Intercalated sandstones vary from minutely interlaminated with the mudstones to thick-bedded and massive. At the smallest scale are abundant starved and low-amplitude ripples, composed of siltstone and very fine-grained sandstone. These probably formed from low-concentration turbidity currents or may be the bypassed remnants of high-concentration flows (Bouma $T_{(b)c-e}$ beds; Figure 4d). Further indication of periodic sediment-gravity flows are thin-bedded, graded, siltstones and sandstones. These less common, thicker turbidites display complete Bouma T_{a-e} sequences.

Other interbedded sandstone and siltstone strata contain ripple cross-laminae and avalanche cross-sets formed by bidirectional movements. These units are most prevalent in the upper mudstone fills. Analogous to modern canyons, tidal currents (plus probably storm currents and rip currents) created tractional flow that was variably upcanyon and downcanyon (see, for example, Reimnitz, 1971; Shepard, 1979; Shepard et al., 1979). Many of the sandstone and siltstone beds, as well as some mudstone layers, are concretionary and ledge-forming. Upon closer inspection, such strata are replete with whole and broken mollusc shells (Figure 4e). These shelly deposits predominate in the upper canyon fills. Sand spillover from the adjacent shelf, then later winnowing by channelized currents, probably formed the shell-lag layers (see Dill, 1964; Stanley and Silverberg, 1969).

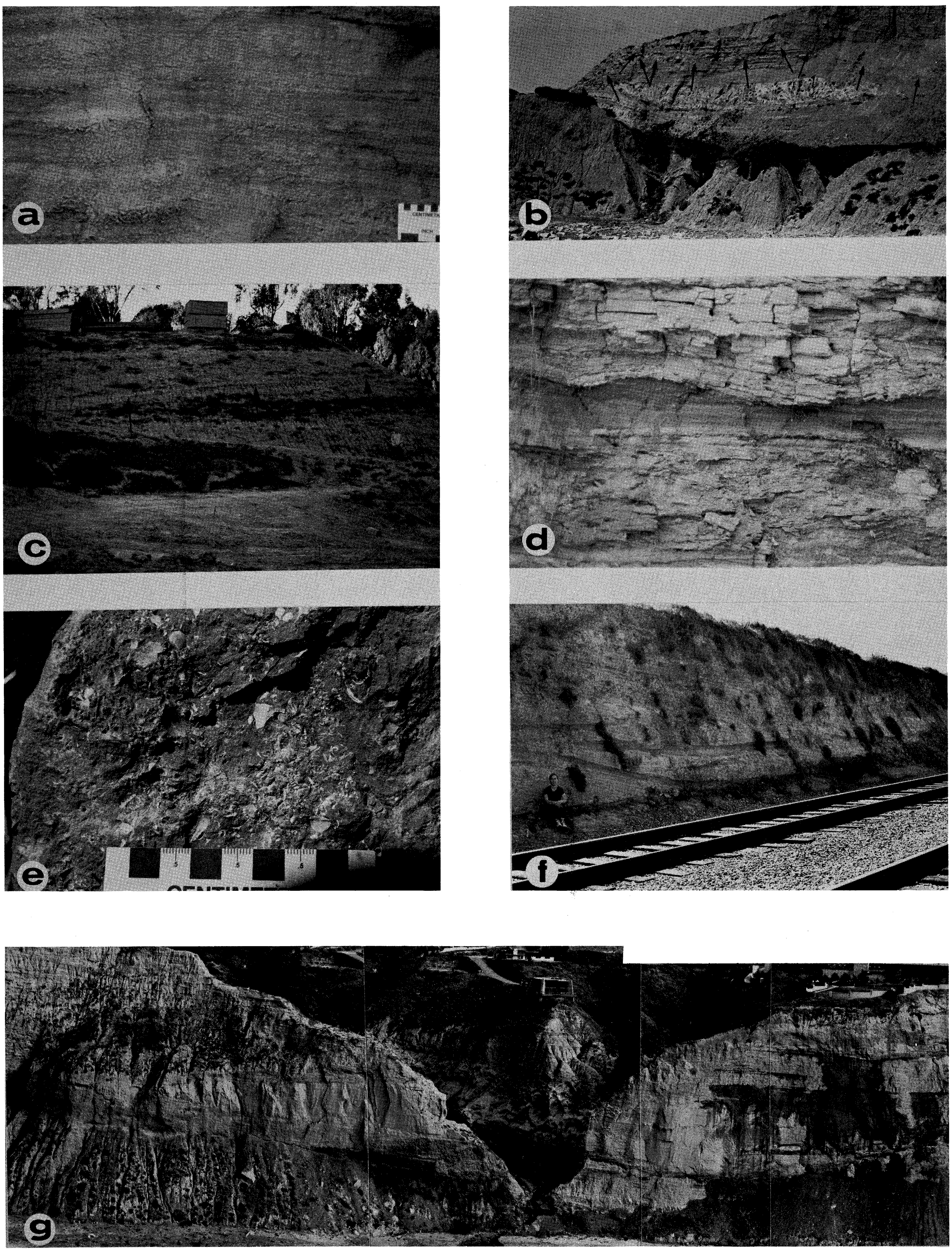
Draped-and-plugged channels (Figure 3) also occur on a variety of scales (Figure 4b and 4f). The basal mudstone drape varies from laminated to burrowed. The sandstone plug is typically silty and fine-grained, faintly horizontally laminated to convoluted, and massive. The coarsest size fraction is 3ϕ. A multi-stage evolution was thus responsible for the formation and fill of the draped-and-plugged channels. Erosion and evacuation represents the first period. Next, fallout of clays and silts from hemipelagic suspension and from low-concentration turbidity currents began draping the channel base. Lastly, coarser-grained density flows interrupted mud draping. Two separate mechanisms, grain flow and fluidized flow (Nardin et al., 1979), have been attributed in the literature as forming analogous laminated-sandstone units. These two flow types may (1) form as transitions from turbidity currents, (2) occur as traction carpets beneath turbitiy currents, or (3) take place as distinct events on very steep slopes (Sanders, 1965; Middleton, 1969; Middleton and Southard, 1977; Stanley et al., 1978; Walker, 1978; Nardin et al., 1979). In the Eocene channels, each separate event left a thin record of its passage. Combined, these multiple flows constructed the sandstone plug.

The fourth, and final, channel-fill type is organized into thinning- and fining-upward sequences (Figure 3). In a complete succession, amalgamated, disorganized and organized, conglomerates form the base. These progressively give way upward to pebbly sandstone; horizontal-laminated, fine-grained sandstone; interbedded sandstone and siltstone; and, ultimately, mudstone with sandstone and siltstone (Figure 4g). The sequence may actually start at any point in this series, then proceed upward. The decreasing grain size and bedding thickness represent a continuous shut down in available material and/or reduction in flow activity. Debris flows, grain flows, and high-concentration turbidity currents are eventually replaced by less-concentrated turbidity currents, and finally by hemipelagic fallout.

As already stated, the channels within the canyon system are variably cross-cutting. The channels meandered, so that the flow direction measured at any one point can be scattered anywhere over a 180° vector. Any single channel can be filled with any of the four facies types - mudstone, interbedded sandstone and mudstone, mudstone-draped and sandstone-plugged, or fining- and thinning-upward. Thus, the canyon complex at any specific locale may display random vertical and lateral sequences. However, as a whole, the canyon system does tend to fine upward. The locally random fill patterns are superimposed on a larger orderly succession. Fining- and thinning-upward successions and plugged-and-draped channels dominate basal canyon deposits. In contrast, interbedded sandstone and mudstone, and solely mudstone-filled, channels stand out as the upper canyon units.

CANYON EVOLUTION

As previously identified by Kennedy and Moore (1971), a major retrogradational (transgressive) - progradational (regressive) cycle is indicated for the late Early to early Late Eocene (Figure 2). However, a smaller scale retrogradational-progradational cycle punctuates the large succession (Figure 5). These local sea-level fluctuations correspond to global variations. The timing of the complete Early to Late Eocene depositional cycle correlates exceptionally well with an onlap "supercycle" of the same age (Vail and Hardenbol, 1979; May et al., 1984). Individual stratification


a
b
c
d
e
f
g

◄—Figure 4. Variable lithofacies present within channels of the Eocene submarine-canyon complex, (a) Laminated, unburrowed, silty mudstone is the dominant channel fill. (b) Three large, cross-cutting, mud-plugged channels overlie a draped-and-plugged conduit. Cliff face is approximately 70 m high. Arrows point to bases of mud-filled channels. (c) Slightly scouring channel. The silty mudstone fill cuts across horizontal, clayey mudstones of the Eocene continental shelf. (d) A T_{b-e} turbidite encased by mudstone. The turbidite bed is approximately 10 cm wide where thickest. (e) Shelly sandstone results from (1) spillover off the adjacent shelf into the canyon head and (2) later winnowing of fines. (f) Multiple, small-scale channels draped by mudstone along their bases and plugged by sandstone. (g) 1-km-wide fining- and thinning-upward channel fill. Basal cross-cutting conglomerate truncates slope mudstones and is overlain by massive laminated sandstones. Interbedded sandstones, siltstones, and mudstones, then a mudstone cap, complete the sequence.

sequences predicted as a response to relative changes in sea level are likewise correlative with specific eustatic events (Figure 5).

Latest Early Eocene through earliest Middle Eocene deposition commenced with retrogradation; these strata are separated from the underlying Early Eocene clastics by a regional unconformity, representing a eustatic lowstand. A soil horizon, formed during subaerial exposure, caps the Mount Soledad Formation. Concurrently, the submarine canyon was initiated farther basinward (Figure 6a). Fluvial erosion probably incised across the exposed shelf (Lohmar and Warme, 1978, 1979; Lohmar et al., 1979). The published literature is replete with similar cases of subaerial inception of canyon systems. Most known canyon heads occur seaward of modern river valleys (Shephard and Dill, 1966). Buried shelf valleys extend from modern river and estuary mouths to canyon heads (see, for example, McClennan, 1973; Twichell et al., 1977; Knebel et al., 1979; Freeland et al., 1981; McGregor, 1981). Some areas, such as western Corsica and Japan, contain submarine canyons almost directly connected to land canyons; the canyon head associated with the Congo River actually extends 20 miles (32 km) into the estuary (Buchanan, 1887; Shepard and Dill, 1966). Heads of Scripps and La Jolla Canyons may be traced inland into fault zones and incised fluvial valleys (Dill, 1964; Shepard and Dill, 1966).

As worldwide sea level began to rise, lagoonal Delmar Formation and paralic Torrey Sandstone successively infringed upon the Mount Soledad surface. Submarine erosion also resulted. The canyon system migrated headward, dissecting the Torrey and Delmar (Figure 5). An analogous situation is the modern Scripps Canyon cutting landward into slightly older beds during the Holocene rise of sea level (Shepard and Dill, 1966; Shepard, 1973). Headward erosion of the Eocene submarine-canyon system maintained its connection to coarse-grained, nearshore sediment sources.

The continued early Middle Eocene eustatic rise then led to partial filling of the canyon system (Figure 5). A tripartite, fining-upward sequence of pebbly sandstone, laminated sandstone, and mudstone, is found in the canyon tributaries. This succession represents progressive detachment of the canyon head from nearshore sediment sources (May et al., 1983 and Figure 6b). This progressively fining fill is mapped as Torrey Sandstone and Ardath Shale to the northwest, solely as Ardath Shale to the southeast.

The initial retrogradation was succeeded by basin-wide progradation during the early Middle Eocene eustatic stillstand (Figure 5). Inner-shelf and paralic sands began building outward. A slight global sea-level fall during the medial Middle Eocene caused these shallow-marine materials to be newly tapped by the canyon system (Figure 6c). Coarse detritus was flushed into the deep basin. Rejuvenation of the submarine-canyon complex took place, leading to submarine erosion. On outcrop, the submarine canyon and inner-fan channels are incised into Ardath mudstones of the shelf and slope. Major submarine-fan growth resulted, represented by conglomerates and sandstones of the Scripps Formation in its type area, along coastal exposures north of La Jolla.

Submarine-fan progradation was interrupted by a second retrogradational phase during the late Middle Eocene eustatic rise (Figure 5). Passive deposition dominated. Mudstones backfilled the canyon complex.

Finally, a late Middle to early Late Eocene regional progradation completed stratigraphic development (Figure 5). Landward, inner-shelf and paralic units of the Scripps Formation spread over outer-shelf mudstones of the Ardath Shale. Lagoonal deposits of the Friars Formation, in turn, advanced over the Scripps. This nearshore succession was truncated by another basin-wide unconformity; fluvial downcutting preceeded regional expansion of the Stadium Conglomerate fan delta. In the more basinal setting, submarine-fan development was reactivated. Alluvial and nearshore materials were once again tapped by the submarine-canyon tributaries (Figure 6d). Outer-shelf strata then marched over the canyon system, capping the succession.

FIELD LOCALITIES

Regional Distribution

The Eocene submarine-canyon system extends far eastward from its outcropping along coastal cliffs (Figure 7). The inland exposures are dominantly mudstone-filled channels, which, in turn, cut mudstones of the Eocene shelf (Figure 8a). Such truncations are often broad, shallow, and extremely subtle, marked only by a grain-size change. Mudstones of the canyon complex tend to be silty and contain rippled siltstone and sandstone lenses. Mudstones of the shelf, in contrast, are often burrowed and contain more clay. Some of the mud-plugged channels do contain thin layers of pebbly sandstone along their bases (Figure 8b). The pebbly sandstone is often suffused with mudstone rip-up clasts, indicating erosive incisement into the shelf units.

Conglomeratic and sandy channel fills are rarer, found only along the main, deep tributaries of the canyon system, or where extending into coeval nearshore units (Figure 7). Two such outcroppings are discussed in detail below, as field-

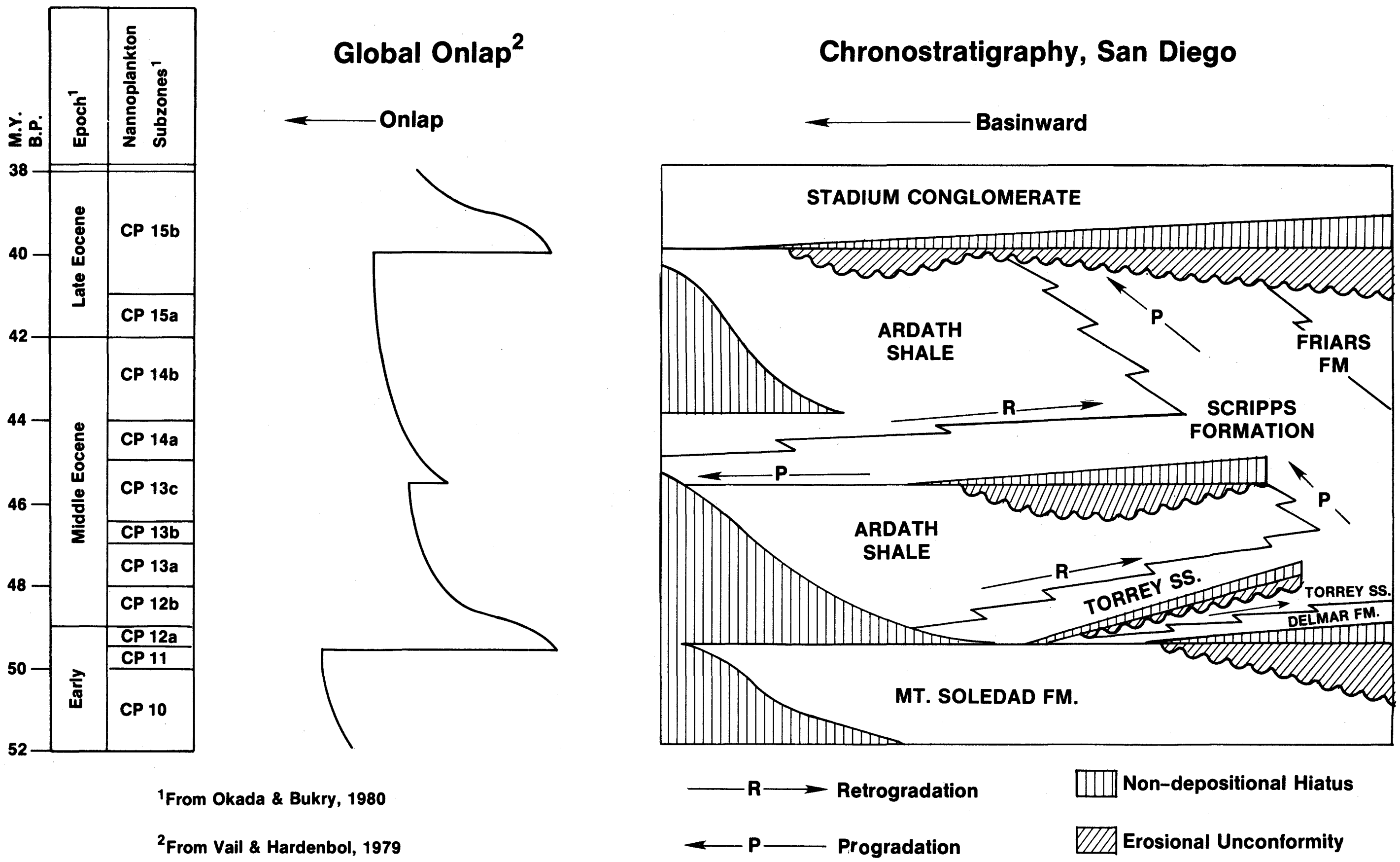


Figure 5. Chronostratigraphic chart showing erosional and depositional events across the San Diego Embayment. Local sea-level changes correlate exceptionally well to worldwide fluctuations as portrayed by the onlap curve of Vail and Hardenbol (1979). Specific depositional events include (1) a basal unconformity related to a worldwide sea-level drop, (2) a thin basal retrogradational sequence caused by global transgression, (3) basinward flushing of coarse-grained, nearshore detritus during a medial Middle Eocene regression, and (4) nearshore and subaerial progradation during a worldwide highstand. Dating within the San Diego Embayment is based upon nannoplankton collections, supplemented by palynology, foraminifera, and molluscs.

trip localities. Exposures of similar, coarse-grained channel complexes are present at the intersection of Genesee Avenue and Interstate 5 and extending into Peñasquitos Canyon (Figure 7). Multiple cross-cutting, fining- and thinning-upward sequences typify these coarse-grained exposures.

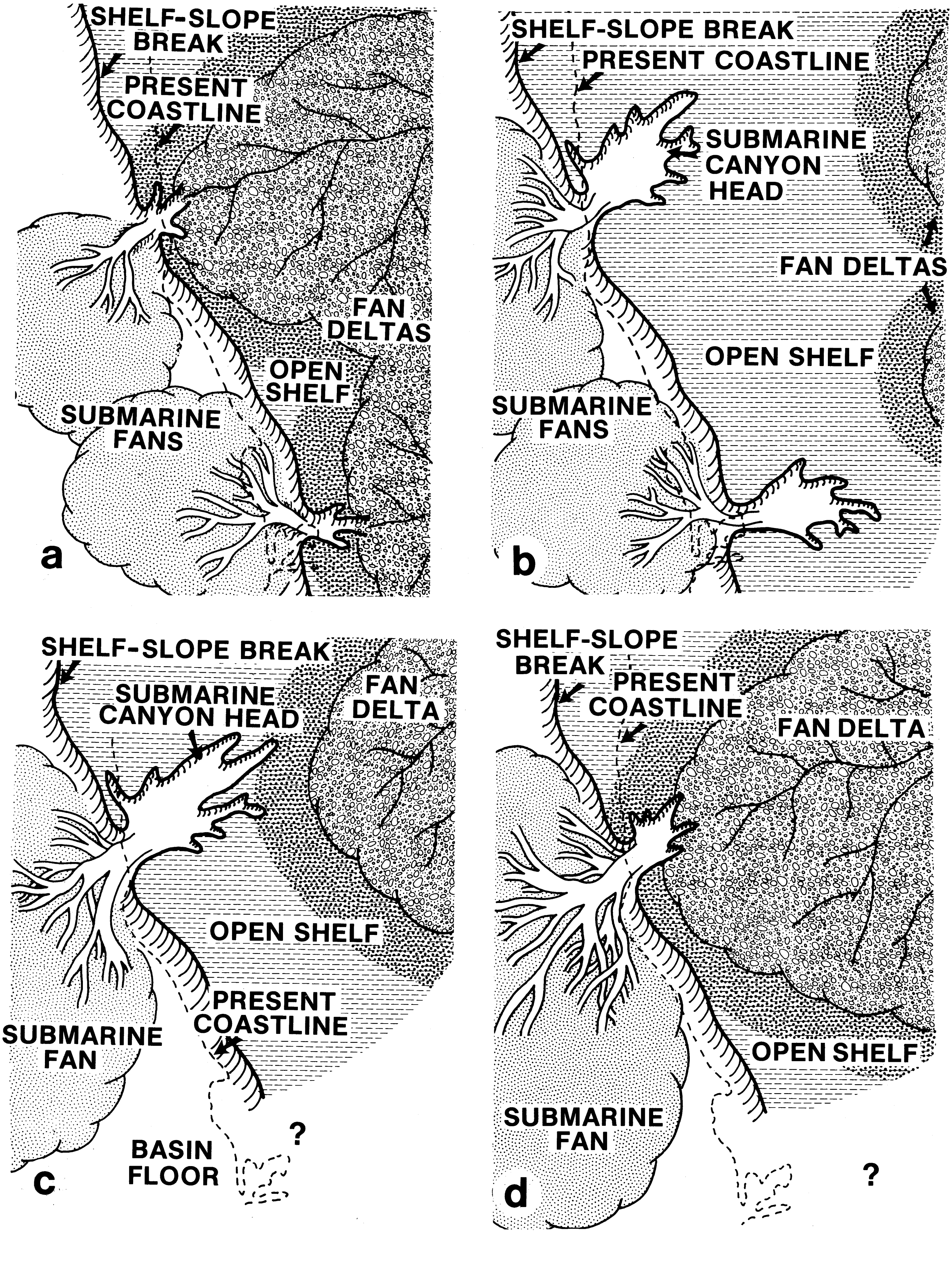
Locality I: Bathtub Rock to Box Canyon

The canyon complex of the Eocene San Diego Embayment was named the Torrey Submarine Canyon after these spectacular beach-cliff exposures (May et al., 1983). This coastal walk is completely within the Torrey Pines State Reserve, managed by the California Department of Parks and Recreation. Rock hammers and sample collecting are strictly prohibited! The reference point for specific stops is the distance south of the entrance to the Reserve.

Stop 1 - Bathtub (Flat) Rock, 1.5 km (0.9 miles)

In the cliff face at beach level, you have been passing along nearshore units of the Delmar Formation and Torrey Sandstone. The green, organic-rich, rippled and burrowed, muddy sandstones of the Delmar

Figure 6. Paleogeographic changes within the San Diego Embayment (also see Lohmar et al., 1979). (a) During the late Early Eocene (Late Penutian) eustatic lowstand, fan-delta deposits underwent subaerial exposure. Fluvial channels entrenched the exposed shelf and funneled coarse clastics directly to a submarine-canyon head. (b) An early Middle Eocene (Ulatisian) global sea-level rise drowned previous fluvial valleys. Submarine canyons eroded headward, then became detached from nearshore sediment sources. (c) A slight eustatic drop occurred in the medial Middle Eocene (latest Ulatisian). Basinward flushing of coarse detritus caused submarine-canyon rejuvenation and submarine-fan progradation. (d) The early Late Eocene (Narizian) eustatic drop led to fan-delta progradation and a last phase of active submarine-canyon erosion and fill. →


SHELF-SLOPE BREAK
PRESENT COASTLINE
FAN DELTAS
OPEN SHELF
SUBMARINE FANS
a
SHELF-SLOPE BREAK
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FAN DELTAS
OPEN SHELF
SUBMARINE FANS
b
SHELF-SLOPE BREAK
SUBMARINE CANYON HEAD
FAN DELTA
OPEN SHELF
PRESENT COASTLINE
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FAN DELTA
OPEN SHELF
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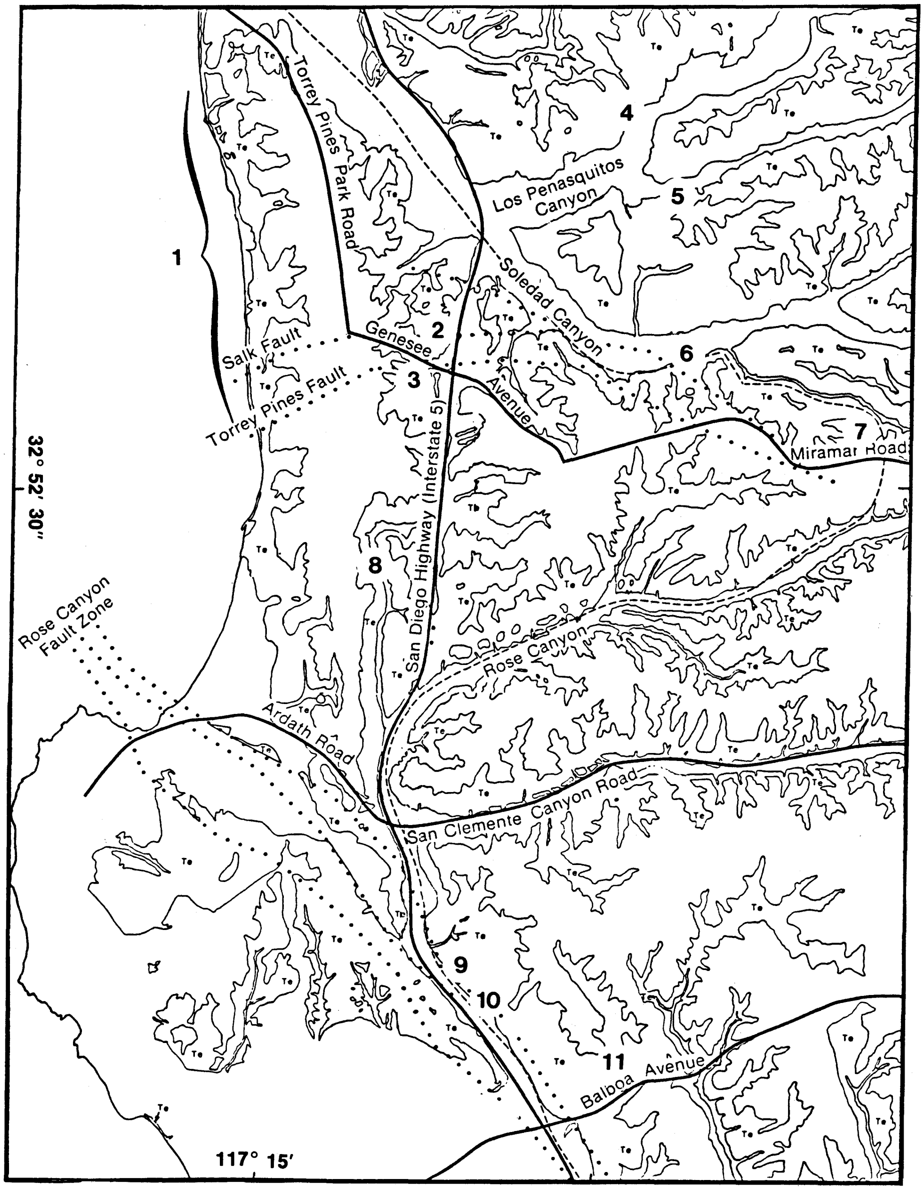


Figure 7. Areal distribution of submarine-canyon exposures. Te designates Eocene outcrops.

	SITE	LOCATION	LONGITUDE AND LATITUDE	
(A) Mudstone-dominated channels:	6	Soledad Canyon	32°53'19"N	117°11'55.5"W
	3	Genesee Ave. South	32°53'15"N	117°13'45"W
	8	Gilman Drive	32°51'59"N	117°14'8"W
	11	Balboa Avenue	32°48'30"N	117°12'27"W
	5	Peñasquitos Canyon	32°54'15"N	117°11'38"W
(B) Mixed sandstone and mudstone channels:	9	Morena Blvd. North	32°50'0"N	117°13'35"W
	10	Morena Blvd. South*	32°49'5"N	117°13'8"W
(C) Fining- and thinning-upward channels:	2	Genesee Ave. North	32°53'22.5"N	117°13'37"W
	4	Peñasquitos Canyon	32°55'1"N	117°12'27"W
	1	Field-trip Locality I (Coastal Walk)	32°54'53"N 32°53'2"N	117°15'23"W 117°14'55"W
	7	Field-trip Locality II (Miramar Road)	32°52'55"N	117°10'40"W

*taken from Kies, 1982

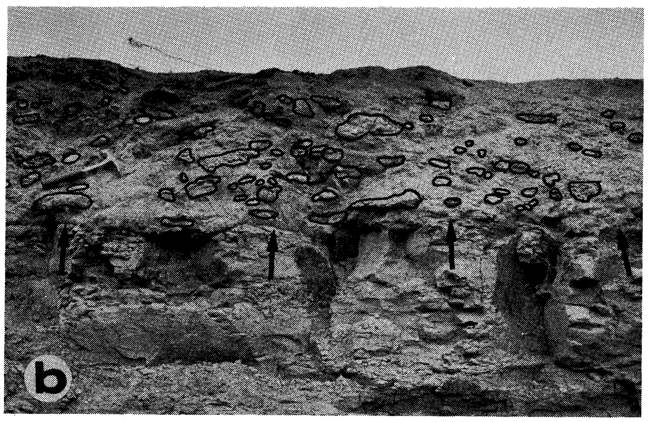


Figure 8. (a) Mudstone-filled channels - which cut mudstone units of the Eocene continental shelf - dominate inland exposures of the submarine-canyon complex. (b) Pebbly sandstones, containing abundant rip-up clasts, often line bases of mudstone-plugged channels. Arrows point to the erosive base of one channel; mudstone clasts are outlined.

represent lagoonal and tidal deposits. The buff, cross-bedded Torrey Sandstone was formed in subaqueous bars and tidal channels (see Boyer and Warme, 1975; Clifton, 1979; Lohmar et al., 1979).

At Bathtub Rock, these shallow-marine deposits are truncated by a sequence of cross-cutting pebbly sandstones - also mapped as Torrey Sandstone. This undulating surface of erosion cuts down across the cliff face, starting from a small topographic bowl on top of the cliffs, north of Bathtub Rock. Disorganized mudstone-clast (intraclast) conglomerates mark the base of the pebbly sandstone facies. This unconformity represents the floor of a submarine-canyon tributary.

Follow the trail up the cliff into the small topographic bowl. Here, the nature of the erosive contact is well-displayed. A steeply dipping surface dissects the cross-bedded, paralic Torrey Sandstone; this surface is one side of the submarine canyon. Bioturbated, concretionary siltstone layers occur within the canyon fill. These ledge-forming strata highlight high-angle bedding surfaces within the submarine-canyon head.

<u>Stop 2</u> - Bathtub Rock to Canyon #1, 1.5-1.8 km

Return to beach level and continue walking south around Bathtub Rock. The canyon floor can be traced across the outcrop to near beach level at Canyon #1 (present-day ephemeral stream valley incised into the cliffs). This submarine unconformity is irregular and stepped, with erosional remnants projecting up into the overlying fill (Figures 9 and 10a). The submarine-canyon floor has been injected into, pried-up, and undercut (Figure 10b). Mudstone- and crystalline-clast conglomerates fill basal scours. Blocks to the size of train locomotives, having caved off the canyon walls, rest upon the erosive base (Figure 10c).

<u>Stop 3</u> - Canyon #1, 1.8 km (1.1 miles)

The lowermost canyon fill is a cross-cutting and very poorly sorted, pebbly, granule to medium-grained, structureless to faintly laminated sandstone. The sandstone beds are amalgamated along surfaces of high depositional relief; mudstone rip-ups - with irregular margins - and crystalline clasts line bases of the cross-cutting units. Each separate cut-and-fill becomes laminated upward above its clast-rich portion. Other amalgamation surfaces are very faint, noticable only by a slight grain-size variation (Figure 10d). Outsize mudstone clasts to 5 meters in length "float" within the sandstone at all levels. This basal fill of the submarine canyon is part of a tripartite fining-upward sequence, consisting of the amalgamated pebbly sandstone, an intermediate laminated sandstone, and uppermost mudstone sequence. This succession probably represents progressive detachment of the canyon tributary from a coarse-grained, nearshore source during the early Middle Eocene eustatic sea-level rise.

Above the pebbly units, well-sorted fine-grained sandstone is characterized by horizontal and convoluted laminae. These laminations are highlighted by abundant organics and mica (Figure 10e). Flame structures, box-like folds, dewatering pillars, dish structures, ripple cross-laminae, and small intraclast stringers are all present (Figure 10f). Laminae become muddier and dewatering features increase upward.

The sandstone strata are then capped by Ardath Shale - tan to gray claystone and silty mudstone. Thin sandstone and siltstone interbeds within the mudstones are variously bioturbated, cross-bedded, rippled, fossiliferous, and cut by sedimentary dikes (Figure 10g). Concretionary, ledge-forming siltstone layers have fallen to beach level from the Ardath mudstone fill. These blocks, when wave-washed, display an abundant variety of trace fossils, dominated by <u>Scolenia</u> (Figure 10h). Bathyal foraminifera are also found in the Ardath mudstones in Canyon #1.

The sandstone and Ardath facies wedge out into the Torrey Sandstone farther north, on top of the cliffs, in Torrey Pines State Reserve. The Ardath facies is overlain by an upper tongue of the Torrey Sandstone at the top of Canyon #1. Stratigraphically, the canyon tributary is thus incised into a

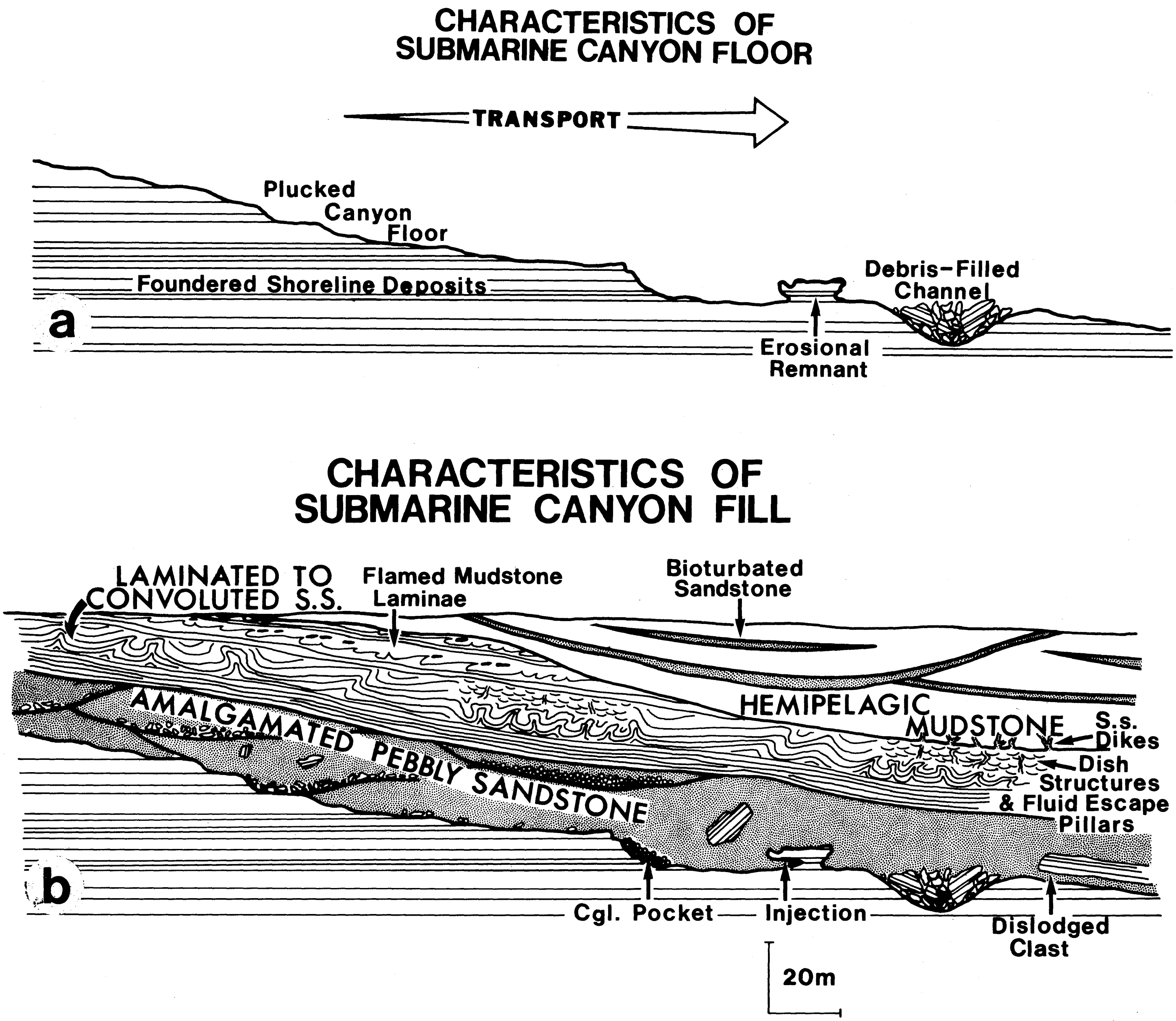
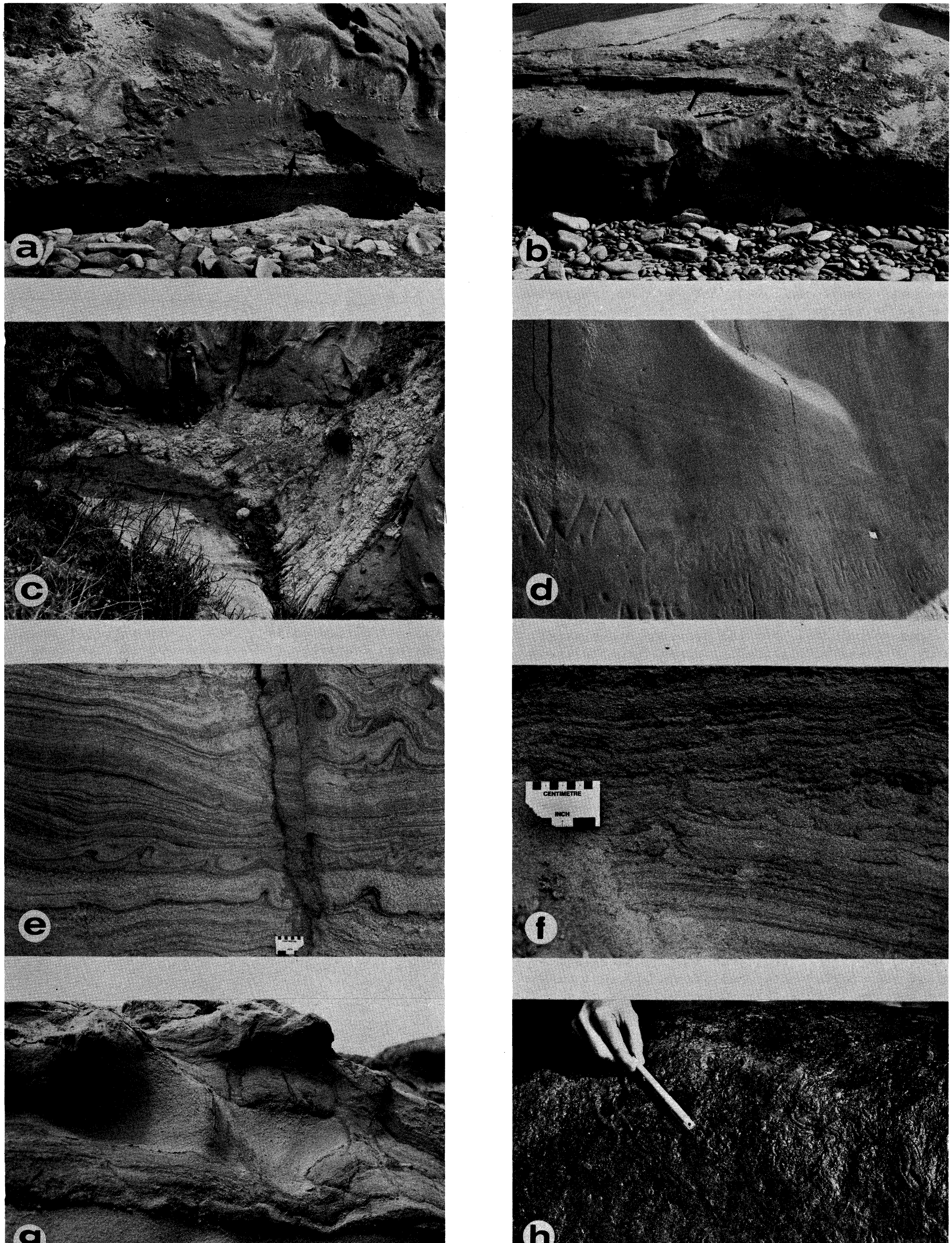


Figure 9. Characteristics of the Eocene Torrey Submarine Canyon tributary at Stop 2, Locality I. (a) Nearshore (lagoonal and barrier bar) deposits were subaerially cut during a late Early Eocene eustatic sealevel drop. The resultant canyon was further shaped during the subsequent sealevel rise, producing an irregular canyon floor. This erosive surface is plucked and stepped, and displays erosional remnants protruding upward, injection features, pry-ups, and intraclast-filled pockets. (See B for scale). (b) The submarine canyon fill is tripartite, representing progressive detachment from the coarse-grained, nearshore source. The basal pebbly sandstone has cross-cutting, amalgamated units with intraclast-rich bases and laminated fill. The overlying planar-laminated sandstone becomes convoluted upward, and displays a concomitant increase in dish structures, fluid-escape pillars, flamed mudstone laminae, and clastic dikes (sedimentary structures are diagrammatic, not to scale). The uppermost cut-and-fill mudstone channels contain siltstone and sandstone layers that are variably graded, rippled, cross-bedded, bioturbated, or richly fossiliferous.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←Figure 10. A tripartite fining-upward succession fills the submarine-canyon tributary at Locality I. (a) Cross-bedded, paralic Torrey Sandstone is eroded by the canyon floor (arrows). This remnant projects upward into the basal pebbly sandstone. The amalgamated, cross-cutting units of pebbly sandstone have mudstone-clast bases and become laminated upward. (b) The undercut canyon floor (arrows) here is composed of Delmar lagoonal units. The Delmar mudstone is eroded and redeposited as clasts above the unconformity. (c) Large mudstone blocks, which fell off the canyon walls, rest upon the canyon floor and are encased by pebbly sandstone. (d) Cross-cutting units within the pebbly sandstone are also subtly marked by slight grain-size changes. (e) The intermediate fine-grained sandstone contains planar to convoluted laminae enhanced by biotite and plant fragments. Upward in the section, the laminae become wavy, flamed (downcanyon to right), and box-like. (f) Muddy laminae, dish structures, and dewatering pillars increase upward within the laminated sandstone. (g) Sandstone dikes cut the uppermost mudstone beds of the laminated sandstone. (h) Bioturbated siltstones of the overlying Ardath Shale contain abundant Scolenia, meandering traces with central furrows and bordering ridges. Similar burrows are produced by heart urchins in modern sediments.

foundered continental shelf and, in turn, capped by a slightly younger prograding shelf. Deposition of these deep-water rocks exposed at Locality I therefore occurred within the head of a submarine canyon.

Stop 4 - Torrey Pines Landslide, 2.2 km (1.4 miles)

Fine-grained, cross-cutting, channel-fill deposits, well-exposed in the cliff face between Canyons #1 and Indian Trail Canyon, represent the final stage of submarine-canyon deposition. Individual channels are up to 600 m wide and 75 m deep. The bases of several channels are draped with mudstone; fine-grained sandstone then plugged these conduits (Figure 4b). A channel-cut nearly 600 m wide extends north and south of the second stream valley south of Bathtub Rock; the submarine-canyon channel is completely filled with fine-grained units. This and the numerous other large muddy channels were probably eroded into the slope by underladen density flows which deposited the bulk of their sediment load out on the basin floor. Meandering currents successively evacuated cross-cutting conduits (Figure 11). The channels were each sequentially filled after being bypassed by the erosive agents which cut them.

Stop 5 - Indian Trail Canyon (Canyon #3), 3.6 km (2.2 miles)

At the third ephemeral stream valley south of Bathtub Rock, a somewhat disorganized to stratified, probably non-marine (fan-delta?) conglomerate outcrops at beach level. This unit is assigned to the Early Eocene Mount Soledad Formation, partly based upon the clast mix of white (Cretaceous-type) silicic and red (Eocene-type) metarhyolite suites. A white, kaolinitic weathered zone is developed on top of the conglomerate, and presumably is a paleosoil horizon (Figure 12). Other evidence of subaerial exposure is the punky, friable nature of the crystalline clasts.

This conglomerate is overlain by cross-bedded and burrowed lagoonal rocks of a transitional Delmar-Torrey facies. These units, in turn, are truncated by the basal pebbly sandstone of the submarine-canyon sequence. Sandstone-injection features, rip-up clasts, and rockfall blocks (off the submarine-canyon walls) are well-displayed along the path up Indian Trail Canyon. The pebbly sandstones are capped by complexly cross-cutting channels of the canyon system; these upper channels are variably filled by fine-grained sandstone, siltstone, and mudstone.

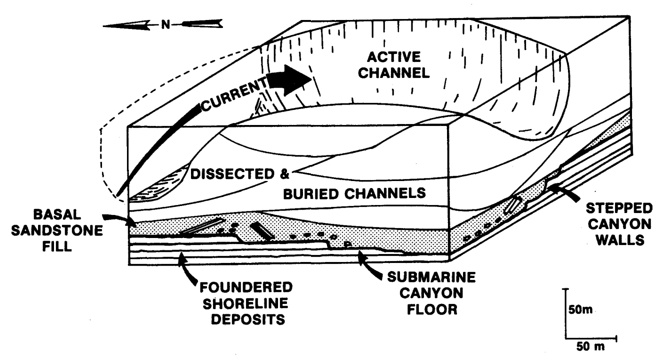


Figure 11. Lithologically varied, cross-cutting channels characterize the Eocene Torrey Submarine Canyon north of San Diego, California. Meandering currents periodically evacuated channels and moved sediment downslope. These channels in turn were plugged by a variety of materials. The scale and nature of such channels depend on canyon configuration and scale, shelf morphology, eustatic change, basin-margin subsidence and uplift, and source fluctuation.

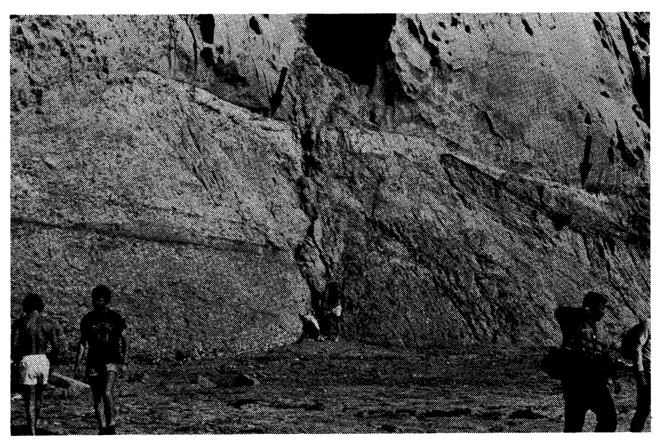


Figure 12. A white, kaolinitic soil zone (arrows) taps the Mount Soledad Formation at the mouth of Indian Trail Canyon. This surface represents a late Early Eocene subaerial unconformity, correlative to a eustatic lowstand. Pebbly sandstone of the submarine-canyon complex, in turn, cuts down into the previously exposed units.

Stop 6 - Hang Glider Port, 4.1-4.5 km (2.5-3.1 miles)

Cross-cutting channels of the canyon complex, on a variety of scales and dominated by fine-grained fills, are well-exposed on the cliff face. Resistant sandstones and siltstones, interbedded with mudstones, outcrop at the tops of the cliffs. These well-cemented layers are variously cross-laminated and horizontal-laminated to completely bioturbated, and often contain both whole and fragmented fossils. Especially abundant are high-spired gastropods (Turritella), thick-shelled bivalves (Ostrea, Acila), and colonial vermetid worm tubes, oftentimes present within monospecific layers and lenses. Exceptionally large Ophiomorpha (over 5 cm thick and 1/2 m long) and Thalassinoides trace fossils are also noteworthy.

These extensive ledge-forming beds are interpreted as shelf deposits - part of a progradational sequence - that capped the submarine-canyon fill. Fossil lags are indicative of periodic storm transport and winnowing; some fossiliferous debris may represent spillover into the canyon head. The neritic-fossil assemblage and abundant macroborings also suggest shelf depths. Blocks of these ledge-forming sandstones can be examined where they have fallen down to beach level.

Stop 7 - Box Canyon (Canyon #4), 5.1 km (3.1 miles)

An exceptionally well-displayed channel-fill sequence, 75 m thick, stretches over 1 km north and south of Canyon #4 (Figure 4g). A fining-upward succession consists of (1) basal amalgamated crystalline- and mudstone-clast conglomerates; then (2) laminated, massive, sandstone; and (3) interbedded sandstone, siltstone, and mudstone; and finally, (4) mudstone. Large convoluted bedding exposed in the massive sandstone suggests rapid, unstable deposition. Large-scale stratification in the conglomerates denotes tractional deposition.

Nested channel-fill deposits along the southern valley margin indicate modification of the canyon walls by a meandering channel thalweg. Smaller channels of conglomerate and sandstone exposed farther south were originally interpreted as submarine-fan channels (Lohmar et al., 1979). Another suggestion is one of terrace deposition adjacent to the main-channel thalweg.

Locality II: Railroad Cut at Miramar Road

Railroad tracks of the Atchison, Topeka, and Santa Fe line pass under Miramar Road approximately 7.4 km (4.5 miles) due east of the Hang Glider Port (Stop 6, Locality I). This second locality is along the railroad tracks, as shown in Figure 7. The longitude and latitude coordinates are 32°52'55" N and 117°10'40" W. Stops are referenced as to distance north from Miramar Road. Although never a previous problem, the cuts are along private property. Permission for examination might be sought from the railroad. Trains do pass through with regularity, and come around curves with little warning. TAKE CARE!

Stop 1 - First Railroad Cut, 0.25 km (0.15 miles)

At the first outcrop north of Miramar Road, buff-colored, Eocene Scripps Formation sandstones are overlain by pebbly sandstones of the reddish, Pleistocene Lindavista Formation. Interbedded sandstones and mudstones with some conglomeratic layers and lenses, compose the Scripps Formation. These strata represent both (1) shelf deposition and (2) fill of submarine-canyon channels incised across the shelf.

Walking north, the first Scripps deposits encountered at track level, along the western cut, are lensoid and irregular sand bodies draped by mudstones. These sandstones internally are trough and hummocky cross-stratified (Figure 13). Tops of these coarse-grained beds are burrowed; Gyrolithes and Ophiomorpha are especially prevalent (Figure 13).

Continuing north, a series of laterally migrating channel fills truncates the interbedded shelf units. The channels are variably draped-and-plugged and fine upward. Mudstone drapes typically thicken along channel margins and thin into the bases (Figure 13). This situation is similar to the "nested channels" described by Walker (1975) in the Capistrano Formation at San Clemente State Beach. Also present are fining-upward channels, which typically have conglomeratic bases. The cobbles display well-developed a-axis imbrication (Figure 13). Margins of these channels are often stepped and steep, with overhanging ledges.

One enigmatic deposit is encountered, being truncated by the channels of the canyon complex. Fine-grained, silty, horizontal-laminated sandstone contains isolated cobbles. Small scour pockets occur around the cobbles (Figure 13e), indicating that the cobbles were spread out over a surface and washed over by currents. The origin of this lithofacies is unknown.

Stop 2 - Second Railroad Cut, 0.5 km (0.3 mile)

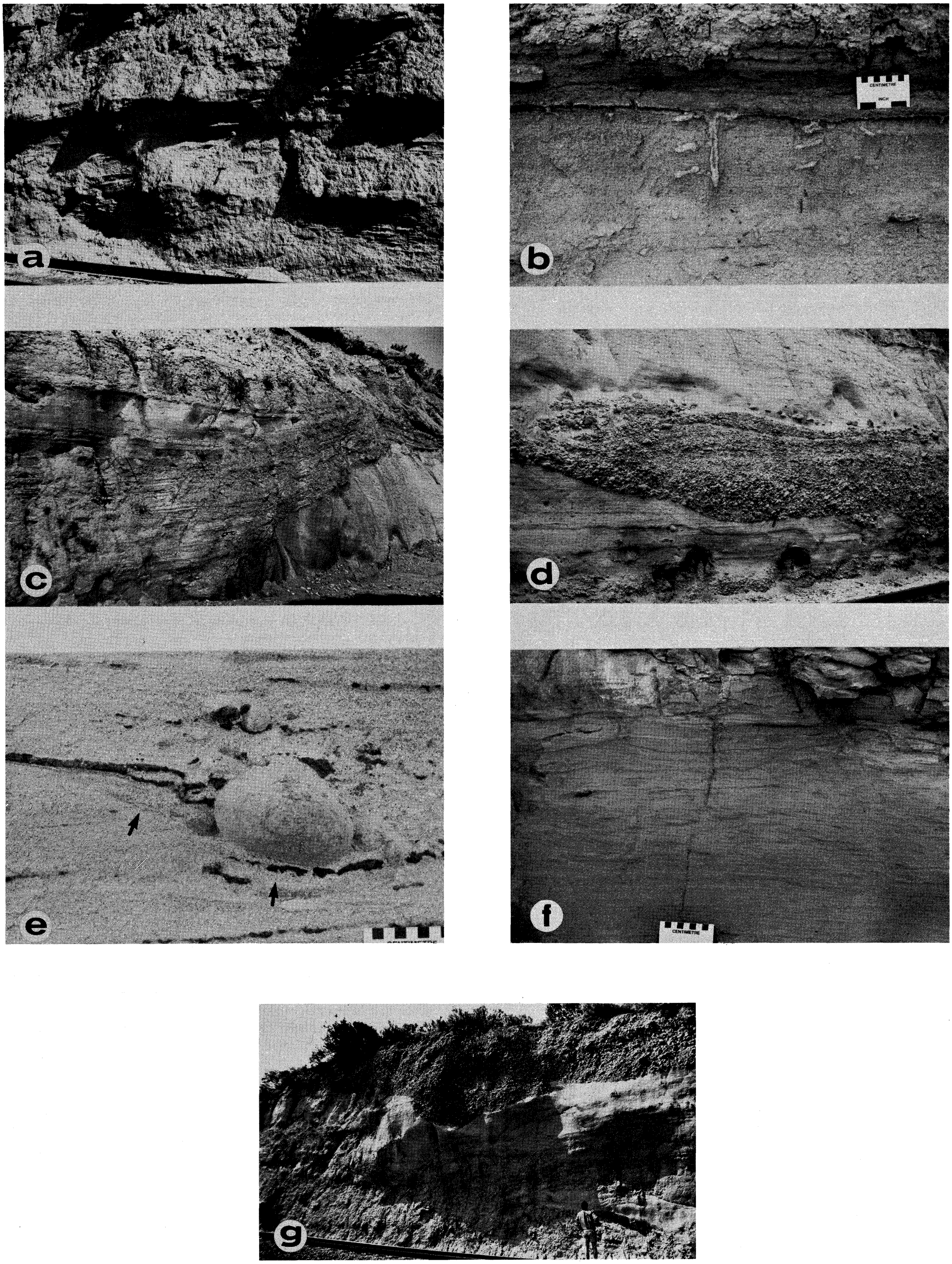
As the railroad tracks curve to the northwest, the Scripps Formation becomes dominantly fine-grained. This sequence is interpreted as shelf units. The mudstones are silty and unburrowed. Upon closer examination, the mudstones actually appear to be composed of multiple, thin, graded cycles.

Interbedded sandstones are of two types. Thin, irregular ledges are hummocky cross-stratified. In contrast, laterally extensive beds appear to be turbidites. Fine-grained sandstones, with horizontal-laminated bases, grade upward to rippled siltstones (Figure 13). These layers display Bouma T_{bcde} successions.

Stop 3 - Third Railroad Cut, 0.8 km (0.5 mile)

The variety of shelf deposits are here truncated by a large sand-filled channel, which in turn is incised by a conglomerate-filled channel (Figure 13). The erosive base is irregular. Mudstone ripup clasts are prevalent in the lower fill.

This portion of the canyon complex is interpreted as representing late Middle to early Late Eocene reactivation. Stadium conglomerate of a fan-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←Figure 13. The submarine-canyon complex truncates coeval shelf units at Locality II. (a) Lensoid sandstone bodies are internally trough- and hummocky-cross stratified. (b) Tops of hummocky-cross stratified beds are burrowed by Ophiomorpha and Gyrolithes, then draped by mudstone. (c) Draped-and-filled channel of the canyon complex. The right-hand channel edge is steep and stepped. (d) Fining-upward channel with basal crystalline-clast conglomerate that displays a-axis imbrication (long axes of cobbles dip upstream, here, to the left). This channel cuts across an enigmatic lithofacies of isolated cobbles in a silty, fine-grained, horizontal-laminated sandstone. (e) Close-up of isolated clasts in the fine-grained, laminated sandstone. Note the scour pocket (arrows) around the cobbles. (f) T_{b-e} turbidite interbedded with shelf mudstones. (g) Progradation of the Stadium fan-delta reactivated submarine-canyon erosion. The basal laminated sandstone fill, which truncates shelf mudstones and sandstones, contains layers of mudstone rip-up clasts. A conglomerate-filled conduit, in turn, is incised into the sandstone fill.

delta system prograded basinward during a eustatic highstand. Nearshore and alluvial detritus was flushed basinward, cutting down into shelf deposits. Ultimately, the fan-delta system capped the submarine-canyon complex. Massive conglomerates of the fan delta may be viewed by continuing along the railroad tracks to the northwest.

CONCLUSIONS

The diversity in submarine-canyon fill types and sequences results not only from hydrodynamic variations, but also from the interaction of such variables as (1) shelf width and gradient, (2) rates of eustasy, subsidence, and tectonics, and (3) input and migration of sediment sources. Canyons that head near pulsating sediment sources are dominated by erosion (Dill, 1981). In contrast, "distal" canyons - those removed from active sources - undergo fill (Dill, 1981). Episodic or progressive variations in sediment supply may thus be controlled by factors such as climatic fluctuation, sea-level change, or river mouth migration. Local sea-level variation is affected by worldwide eustatic events and basin-margin uplift and subsidence. These eustatic and tectonic effects may be in or out of phase, and are further affected by continental-shelf morphology. Therefore, a variety of factors must be considered to explain the fill sequence of any one canyon complex.

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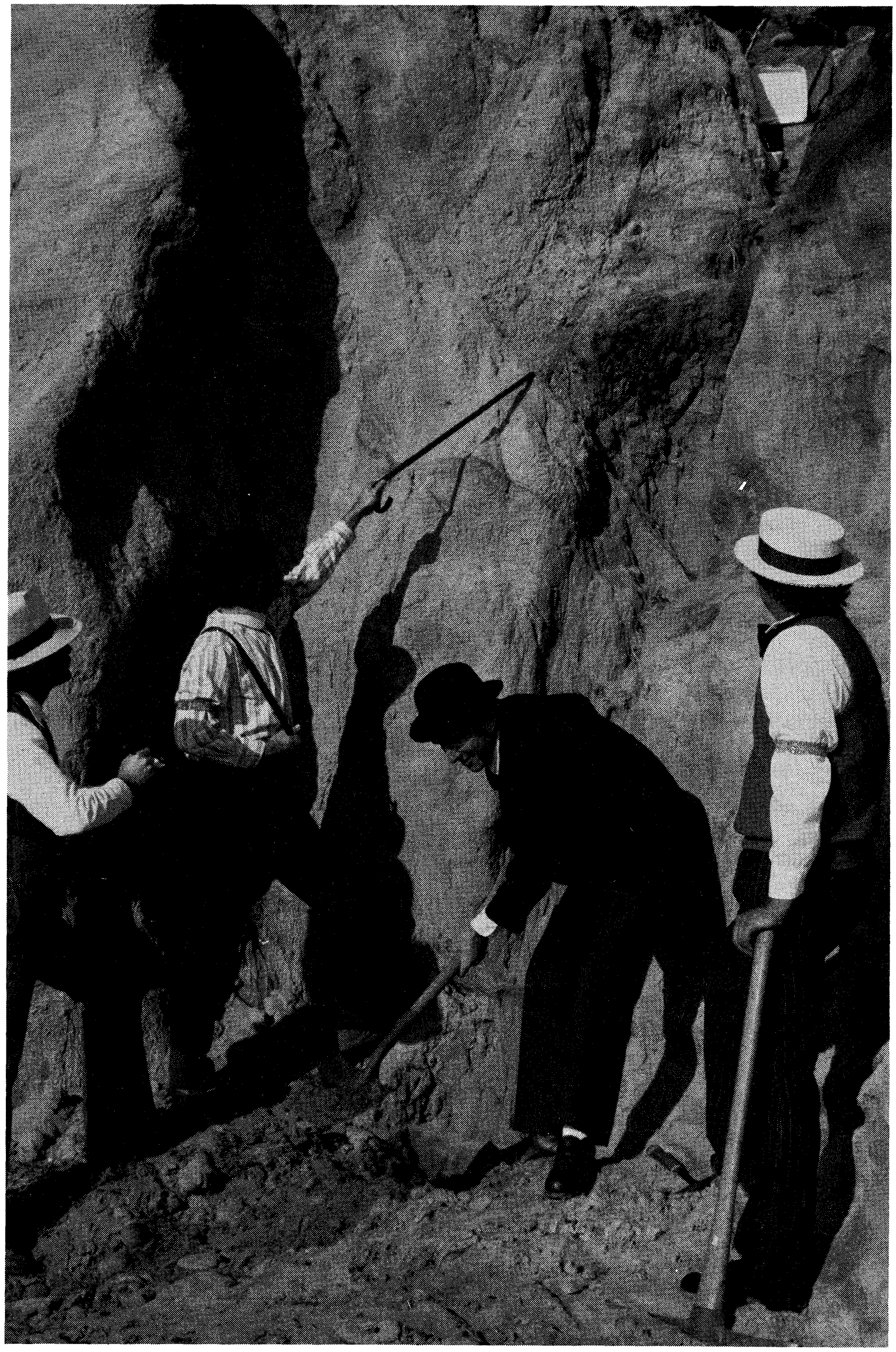

Fault in sea cliffs at Moonlight Beach in Encinitas.

EOCENE LITHOFACIES AND GEOLOGIC HISTORY, NORTHERN SAN DIEGO COUNTY

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INTRODUCTION

As in much of coastal San Diego County the area from Carlsbad to Carmel Valley consists of a narrower coastal plain which laps against a mountainous interior. The coastal plain is made up of nearly flat-lying Pleistocene, Eocene and Upper Cretaceous sedimentary rocks. The mountainous interior is formed from Jurassic Santiago Peak metavolcanic rocks and Cretaceous intrusive rocks, principally tonalite and granodiorite.

The main sedimentary record begins with Upper Cretaceous alluvial and marine conglomeratic sandstone and siltstone. These rocks overlie the older metavolcanic and intrusive rocks along a high relief unconformity. After episodes of tilting, erosion and paleosol formation, deposition during the Eocene laid down a sequence of marine and lagoonal strata which lapped against and covered the underlying terrain. A record of younger sedimentation in the area is not preserved until the Pleistocene.

In this paper are descriptions of the Eocene lithofacies and depositional environments, correlation of the rocks with the recognized stratigraphic nomenclature, and a proposed depositional history. For more detailed descriptions and interpretations of the Eocene section the reader is referred to Ashton (in prep.), Eisenberg (1983), Irwin (in prep.), and May (1982).

LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS

The Eocene section is dominated by cross-stratified, mineralogically immature sandstone. This sandstone occurs in a broad strip along the coast; it commonly does not extend further inland even where the basement contact with Eocene rocks takes an inland bend. Nowhere does this sandstone come in contact with basement rocks although it may reach to within one-quarter of a mile.

The remainder of the Eocene section is mostly an interfingering combination of fossiliferous green claystone and sandstone and coarse, poorly-sorted sandstone. These rocks are found beneath the cross-stratified sandstone and in a belt sandwiched between the cross-stratified sandstone and basement. Where the Eocene-basement contact takes an inland bend the cross-stratified sandstone is commonly replaced by green claystone and sandstone and coarse, poorly sorted sandstone. Smaller volumes of conglomerate and dark siltstone and claystone complete the section.

The Eocene section outlined above can be subdivided into numerous lithofacies, based on a small number of readily and reliably recognized identifying characteristics. These include rock type and texture and any number of sedimentary features. These identifying characteristics have been chosen from field observations and are meant to allow easy recognition of broad lithologic types in the field. Once defined these lithofacies can be mapped in the field to show their detailed horizontal and vertical distribution. From an understanding of the spatial parameters a coherent picture of the stratigraphy, structure and depositional history can be drawn.

Nine lithofacies and three subfacies have been identified based on outcrops in the Encinitas and Rancho Santa Fe 7-1/2 minute quadrangles. The name for each lithofacies is taken from a gross simplification of its distinguishing lithologic characteristics. Figure 1 lists the lithofacies and Figure 2 lists their identifying characteristics. The distribution of these lithofacies as mapped in the Encinitas and Rancho Santa Fe quadrangles is shown on a fence diagram in Plate 2 (in back pocket). In the following section the lithofacies are described and interpreted in terms of depositional environments.

EOCENE LITHOFACIES

LITHOFACIES 1	PEBBLY SANDSTONE
LITHOFACIES 2	CHANNELED CLAYSTONE
LITHOFACIES 3	GREEN CLAYSTONE AND SANDSTONE
LITHOFACIES 4	RIPPLED SANDSTONE
LITHOFACIES 5	CHANNELED AND CROSS-STRATIFIED SANDSTONE
SUBFACIES 5a	PLANAR CROSS-BEDDED SANDSTONE
SUBFACIES 5b	CONGLOMERATE STRINGER SANDSTONE
SUBFACIES 5c	TABULAR AND CHANNEL-FILL CLAYSTONE
LITHOFACIES 6	BURROWED AND CROSS-STRATIFIED SANDSTONE
LITHOFACIES 7	GRAY SILTSTONE AND SANDSTONE
LITHOFACIES 8	CONGLOMERATE WITH SANDSTONE LENSES
LITHOFACIES 9	CONCRETIONARY SANDSTONE

Figure 1. Summary of Eocene lithofacies and subfacies.

LITHOFACIES 1 - PEBBLY SANDSTONE

This lithofacies consists of moderately to very poorly sorted, coarse-grained, granular and pebbly lithic arkoses. Thin pebble and cobble conglomerates are locally common. The larger clasts belong to the Peninsular Ranges suite (Kies, 1982) and are commonly plutonic vein quartz. Green, pebble- and cobble-sized claystone clasts are locally abundant.

Lithofacies 1 rocks commonly occur in nested, erosively-based channels, ranging from ten to several hundred feet in width. Trough cross-stratification is the dominant sedimentary

LITHOFACIES	IDENTIFYING CHARACTERISTICS
1	QUARTZITIC, GRANULAR, PEBBLY SANDSTONE FINING-UPWARD SEQUENCES
2	FINING-UPWARD SEQUENCES SUBORDINATE TO GREEN CLAYSTONE
3	FOSSILIFEROUS CLAYSTONE AND SANDSTONE ABSENCE OF CHANNEL-BASED, FINING-UPWARD SEQUENCES
4	BIOTITE-RICH RIPPLES AND PLANAR LAMINATIONS, UNFOSSILIFEROUS
5	ABUNDANT CROSS BEDS AND CHANNELS, UNFOSSILIFEROUS
5a	PLANAR CROSS BEDS, UNIDIRECTIONAL DIPS ON FORESETS
5b	POWAY-SUITE CONGLOMERATE STRINGERS
5c	TABULAR AND CHANNEL-BASED CLAYSTONE, WHOLLY ENCLOSED BY LITHOFACIES 5
6	ABUNDANT CROSS BEDS AND <u>OPHIOMORPHA</u> BURROWS
7	GRAY SILTSTONE AND SANDSTONE WELL-BEDDED, FOSSILIFEROUS
8	POWAY-SUITE CONGLOMERATE WITH MINOR SANDSTONE LENSES
9	CONCRETIONS SCATTERED OVER SURFACE OF LOW RELIEF

Figure 2. Summary of Eocene lithofacies and their principal characteristics.

structure, although many outcrops are without obvious sedimentary features.

The erosively-based channels are commonly floored with pebbly sandstone, and green claystone and Peninaular Ranges suite clasts. This coarse basal layer may fine upward through coarse- and medium-grained sandstone to green silty claystone (Figure 3).

The pebbly sandstone lithofacies occurs locally in basementward-thickening wedges along the Eocene/basement contact. Good outcrops occur along Palomar Airport Road in Carlsbad, along Alga Road in La Costa and east of Rancho Santa Fe across the San Dieguito River. A few very small outcrops of lithofacies 1 are found seaward of the Eocene/basement contact at localities north and south of Batiquitos Lagoon at the top of the Eocene section (Plate 2 in back pocket).

<u>DEPOSITIONAL ENVIRONMENT</u>

Lithofacies 1 rocks were deposited in coarse-grained deltas which built out into the landward side of a coastal lagoon. Flood waters washed coarse and immature material off the precipitous coastal hills onto muddy lagoonal sediments and into newly carved or deepened distributary channels, or onto the floor of a sandy part of the lagoon.

The channel-based, fining-upward sequences typical of lithofacies 1 probably accumulated as autocyclic pulses during the progradation of coarse-grained lagoonal shoreline deltas. The erosive base of each sequence records a sudden influx of coarse-grained material which scoured the underlying fine-grained deposits. Continued deposition along the distributary under more normal conditions reduced the gradient and carrying power of the distributary. Consequently, each channel filled with vertically finer and finer sediment. Channel switching and delta-lobe abandonment moved the locus of channel formation and deposition to different points around the delta margin. Inactive parts of the delta margin collected muddy, fine-grained sediments until the return of a delta distributary brought coarse sediment again.

LITHOFACIES 2 - CHANNELED CLAYSTONE

Lithofacies 2 is similar to lithofacies 1 pebbly sandstone in that erosively-based channels filled with coarse, pebbly sandstone commonly occur in a fining-upward sequence. The difference between the two lithofacies is that in lithofacies 2 the channels are subordinate to green silty claystone. This claystone contains uncommon sand-filled, polygonal mudcracks (Figure 4).

In fact, the channeled claystone lithofacies can be thought of as an extension of the pebbly sandstone lithofacies in which the uppermost, clayey part of the channel-based, fining-upward sequence is greatly expanded at the expense of the lower, coarser part. The channeled claystone lithofacies is transitional to the pebbly sandstone lithofacies. The boundary between them has been drawn where outcrops consist of more than half coarse-grained sandstone.

The channeled claystone lithofacies is found close to the Eocene basement contact, most commonly adjacent to the seaward side of lithofacies 1 pebbly sandstone. It is also found in the core of a shallow anticline at the south end of San Elijo State Beach in Cardiff-by-the-Sea. Rocks of lithofacies 2 interfinger toward basement with rocks of lithofacies 1 and 3. In the opposite direction it interfingers with rocks of lithofacies 3 and 4 (Plate 2 in back pocket).

<u>DEPOSITIONAL ENVIRONMENT</u>

The channeled claystone lithofacies was deposited in environments immediately lagoonward of coarse-grained lagoonal shoreline deltas. The thick green claystones were deposited in muddy supratidal and intertidal marshes, flats and creeks on the lagoonward fringe of coarse-grained deltas. Mudcracks in the claystone record episodes of exposure and desiccation. During flood periods, coarse-grained sediments extended beyond the edge of the delta and scoured channels, or occupied and deepened existing tidal creeks in the muddy, delta-fringing sediments.

Lithofacies 2 rocks record deposition in environments continuous with and lagoonward of lithofacies 1 coarse-grained deltas. The two lithofacies represent landward and lagoonward parts of one depositional system; this is reflected in the overlapping character of lithofacies 1 and 2.

LITHOFACIES 3 - GREEN CLAYSTONE AND SANDSTONE

Lithofacies 3 is characterized by fossiliferous green claystone and fine- to medium-grained sandstone and siltstone. Oyster beds are common. In outcrop lithofacies 3 may appear similar to lithofacies 2 but differs from it in that oyster beds are present and channel-based, coarse sandstones are absent (Figure 5). Flaser, wavy and lenticular bedding are common. Other sedimentary structures include interlaminated claystone and sandstone, and planar cross-stratification. Shreds and irregular blocks of coal are common, as are trace fossils.

The green claystone and sandstone lithofacies is well exposed in the sea cliffs south of Moonlight State Beach in Encinitas and at north Solana Beach (Figure 6). Here it conformably overlies rocks of lithofacies 2 and underlies sandstones of lithofacies 4 and 5. Lithofacies 3 also occurs at numerous localities inland from the coast beneath the main mass of cross-stratified sandstone and basementward of it in a belt roughly parallel to basement (Plate 2).

DEPOSITIONAL ENVIRONMENT

Lithofacies 3 strata were deposited in a shallow, often brackish coastal lagoon or estuary on intertidal mixed mud and sand flats, and in subtidal channels and bars. The lagoon was probably fringed by mangroves. Oyster bioherms grew in protected parts of the lagoon. Storm and tidal currents swept small, brackish water gastropods and bivalves into tabular-shaped masses. An active infauna of worms and crustaceans mined the often oxygen-starved sediments for organic matter. Chunks of waterlogged wood were buried in the lagoon bottom.

Flaser, wavy and lenticular bedding, and interlaminated mud and sand bedding formed on mixed sand and mud intertidal flats. In slightly deeper, subtidal water, migrating tidal creeks and bars reworked the lagoonal bottom. Deposition of mud from suspension left clay drapes on ripple slip faces. The collapse debris from muddy tidal creek banks was strewn along creek bottoms and ripple slip faces.

LITHOFACIES 4 - RIPPLED SANDSTONE

Lithofacies 4 consists of light-colored, well-sorted, fine- to medium-grained, biotite-rich lithic arkose. It is characterized by a "wispy" appearance in outcrop which is formed by numerous, discontinuous, wavy and non-parallel, biotite-rich laminae. In better exposures the biotite wisps can be seen to form ripple foresets and planar laminae. The ripples commonly show a reversal of foreset dip in superjacent sets (Figure 7). Clay flasers are widespread but uncommon. Planar biotite laminae are laterally continuous and may be shallowly scoured. The fill above the scour is a similar rippled and laminated biotite-rich sandstone.

The rippled sandstone lithofacies occurs in sea cliff exposures south of Moonlight State Beach where it overlies strata of lithofacies 3, and at the north end of Ponto State Beach in Leucadia where it is interstratified with and overlies sandstone of lithofacies 5. Inland from the coast, lithofacies 4 outcrops at scattered localities in a belt parallel to the Eocene-basement contact. Along this outcrop belt and toward basement, lithofacies 4 interfingers with and overlies rocks of lithofacies 3 and 2. In the opposite direction it interfingers with and underlies rocks of lithofacies 5 (Plate 2).

Lithofacies 4 rocks commonly are interstratified with and are volumetrically inferior to lithofacies 5 channeled and cross-stratified sandstones. They have been separated from lithofacies 5 as a mapped unit where they can be seen to compose the majority of outcrops in a particular area, but elsewhere are mapped in with lithofacies 5. In these areas the rippled sandstone lithofacies is more common lower in the section and in more basementward outcrops.

DEPOSITIONAL ENVIRONMENT

Lithofacies 4 was deposited on lower intertidal sand flats. Alternating traction and suspension deposition in biotite-rich, sandy sediments formed biotite flasers and biotite-rich planar laminations. Late-stage emergence run-off cut small scours later filled by renewed tidal deposition.

LITHOFACIES 5 - CHANNELED AND CROSS-STRATIFIED SANDSTONE

Rocks of this lithofacies are light-colored, moderately- to well-sorted, mostly medium-grained, biotite-bearing lithic arkoses. From south to north the grain size decreases and the sorting improves. Lithofacies 5 is characterized by abundant cross stratification. Trough, planar and longitudinal cross-bedding types have been recognized. Trough and planar cross beds commonly have alternating foresets rich in biotite and/or with slight alterations in grain size. Green claystone chips may occur along the base of foresets and along the base of the set.

Longitudinal cross bedding is fundamentally different from planar and trough cross bedding in that longitudinal cross beds dip normal to the general flow direction. Planar and trough cross beds dip generally parallel to flow direction. In addition, single planar or trough foresets usually consist of one homogeneous layer, but longitudinal "foresets" may be made up of several bedding types, including interlaminated clay and sand bedding, lenticular bedding or ripple bedding (Reineck and Singh, 1980). In the field, longitudinal cross bedding has been distinguished from other types by the presence of interlaminated clay and sand bedding along the base of cross bed sets and the lower part of the cross beds (Figure 8).

Lithofacies 5 is also characterized by channels. These occur as single or nested scour surfaces, often lined above the base with clayey sandstone and/or

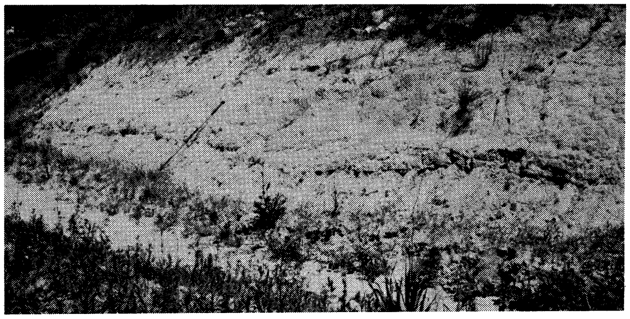

Figure 3. Erosively-based fining-upward sequence in lithofacies 1. Base of sequence is scoured into green silty claystone at the top of the underlying fining-upward sequence. Locality is east of the San Dieguito River at intersection of sections 13, 14, 23 and 24, T. 13S., R. 3W.

Figure 4. Sand-filled polygonal mudcracks in lithofacies 2. South end of San Elijo State Beach.

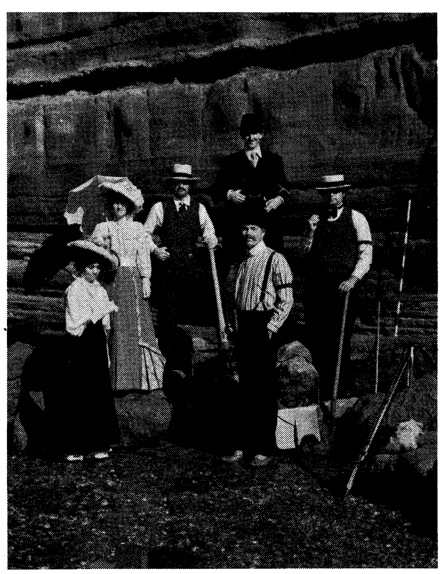

Figure 5. Geologists standing on oyster biostrome of lithofacies 3. Beach cliffs at south end of Solana Beach are comprised of planar-based sandstones and interlaminated mudstones of lagoon-tidal flat environments.

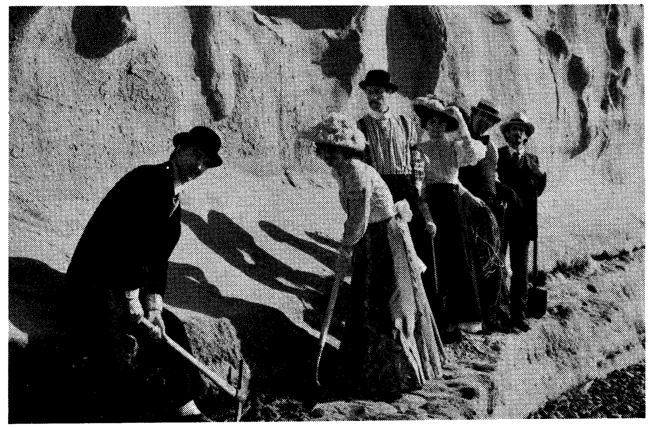

Figure 6. Biotite-rich ripple cross bedding. Superjacent sets have oppositely inclined foresets. Outcrop 200 feet east of El Camino Real, 1,400 feet north of Mountain Vista Drive in Encinitas.

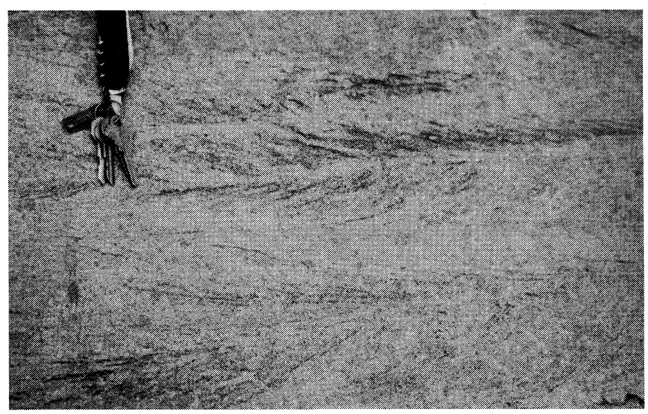

Figure 7. Clay drapes on lateral accretion surfaces in longitudinal cross-bed set. Interlaminated clay and sand bedding at base of set. Locality 800 feet S35°W from the intersection of La Costa Blvd. and El Camino Real.

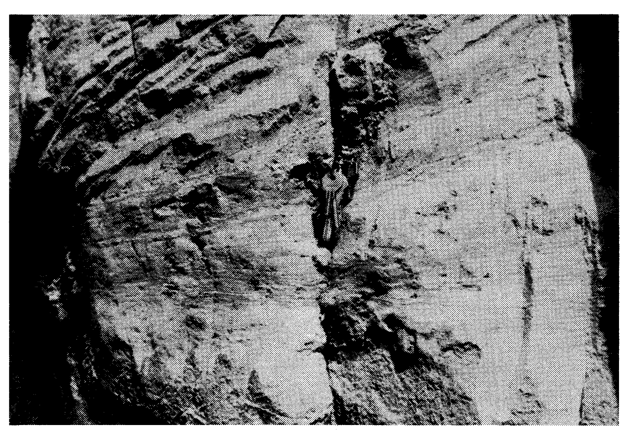

Figure 8. Contact between Delmar and Torrey formations at Moonlight Beach in Encinitas.

interlaminated claystone and sandstone. These channels are filled with longitudinal cross-beds or green or reddish-brown claystone. Channels range from about five to thirteen feet in depth and from 20 to over 140 feet in width.

Trace fossils, principally Ophiomorpha nodosa are locally abundant, as are iron oxide-rimmed concretions. These concretions may range in size from small spheroids six inches in diameter to great oblate masses two feet deep and eight feet wide.

Lithofacies 5 and its subfacies comprise the greatest part of the Eocene section. It crops out in the sea cliffs north and south of Moonlight State Beach and again at Leucadia (Figures 9 and 10). Inland, nearly the entire coastal strip is underlain by these rocks except in areas close to the Eocene basement contact where they are replaced by rocks of lithofacies 4, 3, 2 and 1 (Plate 2).

DEPOSITIONAL ENVIRONMENT

Lithofacies 5 was deposited in sandy subtidal and intertidal environments. Longitudinal cross-stratification formed on migrating subtidal point bars in sandy channels and creeks. Those nearest the associated tidal inlet were floored by a scour surface covered with a lag of claystone clasts and marine fossils. Trough and planar cross stratification formed in subtidal and intertidal channels and bars. Abandoned tidal creeks were filled with clay from suspension. Deposits in these environments interfingered on their landward side with lower intertidal flat sandy sediments.

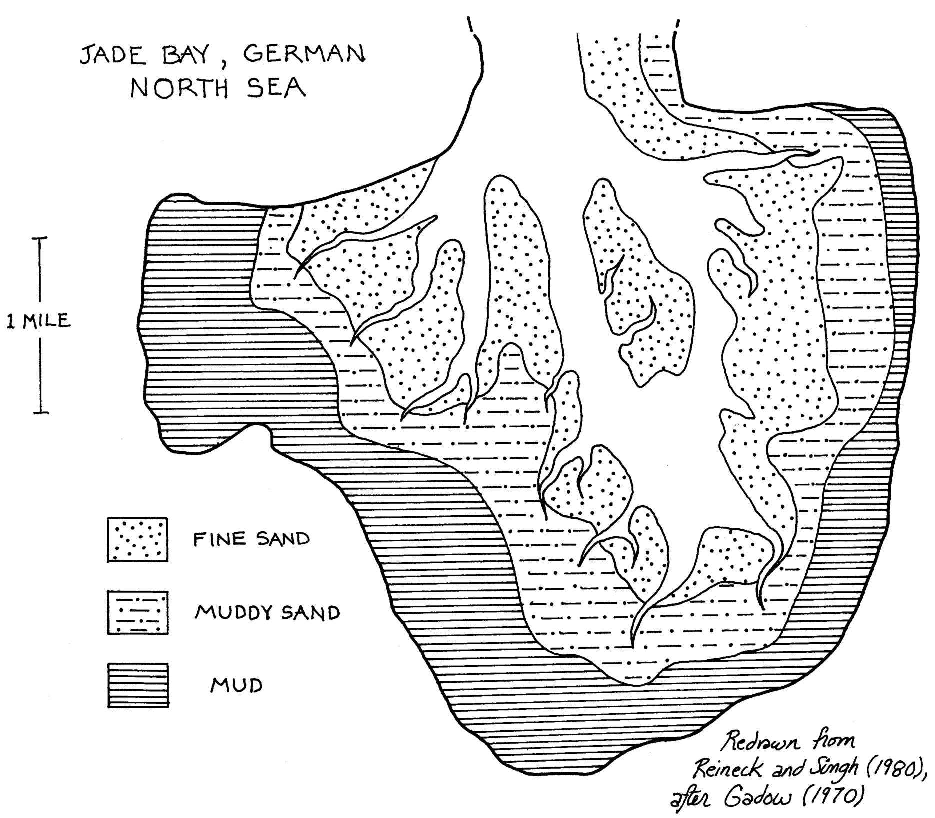

Figure 11. Typical landward-fining distribution of sediments in a tidal bay or estuary.

Lithofacies 5 records, with its subfacies and lithofacies 1 through 4, a complete record of landward to seaward lagoonal environments. Coarse-grained deltas and muddy supratidal/intertidal environments (lithofacies 1, 2, and 3), lay adjacent and parallel to a rugged shoreline. Sandy deposits are found further seaward, representing sandy intertidal flats (lithofacies 4), and intertidal and subtidal channels, creeks and bars (lithofacies 5). The furthest seaward deposits record deposition at the entrance to a tidal inlet.

This landward-fining sequence is common in tidal lagoons and estuaries (Evans, 1965; Klein, 1971; De Jong, 1977; Boothroyd, 1978) (Figure 11). Along a rugged coastline a coarse, lagoon-fringing belt would be an addition to the sequence. A diagrammatic view of the inferred lagoonal depositional belts represented by lithofacies 1 through 5 is shown in Figure 16.

SUBFACIES 5a - PLANAR-BASED CROSS-BEDDED SANDSTONE

The sandstone of this subfacies is similar to that of lithofacies 5 but it is generally coarser grained and trace fossils are uncommon to rare. The distinguishing characteristic of this lithofacies is the abundance of planar-based cross beds, almost to the exclusion of other types. In addition, the reversal of cross-bed dips in superjacent sets, relatively common in lithofacies 5, is not seen in subfacies 5a. Instead, the cross beds dip consistently in a southeasterly direction. The foresets commonly are made of alternating layers of coarse-grained and very coarse-grained to granular sandstone. Subfacies 5a is gradationally underlain by sandstones of lithofacies 5. It is overlain by claystone of subfacies 5c. Laterally subfacies 5a probably interfingers with and grades rapidly into sandstones of the channeled and cross-stratified lithofacies 5.

The planar-based, cross-bedded sandstone subfacies is recognized in a steep-walled canyon on the south side of San Elijo Lagoon just west of interstate 5 and in building pad cuts east of Marine View Avenue in Solana Beach.

DEPOSITIONAL ENVIRONMENT

At the San Elijo Lagoon locality, subfacies 5a can be seen to consist of a nearly 100 foot-thick stack of one- to three-foot-thick planar cross beds whose foresets dip consistently in a southeasterly direction. A few basal planar cross-bed sets, interbedded with longitudinal cross beds, have foresets dipping westerly. At the top of the exposure this subfacies grades rapidly into a thick claystone. The coarseness of the sandstone and lack of burrows both suggest deposition in strong currents, on an unstable substrate. Since the migration of sand waves produce planar-based cross stratification (Reineck and Singh, 1980) it appears that subfacies 5a

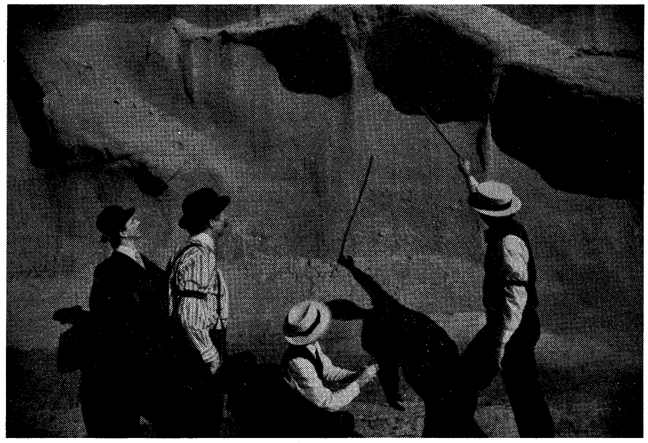

Figure 9. Channeled and cross-stratified sandstone of lithofacies 5 at Moonlight State Beach.

Figure 10. Burrows in lithofacies 5 at Moonlight State Beach.

Figure 12. Conglomerate bed in subfacies 5b. East-facing road cut along County Haul Road. Entrance to road 1,200 feet west of intersection of Encinitas Blvd. and Manchester Avenue.

Figure 13. Lagoon/tidal flat topography draped by conglomeratic storm layer. Same locality as Figure 12.

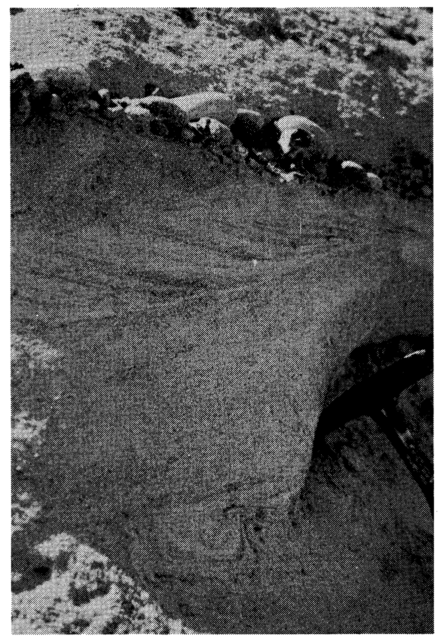

Figure 14. Biotite-rich rippled sandstone truncated by conglomerate stringer. Subfacies 5b. Same locality as in Figure 12.

Figure 15. Conglomerate with sandstone lenses. Lithofacies 8 outcrop in Rancho Santa Fe on south side of private driveway meeting Puerto del Sol 1,400 feet east of the intersection with Linea del Cielo.

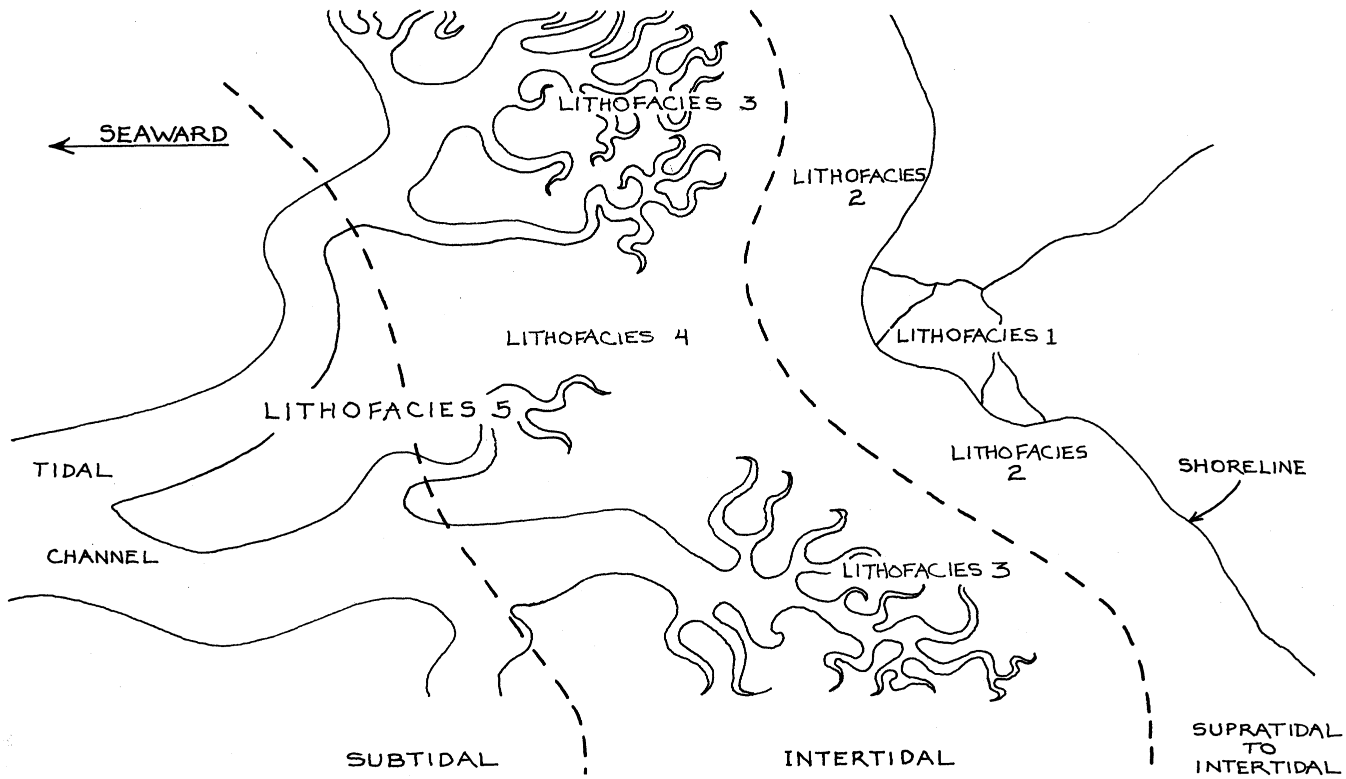

Figure 16. Inferred relationships between Lithofacies 1 through 5 and depositional setting within a tidal lagoon.

records the vertical accumulation of several score unidirectional sand-wave migrations.

The consistent landward dip of the cross beds probably resulted from deposition in a flood-tidal delta. Flood oriented sand waves are the dominant bedform in microtidal and mesotidal (0-2 meter and 2-4 meter tidal range, respectively) flood tidal deltas. Ripples and megaripples are subordinate and generally are destroyed and reformed during each ebb and flood stage. Sand waves are a stable bedform and persist in their flood orientation throughout the tidal cycle (Hine, 1973; Boothroyd, 1978).

A typical flood-tidal delta contains subordinate ebb-dominated areas that accommodate the reverse flow. In these areas, ebb-oriented sand waves have been recorded (Boothroyd, 1978). Flood-tidal deltas may have several lobes. Bedform orientation may be spread nearly 90° on either side of the direction normal to the barrier island trend (Hine, 1973).

In subfacies 5a the lowest, westerly-oriented planar cross strata at the San Elijo Lagoon site may have formed, along with interbedded longitudinal cross-strata, in mostly ebb-dominated channels and bars in a flood-tidal delta. The overlying south- and southeasterly-oriented sets of planar-based cross beds probably formed to one side, the southern, of a flood-tidal delta, on the flood ramp or in flood channels. Just to the west lay the associated tidal inlet and a barrier system trending subparallel to the modern shoreline.

A change in depositional setting, possibly due to a change in basin subsidence, or inlet migration, is recorded at the top of lithofacies 5a where it grades into a tabular claystone of subfacies 5c.

SUBFACIES 5b - CONGLOMERATE-STRINGER SANDSTONE

This subfacies has the characteristics of lithofacies 5, plus a conglomeratic component. The conglomerate occurs as one- to three-cobble thick pebble and cobble conglomerate stringers. The conglomerate also occurs in tabular beds six inches to two feet thick and in irregular beds which pinch and swell along their length from one cobble to more than five feet thick (Figures 12 and 13). These conglomerate beds are wholly enclosed by sandstone with cross-bed and channel features of lithofacies 5.

The conglomerate stringers and beds are laterally persistent. They are not closely spaced in the vertical sense but are separated by five to twenty feet or more of non-conglomeratic sandstone. The beds are commonly planar and horizontal but also may undulate in outcrop above and below a horizontal line. Troughs and channels may be completely or partially lined with conglomerate.

The conglomerates are commonly clast-supported and are moderately- to poorly-sorted. Some less well-defined conglomerate beds are matrix-supported. Most conglomerate beds are not graded but some do show normal or reverse grading. Imbrication is uncommon but suggests flow from the east and south. Clasts within the conglomerates invariably belong to the Poway suite of exotic rhyolites and rhyodacites.

Outcrops of the conglomerate stringer sandstone subfacies outline an elongate, northwesterly-trending lobe that reaches through Rancho Santa Fe to an area northwest of Olivenhain (Plate 2). This lobe of subfacies 5b strata is at least 90 feet thick along the axis and thins rapidly toward the periphery. The average conglomerate bed thickness is at a maximum along the axis of the lobe. Away from the axis the average bed thickness decreases rapidly. Good outcrops occur in Rancho Santa Fe, in eastern Encinitas along El Camino Real and in and around the triangular area bounded by El Camino Real, Manchester Avenue and Encinitas Blvd.

Subfacies 5b is enclosed by and grades into sandstones of lithofacies 5. In the triangular area defined above, subfacies 5b is directly overlain by claystone of subfacies 5c. In Rancho Santa Fe it grades to the southeast into conglomerate of lithofacies 8.

DEPOSITIONAL ENVIRONMENT

Subfacies 5b records the delivery of Poway-suite gravels into lithofacies 5 sandy subtidal and intertidal channel, bar and tidal flat environments. The thickness distribution of subfacies 5b outlines a narrow, northwest-trending lobe. The conglomerate beds thicken to the southeast and imbrication suggests transport from that direction. Subfacies 5b represents the northern distributary of the massive Poway alluvial fan/fan delta that lay south of the study area. This lobe prograded northwestward as a lagoonal delta from the Poway fan source to the south.

The conglomerate stringers are clearly intercalated between sandy tidal deposits. Features characteristic of lithofacies 5, such as channels lined with muddy sandstone and biotite-rich, herringbone ripple cross strata, are present in the sandstones that separate gravel stringers. Some of these features are truncated by a conglomerate stringer (Figure 14). At numerous localities conglomerates undulate through an outcrop, changing from a horizontal feature to a dipping one and back again. The Poway suite gravels evidently were spread across a non-planar, pre-existing tidal carved topography, which in places was also scoured and channeled by the gravel-bearing flood currents.

Lagoonal deltas preferentially grow across the deepest part of a bay or lagoon (Donaldson, 1970). The conglomeratic delta distributary represented by strata of subfacies 5b appears to have followed the same pattern. The conglomeratic lobe trends northwestward, subparallel to the paleoshoreline and the probable trend of the barrier island. Between these two elongate highs the gravels prograded northwestward across the deeper parts of the Eocene lagoon.

Subfacies 5b was deposited as a series of flood gravels flushed across sandy subtidal and intertidal flats and channels. During deposition of the gravels fluvial processes overwhelmed those of the lagoon. A single, narrow, northwesterly-trending distributary extended up from the south. Along its course thick deposits of gravel and sand formed along the prograding delta distributary front. Around its periphery a halo of gravel stringers were intercalated with sandy tidal sediments.

SUBFACIES 5c - TABULAR AND CHANNEL-FILL CLAYSTONE

Subfacies 5c is characterized by three- to ten-foot thick tabular beds of green to reddish-gray, unfossiliferous claystone and silty claystone. Locally these tabular beds are continuous with underlying claystone-filled channels up to 15 feet thick. The claystone may contain a few thin and discontinuous sandy lenses but otherwise appears featureless. No gravel or scour features mark the base of subfacies 5c claystones although the basal contact with lithofacies 5 sandstone or subfacies 5b conglomerate is sharp or gradational over only a foot or two. The upper contact of the claystone is also sharp but locally was eroded before deposition of lithofacies 5 sandstone.

Tabular and channel-fill claystone occurs only locally and, apparently, as thin but laterally persistent lense-shaped masses. It is for the most part wholly enclosed by lithofacies 5 sandstone (Plate 2).

DEPOSITIONAL ENVIRONMENT

The claystone of subfacies 5c was probably deposited from suspension over the pre-existing bottom topography of a sandy tidal lagoon. Tabular claystones record deposition over an abandoned, nearly planar sandy bottom. Where the tabular claystone deviates from the horizontal and follows the bottom of a channel or expands to fill an underlying channel, subfacies 5c represents suspension deposition over abandoned sandy tidal creeks.

The non-scoured but sharp basal contact and the sharp, locally scoured upper contact suggest that subfacies 5c claystones were deposited over sandy tidal deposits after a relatively quick abandonment of the sandy tidal regime, and that sandy tidal environments reoccupied the same site after an interval of deposition in quiet water conditions.

The claystones of subfacies 5c cannot be traced laterally for more than a mile or so in any direction, and appear to pinch out to the west (seaward) as well as to the east (landward). The seaward pinching strongly suggests these claystones are lagoonal, rather than marine in origin.

Subfacies 5c claystones were probably deposited during relatively abrupt interruptions in the accumulation of sandy tidal sediments. These interruptions may have been the result of abandonment of all or part of a sandy tidal creek drainage system. Blockage of a tidal inlet by major storms, migration of a tidal inlet and beheading of the corresponding tidal creek system, or avulsion and stranding of a major branch of a tidal creek system all may have been processes that led to the replacement of a sandy depositional regime with a muddy one.

Brief regressions may have interposed muddy tidal lagoon sediments within sandy tidal lagoon deposits but this appears to be an unlikely explanation for subfacies 5c claystones. This is because subfacies 5c claystones are not continuous basementward with thick, clay-rich sediments deposited along the landward margin of the Eocene tidal lagoon and appear to instead pinch out in that direction.

LITHOFACIES 6 - BURROWED AND CROSS-STRATIFIED SANDSTONE

Lithofacies 6 consists of sandstone similar to that of lithofacies 5 but with a different suite of sedimentary structures. Large, up to four feet thick, laterally continuous trough and planar cross-bed sets are common and are interbedded with and grade laterally into heavily burrowed sandstone. Longitudinal cross beds and claystone beds are absent, although claystone chips and laminae are present on cross-bed foresets at a few sites. Burrows are very abundant and appear to be mostly Ophiomorpha nodosa. Burrows range up to two inches in diameter, with thick, robust burrow walls.

A pronounced change in the dominant cross-bed dip direction occurs in this lithofacies. Lower in the exposed lithofacies 6 section, foreset dips are to the north and northwest. Across a fault, foresets in the higher part of the lithofacies 6 section dip southerly.

A few, thin, sparse conglomerate stringers are also found in lithofacies 6. Low in the section a few, broad, shallow nested channels are lined with a sparse collection of pebbles and cobbles which appear to be mostly Peninsular Ranges suite clasts. The rounded clasts range up to six inches in diameter. A few green siltstone clasts are also present.

High in the section sparse and poorly-sorted pebble, cobble and boulder conglomerate occur as a few, one-clast-thick, laterally persistent stringers. Some of these clasts are nearly one foot in diameter, and all clasts appear to belong to the Peninsular Ranges suite. Pieces of woody material are also present with these conglomerate stringers. The sandstone above and below these stringers is granular and poorly sorted.

Lithofacies 6 is exposed in the sea cliffs north of Moonlight State Beach in Encinitas where it conformably overlies lithofacies 5 sandstone and conformably underlies gray siltstone and sandstone of lithofacies 7. Lithofacies 6 has not been recognized inland from the coast but probably overlies and interfingers with lithofacies 5 sandstone in that direction (Plate 2).

DEPOSITIONAL ENVIRONMENT

The burrowed and cross-stratified sandstone lithofacies rests conformably above sandy tidal channel and bar deposits of lithofacies 5 and below nearshore marine siltstone of lithofacies 7. Lithofacies 6 records deposition in environments transitional between those of lithofacies 5 and 7.

Low in lithofacies 6 are large, consistently northerly-dipping cross strata. Farther to the north, laterally and up section, these cross strata are locally obliterated by burrowing. Burrows are overwhelmingly Ophiomorpha nodosa (large form) with thick, robust walls and burrow diameters approaching 2 inches. These large burrows indicate a littoral environment with strong currents and waves and unstable sands (Boyer and Warme, 1975).

At the top of lithofacies 6 the sandstone is thoroughly burrowed by Ophiomorpha nodosa (small form). These deposits accumulated in quieter offshore environments in stable sands little affected by currents and waves. The contact with siltstones and claystones of lithofacies 7 approximates the seaward limit of littoral sand.

The seacliff sections at Encinitas and Leucadia consistently suggest that the sediments were deposited further and further seaward of a sandy tidal channel environment. These environments include, moving upsection: the seaward side of a tidal inlet; ebb-tidal delta and/or longshore bar troughs; and quiet nearshore sandy bottom. These environments are here referred to, crudely, as an "outer barrier complex".

Conspicuous by their absence are barrier crest dunes, beach and upper shoreface deposits. In the transition from lagoon to nearshore marine environments these littoral deposits would be expected. Apparently a barrier island system was in place during the deposition of lithofacies 6 but any associated shoreline deposits were not preserved. This is especially likely during a transgression and the coastal section clearly records a major transgression. During the advance of the sea over a barred coastline, surf action along a narrow zone near the base of the shoreface may have planed-off shoreline and barrier sediments.

LITHOFACIES 7 - GRAY SILTSTONE AND SANDSTONE

Lithofacies 7 is characterized by fossiliferous, gray, well sorted, very fine- to fine-grained, biotite-bearing lithic arkose and siltstone, and grayish-green silty claystone. Laterally persistent biotite-rich laminations are common and small pieces of coal are present locally. Calcium carbonate-cemented, spheroidal to oval-shaped concretions, up to one foot in diameter, are common.

One of the fossiliferous beds in lithofacies 7 contains abundant, large, thick-shelled bivalves and gastropods which float in a matrix of gray siltstone and very fine-grained sandstone. Floating amid the mollusc shells are numerous granules and pebbles of plutonic vein quartz and a few bits of coal. This unusual fossil bed can be traced laterally more than 400 feet. This bed is probably a storm return-surge deposit.

Microfossils from this site (S.D.S.N.H. 296) have been studied by Mark Filewicz and Al Almgren of Union Oil Company. Nannofossils indicate a middle Eocene age, and are indicative of the Nannotetrina quadrata zone, subzone probably CP13c of Okada and Bukry (1980). Fragments of Micrantholithus and Pemma suggest close proximity to shore.

Only benthonic foraminifera were found in the sample. They indicate a probable age of B-1 to B-1A zone of Laiming (1943), or upper Ulatisian marine stage of Mallory (1959). Most of the species indicate outer neritic depths but the presence of one specimen of Amphimorphina cf. A. californica suggests a possible upper bathyal depth.

Bukry (1980) previously examined the same sample for coccoliths and suggested that the assemblage was a shallower-water biofacies of the middle Eocene Ardath Shale assemblage.

Gray siltstone and sandstone of lithofacies 7 are recognized in the sea cliffs from west of Daphne Street in Leucadia north to the Grandview Avenue beach access stairway. Lithofacies 7 rocks rest conformably on lithofacies 6 sandstone and are overlain above a scoured surface by longitudinally cross-bedded sandstone of lithofacies 5. Inland of the coast, lithofacies 7 has not been recognized but probably pinches out in that direction between lithofacies 6 sandstone and the scour surface that is overlain by lithofacies 5 sandstone (Plate 2).

DEPOSITIONAL ENVIRONMENTS

Lithofacies 7 is underlain conformably by outer barrier complex sandstones and overlain, along a scour surface, by tidal channel deposits. The thin but laterally extensive section consists mostly of partly fossiliferous gray siltstone and lesser amounts of claystone and sandstone. Much of it is bioturbated. Undisturbed parts typically contain biotite-rich planar laminations. These structures indicate deposition in quiet subaqueous environments subject to little current or wave activity. The sedimentologic and paleontologic characteristics suggest an inner shelf environment.

LITHOFACIES 8 - CONGLOMERATE WITH SANDSTONE LENSES

Lithofacies 8 consists of moderately- to poorly-sorted, clast-supported pebble and cobble conglomerate. Beds are from six inches to more than four feet thick and are separated from one another by thin, discontinuous sandstone lenses. Some poorly developed normal and reverse grading is present although overall the conglomerate is not obviously graded. Clasts are of the Poway suite. Pebble- and cobble-sized green silty claystone clasts are present but uncommon (Figure 15).

The matrix is light reddish-brown, moderately-sorted, fine- to medium-grained lithic arkose. Pink volcanic rock fragments are abundant. This sandstone also occurs as one- to six-inch-thick, one- to ten-foot-long lenses within the conglomerate. Inclined beds of one-clast-thick conglomerate are common in the sandstone lenses.

Conglomerates of lithofacies 8 are found in southern Rancho Santa Fe and in an area eastward across the San Dieguito River. In Rancho Santa Fe, lithofacies 8 is enclosed wholly by strata of subfacies 5b and these two facies grade laterally and vertically into one another. East of the San Dieguito River the conglomerates of lithofacies 8 conformably overlie green claystone and sandstone of lithofacies 3 along a sharp, planar contact. The conglomerate is overlain by concretionary sandstone of lithofacies 9 (Plate 2 in back pocket).

DEPOSITIONAL ENVIRONMENT

The coarse, conglomeratic nature of lithofacies 8 and the position of the recognized outcrop localities close to a rugged lagoonal paleoshoreline both suggest that deposition of lithofacies 8 took place in a gravelly delta and/or alluvial fan. Since these conglomeratic bodies apparently wedge out lagoonward between sandy and muddy lagoonal deposits they were probably deposited on the outer fringe of a conglomeratic fan delta.

Lithofacies 8 was probably formed as sheet flood and shallow braided-bar deposits. In places, gravels were swept into shallow bars by intermittent fluvial activity. The sandstone lenses formed as lateral sand-wedge or bar-front deposits during the waning phases of floods. As sand accumulated along the margin of a bar during waning currents, inclined layers built subparallel to the bar slope. Stronger depositional pulses intercalated layers of gravel within the sand.

Lithofacies 8 and 5b occur due west of the northern limit of the Stadium Conglomerate at Rancho Bernardo (Kennedy, 1973). These facies probably represent the northwestward depositional limit of the Poway-suite fan-delta system.

LITHOFACIES 9 - CONCRETIONARY SANDSTONE

The concretionary sandstone of lithofacies 9 is a gray-white, moderately- to well-sorted, medium- to fine-grained biotite-bearing lithic arkose. Concretions form isolated oval or spheroidal masses six inches to two feet in diameter. They are cemented, as is the sandstone, by calcium carbonate. No fossils or sedimentary structures were recognized in the few poor exposures.

This lithofacies was recognized in an area east of Rancho Santa Fe across the San Dieguito River. It is very poorly exposed in dirt road beds and as concretions scattered over the low, brushy mesa top. Lithofacies 9 apparently forms a northward- and westward-thinning wedge with a maximum thickness of 40 feet. It conformably overlies lithofacies 8 conglomerate except to the north where it probably overlies rocks of lithofacies 1 and 3, and its upper surface is presently being eroded (Plate 2).

DEPOSITIONAL ENVIRONMENT

Few clues are available to aid in the identification of the depositional environment of lithofacies 9. The pertinent facts are that this well-sorted, fine- to medium-grained sandstone overlies deltaic/alluvial fan fringe conglomerate and that it was deposited in a paleoembayment of the coastal basement hills. The concretionary sandstone was probably deposited in a shallow, quiet-water lagoonal bay or estuary.

STRATIGRAPHY

Inland from the coastal bluffs the stratigraphy is not as well defined although, as along the coastal section, one moves generally upsection from south to north.

The sandy lithofacies 5 and its subfacies extend in a broad band along the coastal strip. This body of rock represents a mass of continuously deposited sandy tidal lagoon strata. Along the coastal section the Ardath Shale (lithofacies 7) intervenes between and separates the transgressive phase from the regressive phase of sandy tidal lagoon deposition. Inland, no intervening wedge of marine shale and siltstone occurs to differentiate the transgressive and regressive sections. The landward limit of lithofacies 7 marine strata in the Carlsbad to Solana Beach area occurs parallel to and just inland of the present shoreline (Plate 2).

The stratigraphically lower part of lithofacies 5 and its subfacies have been assigned to the Torrey Sandstone. Parts thought to be the lateral stratigraphic equivalents of the Ardath Shale are referred to the Torrey Sandstone and Scripps Formation (undifferentiated). This unit occurs from roughly north of Olivenhain Road to Batiquitos Lagoon and probably includes section well above and below a hypothetical boundary separating the transgressive and regressive phases. Lithofacies 5 north of Batiquitos Lagoon has been assigned to the Scripps Formation (Plate 3 in back pocket).

Along the coastal bluffs, differentiation of the Torrey and Scripps units is made unambiguous by the intervening wedge of marine strata. Inland the units have no sharp boundaries because of the absence of the Ardath Shale. This is less than satisfying in light of the "mappability" requirement of formal nomenclature, but the units inland have been so described to provide a consistent stratigraphic tie to the more clearly defined section along the coastal bluffs.

Inland of the coastal section, lithofacies 5 and its subfacies are underlain along a distinct, conformable contact by lithofacies 3 green claystone and sandstone. In this area, as along the coastal section, lithofacies 3 has been assigned to the Delmar Formation.

Heading toward the Eocene and basement contact lithofacies 5 is rapidly replaced, first by the sandstones of lithofacies 4 and then by an interfingering combination of lithofacies 3, 2 and 1. These last three lithofacies form a distinct, three-dimensional band which runs parallel to the basement contact and represents a continuously developed sequence of muddy inner lagoon and coarse lagoonal-delta deposits. East of Rancho Santa Fe the hilly basement outcrops bend inland but are not followed inland by Torrey sandy outer lagoon strata. Instead, the sandy outer lagoon strata are replaced by muddy inner lagoon and coarse lagoonal-delta deposits. The basement embayment east of Rancho Santa Fe was also an embayment in the middle Eocene, where muddy inner lagoon and coarse lagoon-fringing sediments accumulated in a shallow bay or estuary (Plate 2).

The transition from lithofacies 5 and subfacies, through lithofacies 4 to lithofacies 3, 2 and 1 is a record of the environments that existed in a landward to seaward section across the Eocene tidal lagoon. Coarse-grained deltas and muddy supra/intertidal environments (lithofacies 1, 2 and 3) lay adjacent and parallel to a rugged, hilly coastline. Sandy deposits were found further seaward toward the barrier island, deposited in sandy intertidal flats (lithofacies 4), and intertidal and subtidal channels, creeks and bars (lithofacies 5). The furthest seaward deposits in the lagoon were formed in a tidal inlet.

This landward-fining sequence is common in tidal lagoons and estuaries (Evans, 1965; Klein, 1971; De Jong, 1977; Boothroyd, 1978). Tidal current strength wanes from the seaward to the landward portions of a tidal lagoon or estuary, and there is a corresponding decrease in the grain size of the material transported and eventually deposited. A typical example of the distribution of sediment in a modern tidal setting is shown in Figure 11. Along a rugged, hilly coastline fronted by a narrow lagoon a coarse-grained belt fringing the landward side of the lagoon would be an expected addition to the sequence. A similar fringing residuum of coarse-grained material, trapped along the landward margin of a muddy tidal flat, was recognized in Middle Proterozoic strata in South Africa (Vos and Erikkson, 1977).

Those parts of the basement-fringing inner lagoon sequence dominated by lithofacies 3 green claystone and sandstone are analogous to the Delmar Formation. Those parts dominated by lithofacies 1 and 2 green claystone and coarse sandstone are roughly analogous to the non-marine and lagoonal claystone and sandstone of the Friars Formation in San Diego.

It would be difficult to formally differentiate the Eocene lithofacies in the area adjacent to basement due to interfingering and rapid replacement between lithofacies. Therefore, following Kennedy (1975) these rocks have been assigned to the Delmar and Friars Formations (undifferentiated).

Nearly flat-lying Eocene rocks meet basement at a high angle; the result is a pronounced buttress unconformity. The Eocene-basement buttress unconformity is well exposed north and south of Alga Road in La Costa, one-half mile east of El Camino Real, and again in the angle formed by the San Dieguito River and Lusardi Creek, east of Rancho Santa Fe. Relief on the buttress unconformity at the former locality is over 150 feet, at the latter locality it is nearly 400 feet.

The buttress unconformity is a direct result of the topography in existence at the time of deposition. The metavolcanic and intrusive basement rocks formed a rugged line of coastal hills. As transgression and deposition began in the early middle Eocene these hills formed a barrier to landward migration of the sea. As deposition proceeded, Eocene sediments aggraded vertically, and lapped against and eventually buried much of the hilly coastline. Subsequent erosion has stripped away much of the Eocene and younger protective sedimentary cover from the basement rocks, leaving an exhumed topography very similar to that of Eocene time.

In addition to the buttress unconformity, the rugged coastline caused a steep depositional contact to form between muddy inner and sandy outer tidal lagoon facies. This was because the sea was prevented from advancing very far inland by the coastal hills, and lagoonal depositional environments maintained a nearly constant position relative to the paleoshoreline as sediments aggraded vertically. The result was relatively steep depositional contacts between interfingering Eocene tidal lagoon lithofacies, arranged in belts roughly parallel to basement (Figure 17). The most obvious of these contacts is that between dominantly sandy outer lagoon lithofacies (lithofacies 5 and subfacies and lithofacies 4) and dominantly muddy inner lagoon lithofacies (lithofacies 3 and 2).

The boundary between sandy outer and muddy inner tidal lagoon facies identifies the landward side of a transgressive barrier system (Kraft and others, 1979) and, in the area under discussion, separates strata of the Delmar and Friars Formations (undifferentiated) from strata of the Torrey Sandstone and/or Scripps Formation.

Just as there are transgressive and regressive sections in the sandy outer tidal lagoon lithofacies, there are also transgressive and regressive parts in the muddy inner tidal lagoon section. The transgressive muddy inner lagoon section is found beneath the sandy outer lagoon lithofacies and in a belt sandwiched between sandy outer lagoon rocks and basement. The regressive part of the muddy inner lagoon lithofacies overlies the sandy outer lagoon section although it is only very locally preserved. Small outcrops of lithofacies 1 and 3 overlie lithofacies 5 at localities north and south of Batiquitos Lagoon, and south of Palomar Airport Road. These small outcrops show that inner lagoon depositional environments advanced seaward at least as far as the present coastline after having been pressed up against the coastal hills during the preceding transgression. These outcrops are of very limited extent and have not been formally differentiated (Plates 2 and 3).

In the northwestern corner of the Encinitas quadrangle dips to the north and west and down-to-the-northwest faulting have apparently brought the regressive part of the inner tidal lagoon section adjacent to the underlying, regressive portion of the sandy outer tidal lagoon section. Because of the faulting

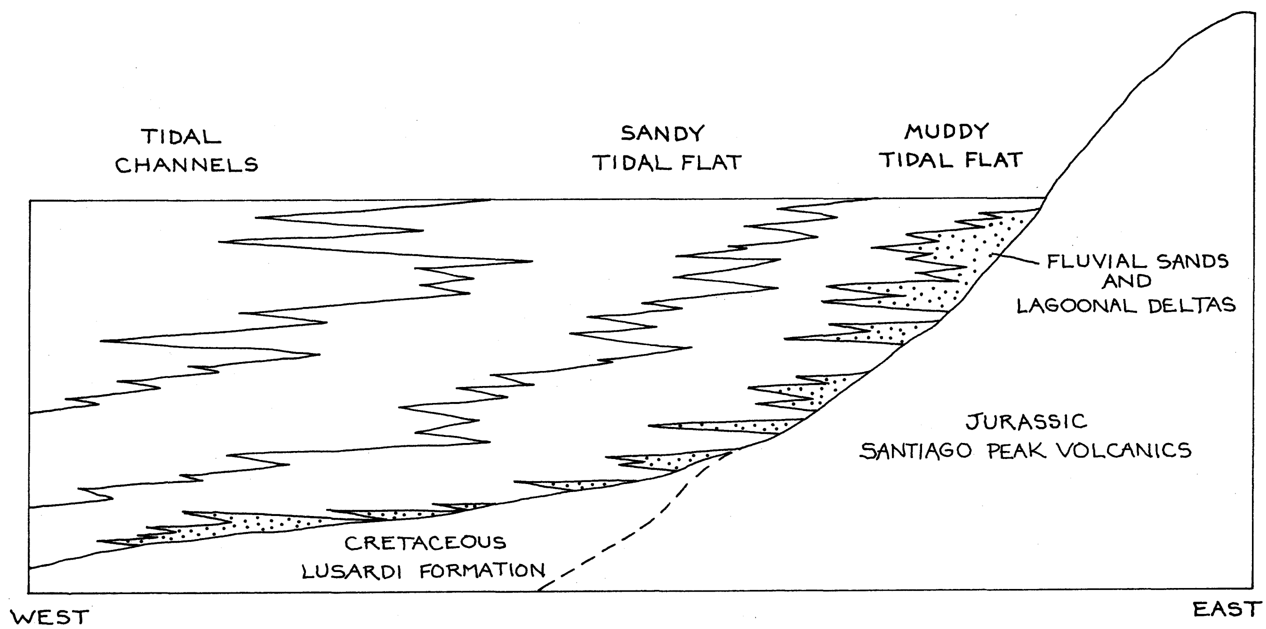

Figure 17. Diagrammatic cross section through Eocene strata adjacent to the basement contact. During a transgression tidal environments are compressed against the steep paleoshoreline and advance landward slowly. Sediments in each environment accumulate vertically.

and the paucity of outcrops in this area the complete distribution of lithofacies and the stratigraphic relationships remain unclear. This has been indicated formally by assigning the rocks to the Delmar and Friars Formations (undifferentiated) (Plate 3).

East of Rancho Santa Fe across the San Dieguito River the Delmar and Friars Formations (undifferentiated) are overlain by a 40 foot-thick Poway-clast alluvial fan deposit (lithofacies 8). It is overlain by a poorly-exposed, thin, concretionary sandstone (lithofacies 9) probably deposited in a quiet water lagoonal bay or estuary. These rocks correspond lithologically and stratigraphically with the Stadium Conglomerate and Mission Valley Formation, respectively, and have been assigned to those La Jolla Group units (Plate 3).

RELATION TO THE SANTIAGO FORMATION

The Santiago Formation of the Santa Ana Mountains long has been recognized as in part equivalent to La Jolla Group strata in San Diego (Woodring and Popenoe, 1945). Many questions have been raised, however, as to where and how the two units meet (see Eisenberg, 1983 for a discussion).

The difficulty in correlating between the Santiago Formation and the La Jolla Group arises because these in part coeval units are similar in lithology and depositional environments in the area where they meet. Workers have expanded the area of outcrop assigned to each nomenclature outward from the original type localities until they have bumped into one another in the area south of Camp Pendleton and north of San Elijo Lagoon Because the units are similar no general agreement has been reached on the nature of the convergence. A geologically meaningful boundary between the two nomenclatures can be drawn, however, if their relationship to bedrock topography is taken into account.

Several studies have noted the significant effect of basement topography on Eocene deposition (Weber, 1963; Peterson and Nordstrom, 1970; Young, 1980; Eisenberg, 1983). Just north of Palomar Airport in Carlsbad a pronounced basement ridge juts to within three miles of the present coastline. Abbott (1963) and Wilson (1972) both recognized that this headland was a barrier to deposition between strata of the Santiago Formation and the La Jolla Group. This basement ridge probably acted as a depositional boundary between regions to the north and south. As such it could act as a boundary between coeval stratigraphic units similar in lithology and depositional environments.

Eocene strata south of this ridge would be referred to the La Jolla Group. Strata north of the ridge would be rererred to the Santiago Formation. In this way the artificial problem of determining the appropriate formal nomenclature would be resolved in a geologically meaningful manner and workers would be able to concentrate fully on the lithology, depositional history, etc. of Eocene rocks in this part of northern San Diego County.

DEPOSITIONAL HISTORY AND PALEOGEOGRAPHY

EARLIEST MIDDLE EOCENE

A worldwide transgression in the early middle Eocene (Vail and Hardenbol, 1979) caused the sea to advance landward against and over a hilly coastline composed of Mesozoic sedimentary and volcanic rocks. A barrier island chain formed to the west of and roughly parallel to the position of the present coastline. Landward of the sandy barrier, muddy tidal flats and creeks created a pattern within a brackish lagoon and coarse-grained deltaic deposits fringed the base of the coastal hills. In the lagoon, oyster bioherms were built and an active infauna churned the bottom sediments. Unusually strong storms washed coarse clastic material from the coastal hills into muddy tidal flats and creeks (Figure 18).

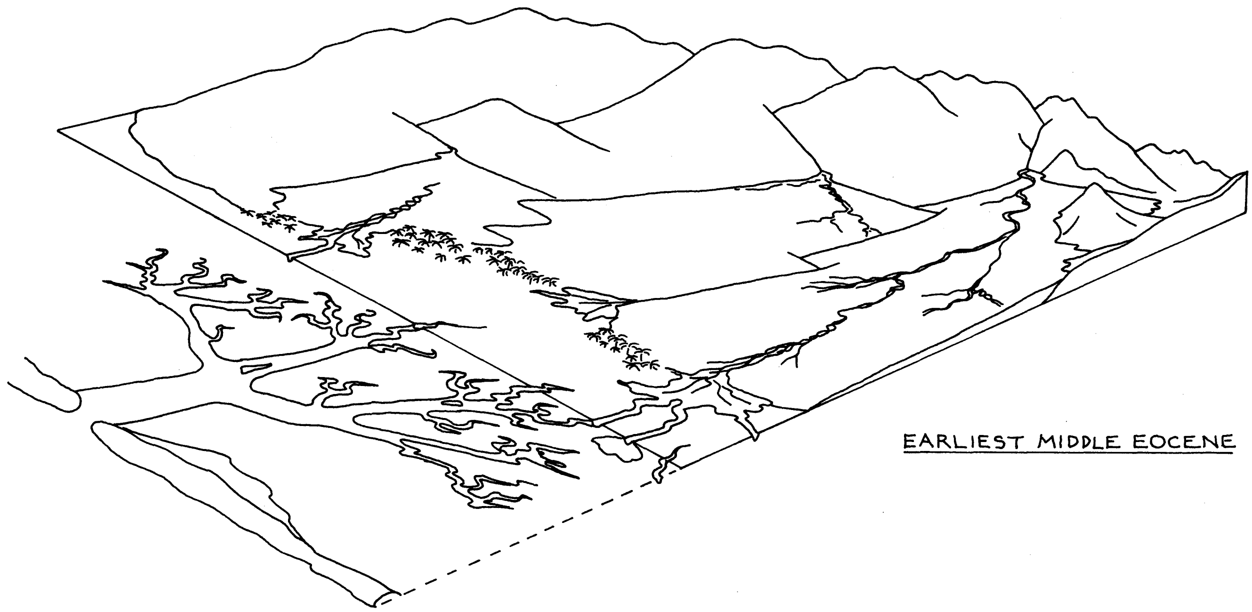

Figure 18. Paleogeographic reconstruction for the earliest middle Eocene, looking northeast over the field area. The solid western boundary line lies approximately along the trend of the present shoreline.

The various tidal environments shifted landward as transgression continued. The barrier island chain moved closer to the position of the present shoreline. Sandy tidal channel and flat deposits overran muddy lagoon deposits, which in turn began to accumulate over the coarse shoreline fringe.

The climate was hot and humid. The shoreline probably was lined with red mangrove swamps and palm groves (Link and others, 1979; Wosika, 1975).

EARLY MIDDLE EOCENE

As transgression continued the sandy barrier system moved to just west of, and then along the position of the present shoreline. Sandy outer tidal lagoon, muddy inner tidal lagoon and coarse, deltaic, lagoon-fringe deposition shifted landward as well, although the coastal hills prevented these environments and the corresponding accumulated sediments from shifting very far landward.

Soon after sandy outer tidal lagoon sediments had transgressed over muddy, inner tidal lagoon sediments a Poway-clast conglomerate entered the area. The conglomerate arrived in the form of a braided-bar fluvial system which advanced from the conglomeratic Poway system in the San Diego area. Regression in the late Eocene resulted in the deposition of widespread and thick fan-delta deposits of this conglomeratic system, i.e., the Stadium Conglomerate. In the early middle Eocene however, deposits of this system were far more areally restricted.

The braided-bar fluvial conglomerates advanced as far north as the southern side of Rancho Santa Fe. Through this distributary a narrow finger of gravel beds and stringers spread northwestward along a line approximating the deepest parts of the tidal lagoon. The gravels reached nearly to the present position of Batiquitos Lagoon. Flood conditions flushed Poway-suite gravels over the sandy bottom of the lagoon, leaving gravel beds and stringers draped over sandy tidal flat and channel deposits. Alternating flood, and normal tidal depositional regimes resulted in the intercalation of numerous gravel beds and stringers in this part of the sandy, inner tidal-lagoon section (Figure 19).

The climate continued hot and humid. The storm return surge of tropical cyclones at times flushed lagoonal debris out of the lagoon and onto sandy and muddy bottomed areas seaward of the barrier islands. Storm surges and their associated deposits continued to occur into the medial middle Eocene.

MEDIAL MIDDLE EOCENE

During this time the sea made its maximum advance toward the land. Marine silt and clay were deposited along the position of the present shoreline, and landward, sandy and muddy tidal lagoon facies maintained their respective positions in a much narrower lagoon. The coastal hills inhibited the transgression, and lagoonal facies and the corresponding deposits maintained a nearly constant position relative to the shore as the sediments piled up (Figure 20).

Tidal channels in these and younger Eocene rocks are not as consistently well developed as compared to tidal deposits lower in the Eocene section. This may be because at times the barrier consisted of a complex of shoals and minor bars rather than a fully developed barrier with beach, dune and back-barrier environments. Also, the barrier at times may have been completely absent.

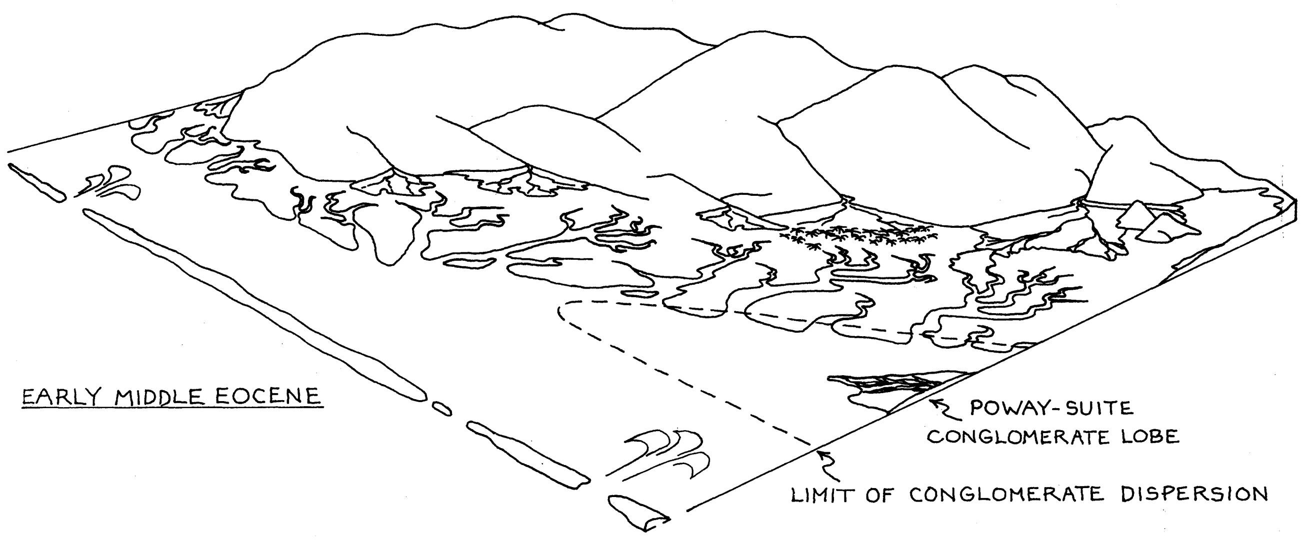

Figure 19. Paleogeographic reconstruction for the early middle Eocene, looking northeast over the field area. The barrier island chain lies approximately along the trend of the present shoreline.

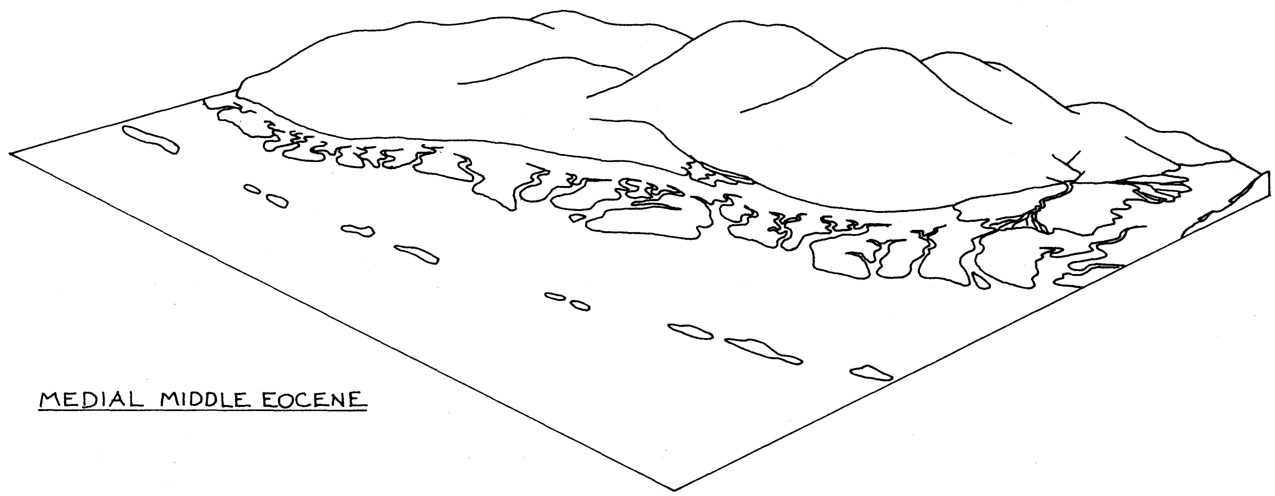

Figure 20. Paleogeographic reconstruction for the medial middle Eocene, looking northeast over the field area. The western boundary line lies approximately along the trend of the present shoreline.

The general transgression during the Eocene was interrupted by a brief worldwide drop in sea level (Vail and Hardenbol, 1979). This brief regression shifted marine and lagoonal environments seaward. Along the position of the present shoreline a southward-migrating tidal inlet scoured into the semi-indurated nearshore marine deposits left behind as the sea retreated. The teeth of sharks and rays collected along the base of the tidal inlet.

To the south, at Torrey Pines State Park the same slight middle Eocene regression is recorded in a submarine canyon sequence. The drop in sea level caused inner fan channels to prograde over and cut into older base of slope and lower submarine fan deposits (May, 1982).

LATE MIDDLE EOCENE

A slowing of subsidence and/or an increase in sedimentation caused the lithofacies to slowly prograde during the late middle Eocene worldwide transgression and highstand (Vail and Hardenbol, 1979). Progradation was at times interrupted or briefly reversed during periods of increased subsidence and/or reduced sedimentation, but the overall depositional regime was progradational.

A fluvial system draining southward from a basement headland located north of the present position of Palomar Airport delivered coarse pebbly sand into the tidal lagoon. The initial influx of coarse sediment covered sandy tidal deposits. Successive depositional pulses built a coarse-grained delta out into the lagoon. As the sites of progradation shifted, the delivery of coarse-grained material to the lagoonal delta slowed and stopped, and the delta was covered by muddy inner tidal-lagoon sediments.

To the southeast, in a lagoonal bay or estuary, bedrock hills were nearly buried by prograding coarse-grained lagoonal delta deposits and muddy lagoonal deposits. These inner lagoon facies advanced seaward over older, outer lagoon strata until they came close to or reached the position of the present shoreline (Figure 21).

the riparian habitats provided by the streams (Novacek and Lillegraven, 1979).

SUMMARY

Two major regressive-transgressive sedimentation cycles are recorded in the middle and late Eocene strata that are exposed along the coastal plain of San Diego County between Carlsbad and Carmel Valley. During each half-cycle, paralic depositional facies shifted landward and seaward, punctuated by incursions accumulated within the subsiding basin.

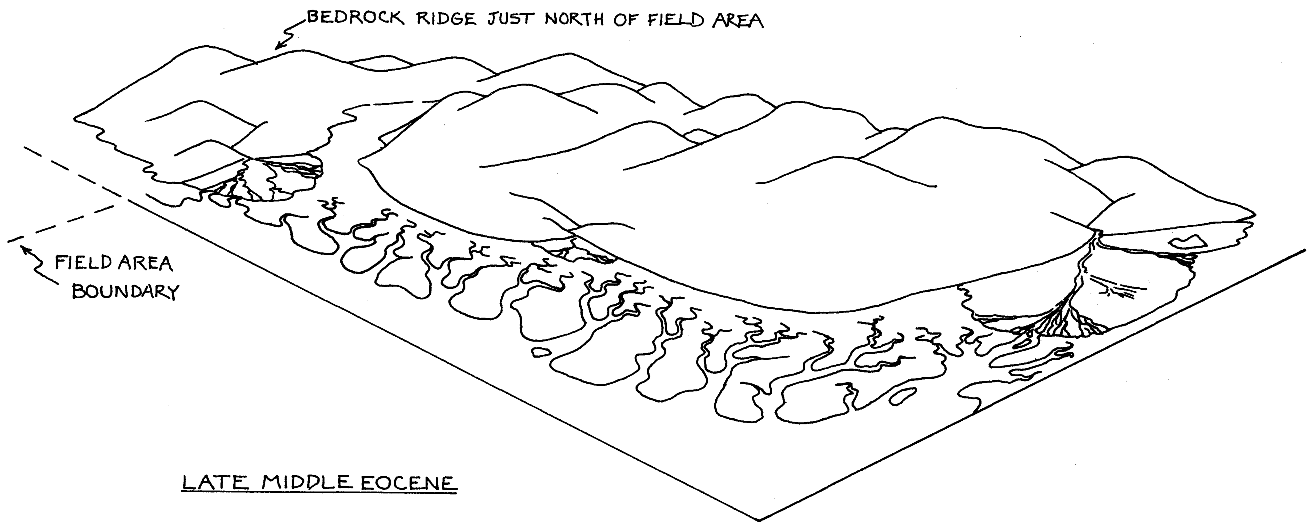

Figure 21. Paleogeographic reconstruction for the late middle Eocene, looking northeast over the field area. The western boundary line lies approximately along the trend of the present shoreline.

LATE EOCENE

In the early late Eocene a major worldwide retreat of the sea (Vail and Hardenbol, 1979) enhanced the march of depositional environments seaward. A fluvial braided-bar and alluvial fan system composed of Poway-suite gravels extended into the area from the southeast. These gravels overran the mud and coarse sandstone that had been deposited in a lagoonal bay or estuary on the landward side of the lagoon.

Although the sedimentary record is not preserved it is likely that during this regression paralic depositional environments were in place some ways seaward of the present position of the shoreline.

During the ensuing late Eocene transgression the paralic facies moved inland once more. In a small, quiet water bay or estuary formed by an embayment in the coastal basement hills, fine-grained sands accumulated over Poway-suite alluvial and fluvial gravels.

The climate had become progressively drier during the middle Eocene until by the late middle and late Eocene a semi-arid climate prevailed (Peterson and Abbott, 1979). Pollen studies suggest that the climate may have been a seasonally-dry savannah type (Carr, 1975). A variety of Late Eocene terrestrial vertebrates lived in and along the streams that wandered down to the coast from a wetter interior. Crocodiles, turtles, tree-dwelling marsupials, mammalian insectivores and primates all thrived in

For the most part deposition took place on a narrow shelf, along a precipitous coastline, under a dominantly tidal type of depositional regime. The paleotide ranged from the low mesotidal to high macrotidal of Hayes (1979). During transgression the landward advance of the sea was impeded by the rugged coastal hills. As a consequence, a pronounced buttress unconformity formed between basement and Eocene rocks, and a steep depositional contact formed between sandy outer and muddy inner lagoonal depositional facies.

A diagrammatic summary of Eocene deposition versus age and worldwide sea level is shown in Figure 22.

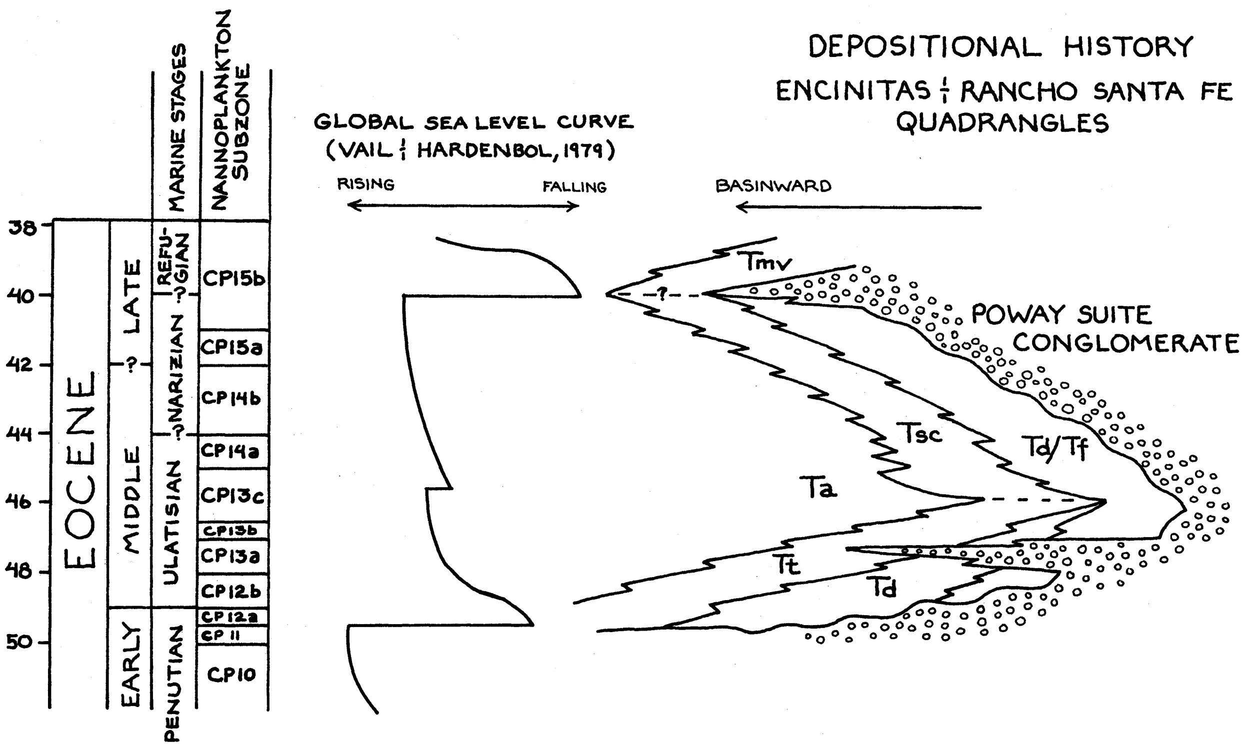

Figure 22. Diagrammatic summary of Eocene deposition versus worldwide sea level and geologic age.

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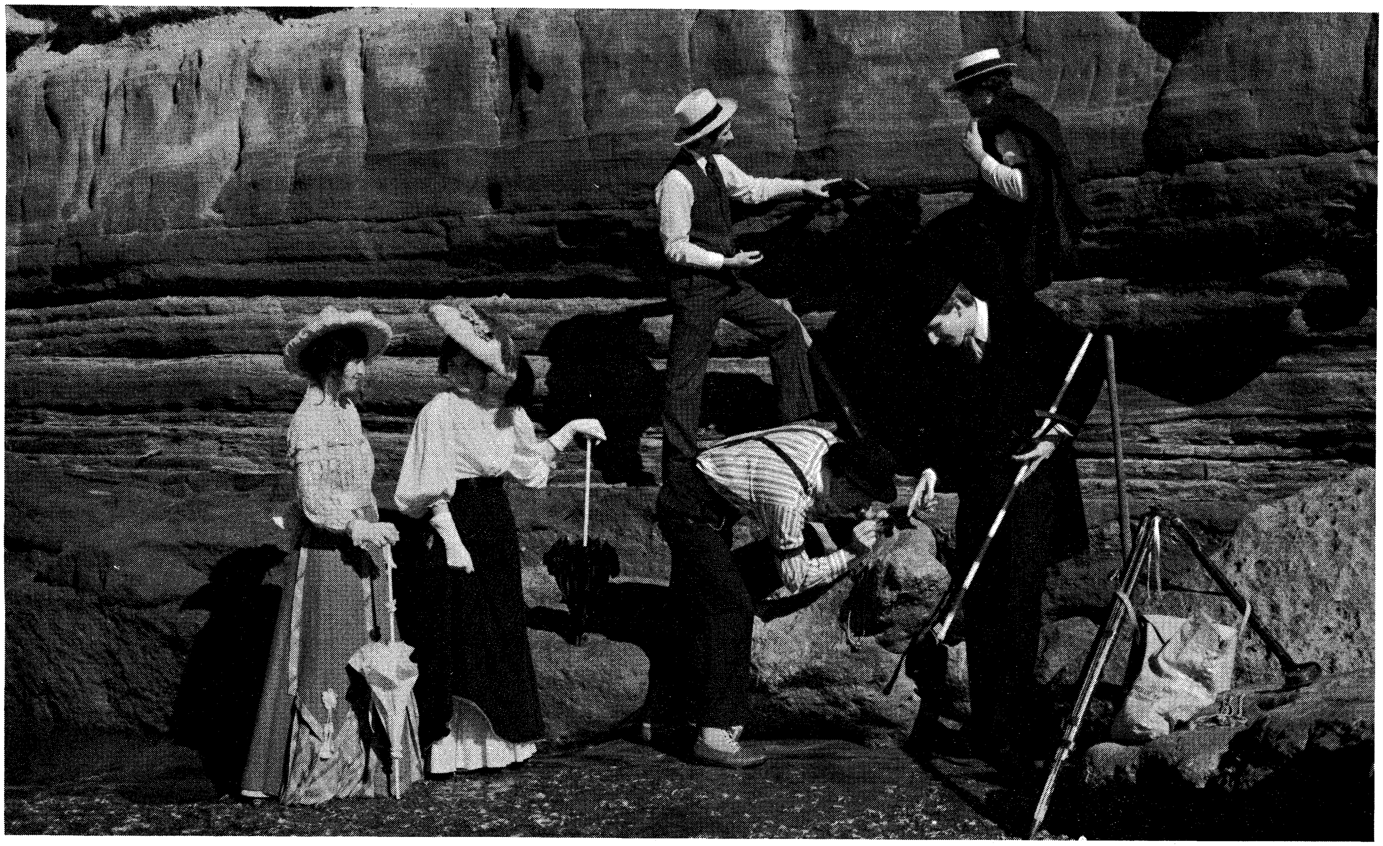
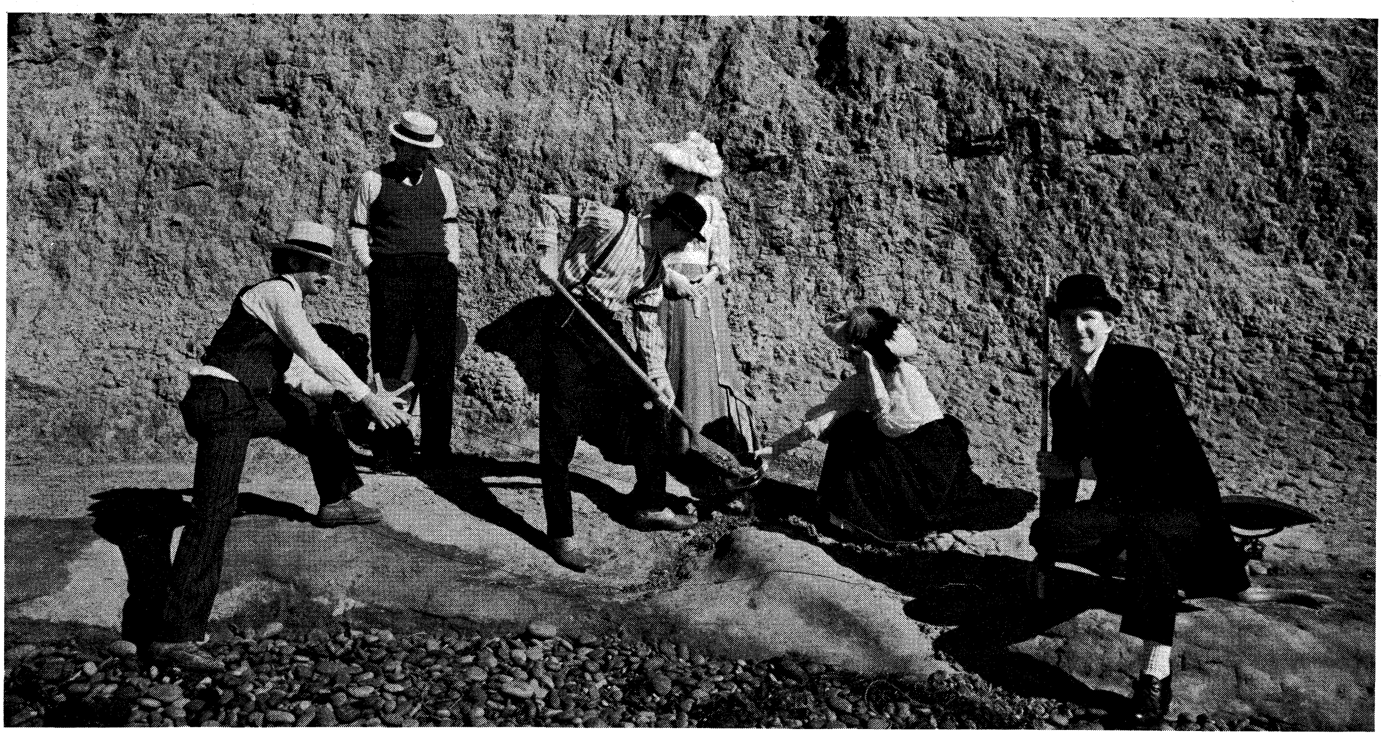


Oyster biostrome overlain by tidal sandstones in southern Solana Beach.



Estuarine facies at San Elijo State Beach in Cardiff-by-the-Sea.

EOCENE LITHOFACIES EXPOSED IN SEA CLIFFS FROM LEUCADIA
TO CARDIFF-BY-THE-SEA, SAN DIEGO COUNTY

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In the mid-Eocene a major marine transgression occurred resulting in the deposition of the Mount Soledad, Delmar, Torrey and Ardath formations (Kennedy and Moore, 1971). During a succeeding marine regression, rocks of the Scripps and Friars formations were deposited.

A succession of Eocene lithofacies is present in the sea cliffs at Cardiff-by-the-Sea, Encinitas, and Leucadia, California (Figure 1). The lithofacies record the migration of several depositional environments that existed during the mid-Eocene marine transgression. Outcrops of the lithofacies occur along a

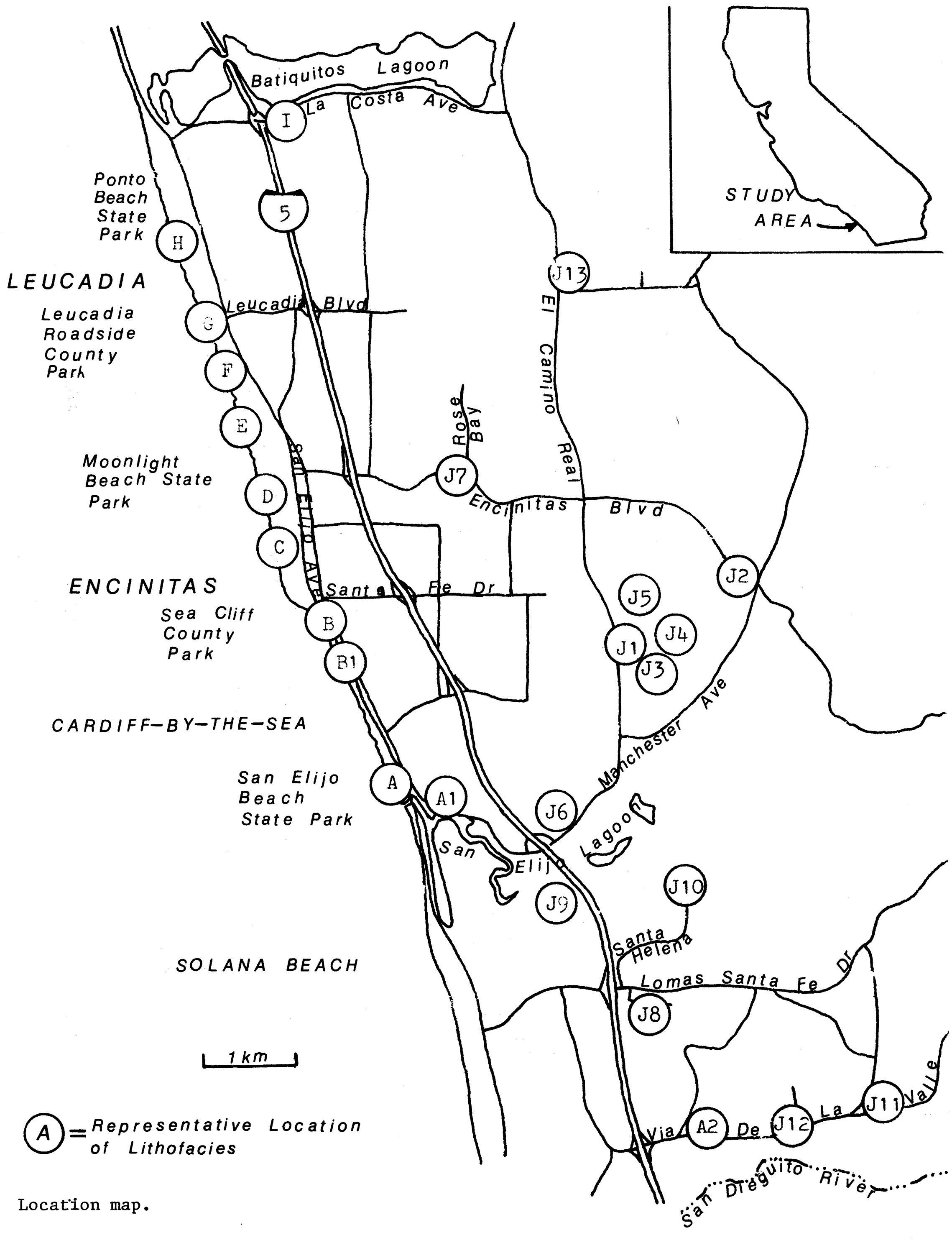


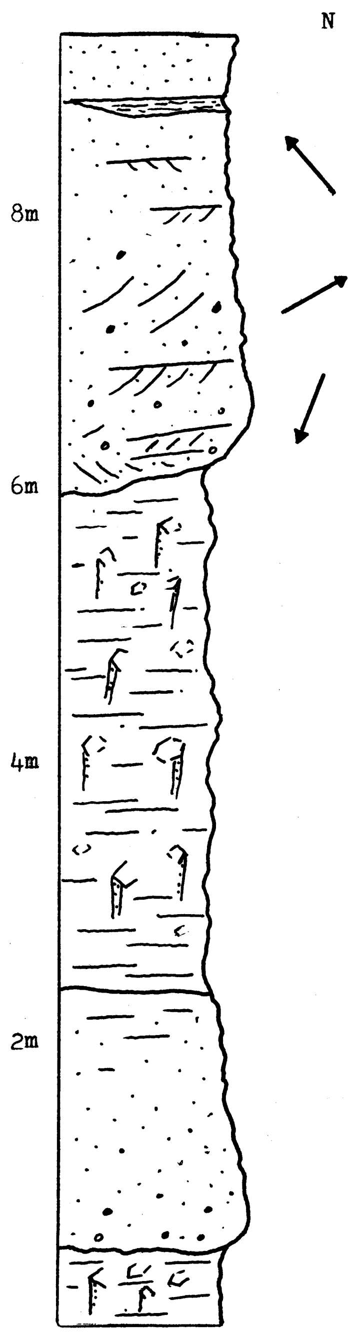
Figure 1. Location map.

trend that is roughly parallel to the Eocene paleoshoreline.

In a 4 ± km stretch of sea cliffs at Cardiff-by-the Sea and Encinitas, rocks of the Delmar Formation are well exposed. At least three lithofacies can be distinguished within the 40 ± m thick interval of horizontal to gently-dipping strata that are present.

The lowest lithofacies recognized, here designated as lithofacies A, is exposed at San Elijo Beach State Park. A representative vertical section of the unit (Figure 2) can be seen below the lifeguard tower at the southern limits of the park. The lithofacies is characterized by olive mudstones with sharply defined lenses of light brown, medium- to coarse-grained sandstone. The presence of megascopic body fossils or well defined trace fossils is not apparent. Mudstones in the unit record episodes of prolonged subaerial exposure during deposition by the presence of red mottling and sand-filled mudcracks. Sandstone lenses within the lithofacies are normal graded with small- and large-scale cross bedding.

CROSS BED DIP AZIMUTHS

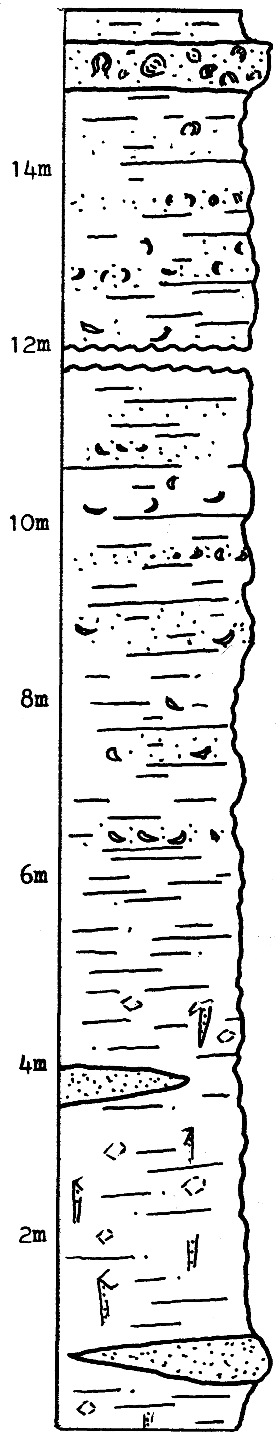


DESCRIPTION	INTERPRETATION
	LITHOFACIES A (CHANNELED SUPRATIDAL MUD FLATS)
Sandstone	
Small lens of green mudstone	Channel abandonment
LARGE SANDSTONE LENS	CHANNEL DEPOSIT
Poorly-sorted immature arkosic sandstone	Terrigenous influx of coarser-grained sediments
Numerous truncated sets of both trough- and wedge-types of cross beds	Migrated bed forms under variable higher energy flow regime, tidal reworking (?)
Mud chips	
Pebbles and granules of angular vein quartz	Rip-up clasts and grains derived from proximal source terranes
Sharp irregular contact, local relief up to 60 cm	Erosional
RED AND GREEN SILTY MUDSTONE	SUPRATIDAL DEPOSITION
Few primary sedimentary structures	Lower energy flow regime with lower sedimentation rates
Sand-filled fissures up to 5 cm wide and 50 cm deep, polygonal on flat exposures	Sand-filled mud cracks
Non-fossiliferous	Low preservation potential of fossils
Oxidized zones with red mottling	Periodic subaerial exposure
	Migration and/or cessation of channel deposition
Sharp contact	
LARGE SANDSTONE LENS	CHANNEL DEPOSIT
Irregular to bulbous or undulatory upper and lower contacts	Abrupt change in sedimentation rate
Poorly-sorted medium- to very coarse-grained sandstone grading upward to silty sandstone	Proximal source terranes
Sharp contact	Erosional
Olive silty mudstone with red mottling and sand-filled fissures	Supratidal deposition

Figure 2. LITHOFACIES A: stratigraphic column exposed in the sea cliffs at the southern limits of San Elijo State Beach.

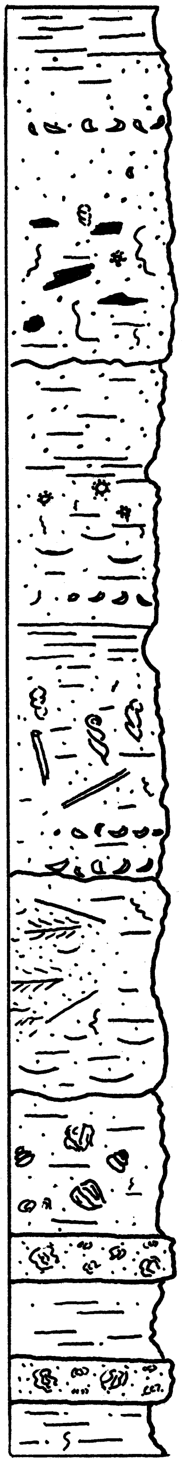
To the north in the lower sea cliffs at Sea Cliff County Park and in the northern portions of San Elijo Beach State Park the lowest lithofacies grades upward into an overlying lithofacies. This unit is designated as lithofacies B (Figure 3) and is characterized by thin- to medium-thick interbeds of mudstones and muddy fine- to medium-grained sandstones. Scattered small disarticulated oyster valves are abundant especially within the sandy layers. The coarse-grained sandstones and the sand-filled mudcracks present in the underlying lithofacies are absent.

From Sea Cliff County Park to Moonlight Beach State Park a third overlying lithofacies (lithofacies C, Figures 4 and 5) of the Delmar Formation is exposed. Strata present in these sea cliffs consist generally of interlayered and interlensed, carbonaceous gray mudstones and olive or brown siltstones and sandstones. Beds and lenses rich in large articulated oysters (cf. Ostrea idriaensis) and other bivalves are common as are the trace fossils of burrowing crustaceans and worms. Present are numerous thick, normal-graded intervals consisting of bioturbated, or locally



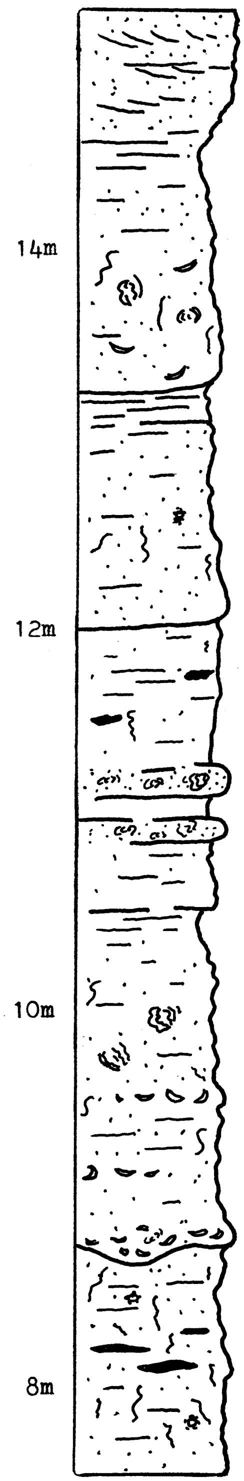
DESCRIPTION	INTERPRETATION
-oyster bed-	-base of lithofacies C-
Green siltstone with thin beds and stringers rich in small disarticulated oyster valves	LITHOFACIES B (INTERTIDAL ZONE)
-break in section-	-obscured-
Interbedded siltstone and fine-grained sandstone	Intertidal muds and sands deposited near the landward fringes of the back-barrier lagoon
Thin- to medium-thick beds	
Thin fossilsferous silty sandstone beds	
Macroscopic body fossils consist primarily of small disarticulated oyster valves	Shell fragments derived from nearby biostromes
No red mottling	No prolonged subaerial exposure
Gradational contact	-base of lithofacies B-
	LITHOFACIES A
Green siltstone with red mottling and sandstone lenses	Supratidal mud flats cut by channels filled with clastic terrigenous sediments
Sand-filled fissures	Sand-filled mud cracks
Lens of immature sandstone	Channel deposit

Figure 3. LITHOFACIES B: representative stratigraphic column exposed in the sea cliffs at Sea Cliff County Park and northerly San Elijo Beach State Park.



DESCRIPTION	INTERPRETATION
	LITHOFACIES C (SUBTIDAL TO LOWER INTER-TIDAL ZONE)
Interval of muddy sandstone with shell stringers grading upward to gray carbonaceous mudstone	Broad subaqueous tidal channel fill
Olive or brown bioturbated muddy sandstone	
Scattered chunks of coal	Carbonized branches
Irregular poorly-defined contact	Diastem (?)
Silty layer	
Small *Ophiomorpha*	Crustacean burrow
Very small mud-lined troughs	Ripple troughs
Stringers of shells	Scour lags
Interval of muddy sandstone grading upward to dark gray carbonaceous mudstone with articulated bivalves	Death assemblage due to siltation (?)
Slender tubular burrows and *Gyrolithus*	Worm tubes and crustacean burrows
Shell stringers	Scour lags
Sharp slightly irregular contact	Erosional surface
Greenish gray silty to clayey fine- to medium-grained sandstone that grades laterally into sandstones with herring-bone cross strata	
Very small troughs	Ripple troughs
Sharp undulatory contact	Erosional surface
Silty sandstone with large articulated oyster valves and scattered gastropods	(Delmar Formation)
Medium-thick oyster bed with calcareous cement	Biostrome
Olive silty sandstone	(SUBTIDAL TO LOWER INTER-TIDAL ZONE)
Oyster bed	Base of lithofacies C
Olive siltstone	LITHOFACIES B

Figure 4. LITHOFACIES C (lower portion): representative stratigraphic column exposed in the sea cliffs north of Sea Cliff County Park and south of Moonlight Beach State Park.



DESCRIPTION	INTERPRETATION
Light brown sandstone with small- to medium-scale cross strata and mud-draped troughs	
(Base of Torrey Sandstone)	Base of lithofacies D
(Top of Delmar Formation)	LITHOFACIES C
Normal-graded interval	(SUBTIDAL TO LOWER INTERTIDAL ZONE IN OUTER LAGOON)
Sandstone grading upward into gray siltstone	
Bioturbated with several oyster valves	
Broad undulatory contact	Broad erosional surface/channel floor
Interval of sandstone grading upward into thickly-laminated mudstone	Channel-filling deposit with washover sands (?)
Broad undulatory contact	Broad erosional surface/channel floor
Carbonaceous siltstone and sandstone	
Richly fossiliferous resistant calcareous lenses with numerous articulated small thin-shelled clams and whole oysters	Biostromes
Thin siltstone bed	
Normal-graded interval	Broad subaqueous (?) channel fill
Olive or brown silty fine- to medium-grained subangular to subrounded sandstone with large whole oysters	
Shell stringers	
Zone rich in shell fragments	Scour lags
Sharp contact with a local relief up to several centimeters	Erosional surface (SUBTIDAL TO LOWER INTERTIDAL ZONE IN OUTER LAGOON)
Silty to clayey sandstone	
Thin coal lenses	Carbonized organic debris from nearby marshes or swamps
Strongly bioturbated interval	

Figure 5. LITHOFACIES C (upper portion): representative column exposed in sea cliffs south of Moonlight Beach State Park.

cross-bedded, sandstone that fines upward into siltstone or mudstone. Each interval usually has a conspicuous sharp, planar to irregular, erosive, basal contact that often has concentrations of fossilized shells. Carbonaceous materials occur in the lithofacies as disseminated chunks of black coal or as carbonized floral hash.

The three lithofacies of the Delmar Formation exposed in these beach cliffs record a landward migration of a variety of protected marine or paralic depositional environments. The lowest lithofacies is best interpreted as the deposits of supratidal mudflats which were periodically incised by channels carrying clastic sediment derived from nearby source terranes.

The overlying facies of the Delmar Formation reflect the landward encroachment of protected (back-barrier) intertidal to shallow subtidal environments within an estuarine or lagoonal setting. Evidence exists of an active paleo-infauna including biostromes of brackish water oysters. Intertidal mud flats, and deposits that resulted from large-scale lagoonal outwash events and/or the meandering of broad tidal channels, can be recognized.

Approximately 350 meters south of the parking lot at Moonlight Beach State Park the stratigraphic contact of the Delmar Formation and the overlying Torrey Sandstone is exposed. In fairly continuous outcrops the Torrey Sandstone can be traced to the north for about two kilometers. However, due to breaks that are present in the section, only a rough estimate of about 50 meters can be made for the composite thickness of the Torrey Formation that is exposed.

The Torrey Sandstone present along the sea cliffs can be divided into three separate but gradational lithofacies. The lowest lithofacies (lithofacies D, Figure 6) is exposed in the southerly portions of Moonlight Beach State Park. The unit is

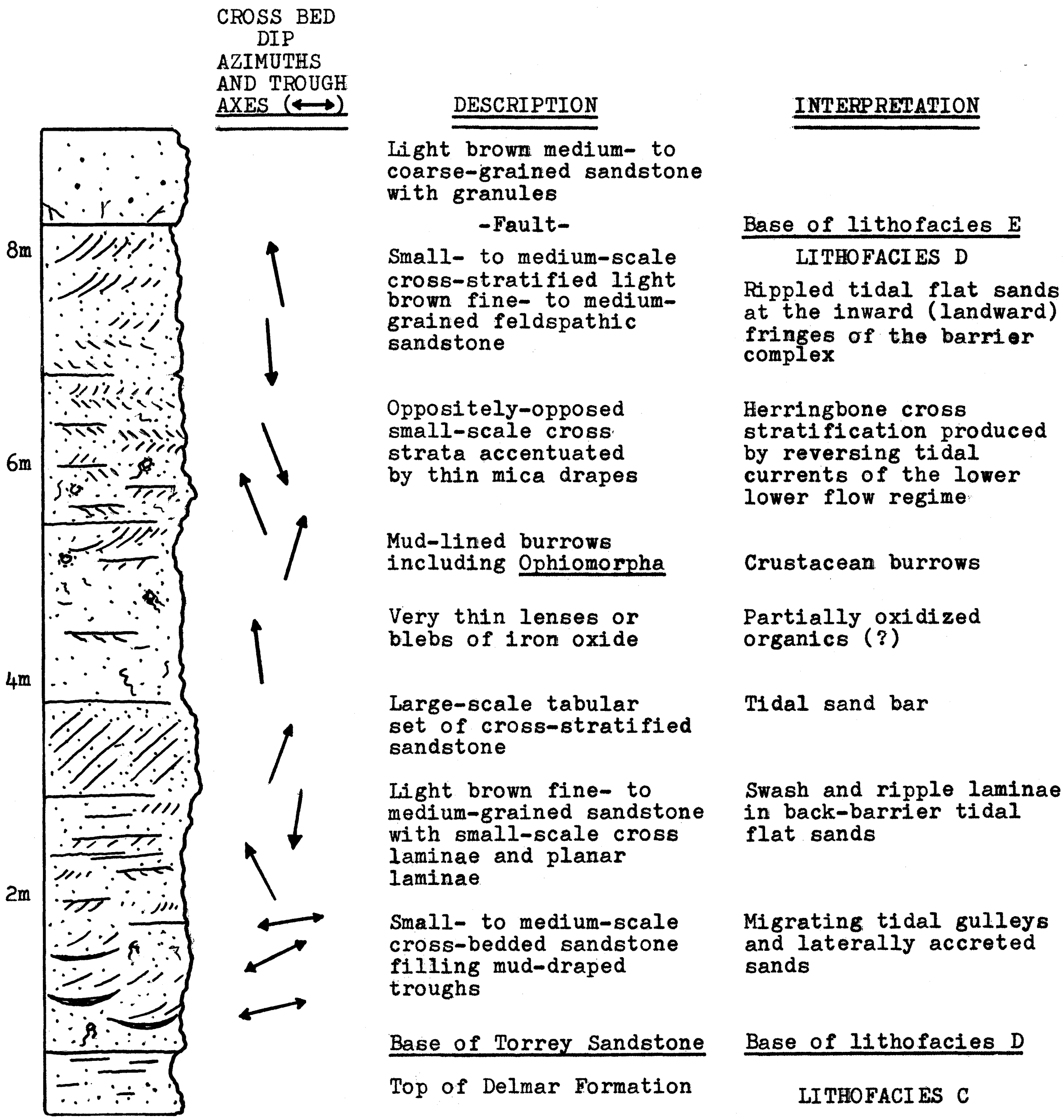
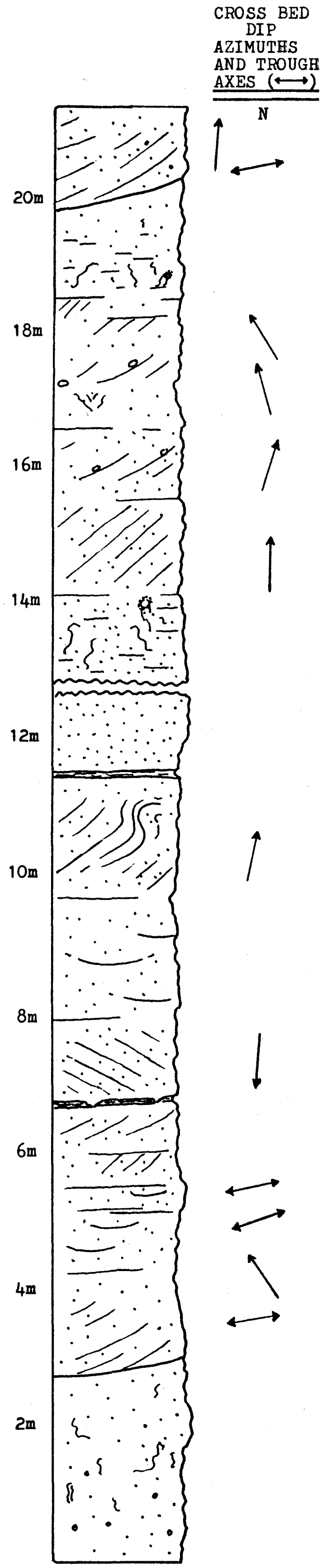
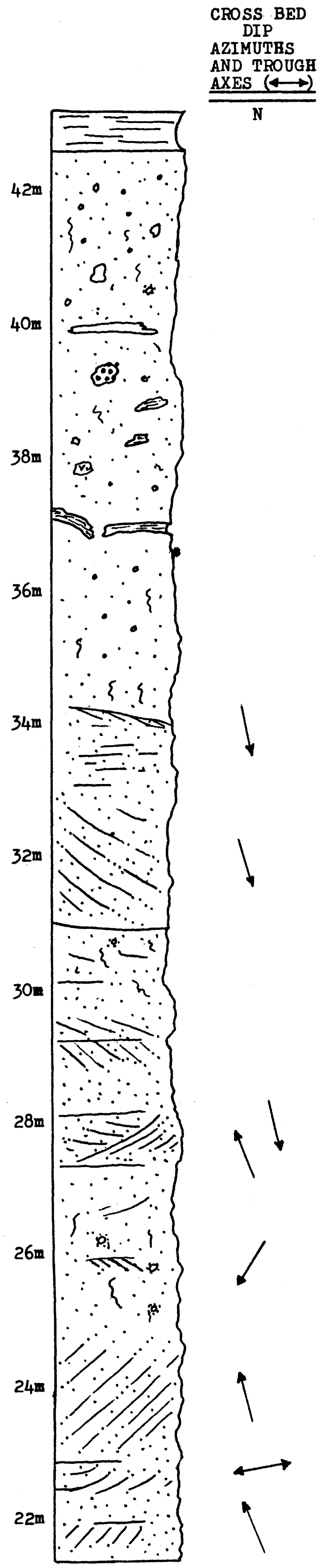


Figure 6. LITHOFACIES D: representative stratigraphic column exposed in the sea cliffs south of Moonlight Beach State Park.



DESCRIPTION	INTERPRETATION
Large conspicuous channel outline (25 m wide, 2 m deep), channel fill consists of subangular to subrounded medium-to coarse-grained lithic arkosic sandstone that exhibits the longitudinal type of cross bedding	Washout channel (storm breach) LITHOFACIES E Primarily bars, dunes, tidal inlet and storm breach channels of the sandy barrier complex
Small chunks of reddish brown peat	Partially oxidized organic debris
Bioturbated muddy sandstone	
Interval of poorly preserved large-scale tabular and trough cross-bedded sandstone with scattered isolated rounded cobbles including dull red rhyolitic (Poway) clasts	
"Cone in cone" biogenic structure	Collapsed burrow
Bioturbated cross-bedded sandstone with isolated rounded cobbles including resistant gray volcanic clasts	
Large-scale tabular cross bedding	Migrating sand waves (bars)
Iron oxide concretions and staining	
Tubular mud-lined burrows a few centimeters in diameter, <u>Ophiomorpha</u>	Crustacean burrow
Bioturbated muddy fine- to medium-grained sandstone	
-obscured by modern Moonlight Beach-	
Interval of fine- to medium-grained sandstone, sedimentary structures are lacking	
Thin mudstone bed	Temporary progradation of lagoonal sediments (?)
Large-scale cross-bedded micaceous sandstone with contorted cross strata	Soft sediment channel slump, migrating tidal inlet
Light brown medium-grained sandstone with poorly preserved troughs that are typically 1± meter wide and a few tens of centimeters deep	Small tidal inlet channels
Some mud drapes and laminae with peat	
Planar-based tabular set of large-scale cross-bedded sandstone	Sandwave (or bar)
Thin discontinuous mudstone bed	
Large-scale trough or longitudinal cross bedding, mud drapes are present on several of the cross laminae	Tidal channels in the landward portions of the sandy barrier complex
Poorly-defined troughs, small-scale cross bedding, and planar clay laminae. Some laminae are rich in peat. Iron oxide staining	Proximal to the landward fringes of the barrier complex
Large-scale trough or longitudinal cross bedding in light brown micaceous medium- to coarse-grained sandstone, cross strata are tangential with base of set	
Very broad concave-up contact	Broad channel floor
Interval of light brown medium- to coarse-grained sandstone with granules	Burrowed quick beds (?)
Crudely fines upward	
Bioturbated	
Sedimentary structures are lacking	
Fault	<u>Base of lithofacies E</u> Lithofacies D

Figure 7. LITHOFACIES E: (lower portion): representative stratigraphic column exposed in the sea cliffs of Moonlight Beach State Park.



DESCRIPTION	INTERPRETATION
Ardath Shale Formation (?)	
Sharp apparently conformable contact	Base of lithofacies G
Top of Torrey Sandstone	LITHOFACIES F
Bioturbated gray poorly-sorted subangular to subrounded micaceous medium- to coarse-grained sandstone with several scattered sand-supported pebbles and cobbles	Offshore storm outwash and/or storm lag deposits Fluctuating flow regimes
Tubular mud-lined burrow, *Ophiomorpha*	Crustacean burrow
Stringer of coal	Carbonized tree branch
Carbonaceous cluster (10± cm in diameter) of thin tubular structures	Fossilized worm colony
Sand-supported subangular to subrounded pebbles and cobbles including clasts of siltstone and clasts of pegmatitic and porphyritic volcanic composition	Storm deposits with rip-up clasts
Discontinuous (broken) undulatory thin layer of gray and brown siltstone	Large rip-up clast
Bioturbated brownish gray medium- to coarse-grained sandstone with scattered granules and pebbles	Storm outwash deposits
Gradational contact	Base of lithofacies F
Bioturbated grayish-brown sandstone with poorly preserved cross beds	LITHOFACIES E Cross-bedded sandstone due primarily to the lateral migration of bars, dunes, and tidal inlet channels within the sandy barrier complex
Planar wedge set of cross strata	
Laterally discontinuous interval of of sandstone with thick planar laminae	Offshore shoal (?)
Very broad trough-based large-scale set of cross beds. Cross strata are up to 4 cm thick and are accentuated by heavy minerals and dark lithic fragments	Migrated tidal inlet channel
Tabular cross beds, sets up to 1 m thick, in light gray and light brown sandstone. Crossbeds consist of alternating cross strata (up to 5 cm thick) of medium- and coarse-grained sandstone	Sand bars and/or small flood tidal deltas
Bimodal truncated trough cross-bed sets	Dunes of the upper lower flow regime
Bioturbated light brown medium- to coarse-grained sandstone with poorly preserved small- and large-scale tabular and trough cross beds	
Scattered chunks and very thin lenses of dark reddish brown peat	Partially oxidized organic debris
Ophiomorpha	Crustacean burrow
Fault	
Large-scale tabular cross-bed set up to 2 m thick (wedges out laterally)	Sand bar
Interval of large-scale trough and tabular cross-stratified sandstone with bioturbated zones	Bars, dunes and/or tidal channels of the sandy barrier complex

Figure 8. LITHOFACIES E (upper portion) and LITHOFACIES F: representative stratigraphic column of the Eocene deposits (upper Torrey Sandstone) exposed in the sea cliffs south of Leucadia Roadside Park.

characterized by light brown, fine- to medium-grained sandstone with ripple cross laminae that are accentuated by thin mica drapes. Common are oppositely opposed superjacent sets that produce the "herringbone" type of cross stratification (a product of reversing tidal currents of the lower lower flow regime). Also, small troughs with thin mud drapes and tabular sets of large-scale cross bedding are present.

Small-scale cross bedding gives way to large-scale trough and tabular cross bedding that characterizes an overlying lithofacies. This second facies (lithofacies E, Figures 7 and 8) is exposed just south and to the north of the parking lot at Moonlight Beach State Park. In the sea cliffs to the north (near the beach access at south El Portal Street and Neptune Avenue, Leucadia), a large channel configuration can be seen within cross-bedded sandstone. This feature is similar to what Clifton (1979) described as an "outwash channel" within barrier sands of the Torrey Sandstone.

Further to the north, the large-scale cross-bedded facies grades into a third lithofacies of the Torrey Sandstone. This lithofacies (lithofacies F, Figure 8) consists predominately of brown or light gray medium- to coarse-grained sandstone that is strongly bioturbated. Several isolated sand-supported, subangular to subrounded, pebble- to large cobble-sized clasts are present. Cobbles of siltstone or porphyritic volcanic or granitic composition can be seen. Primary sedimentary structures, for the most part, are lacking.

The three lithofacies of the Torrey Sandstone, present in the beach cliffs of the study area represent a continuation of the marine transgression recognized in strata of the underlying Delmar Formation. The lower, middle, and upper lithofacies, respectively, record the landward migration of the inner, medial, and outer portions of the sandy barrier complex.

The rippled sandy facies which overlies the uppermost facies of the Delmar Formation can be interpreted as sediments deposited in back-barrier tidal sand flats at the outer (seaward) limits of the lagoonal environment. The large-scale cross-bedded lithofacies is most likely the product of the various shifting sand bars and numerous tidal inlets that were present in the core of the barrier complex. The sandy barrier complex was apparently of very low relief, perhaps largely inundated during high tides, and easily breached during storms.

The uppermost lithofacies of the Torrey Sandstone can be best thought of as a transition zone between nearshore and offshore marine environments. The lack of sorting and the extensive bioturbation suggest that the sediments were deposited during stormy episodes followed by prolonged quieter periods. The sediments can be described as storm lag and/or storm outwash detritus which were probably stranded out beyond fair-weather wave base.

Approximately 500 meters south of the beach access trail at Leucadia Boulevard and Neptune Avenue in Leucadia, a gently-inclined stratigraphic contact between the uppermost facies of the Torrey Sandstone and an overlying lithofacies (lithofacies G, Figure 9) is present. From this location the facies is exposed to the north, in the sea cliffs, for about 1.5 kilometers. The lithofacies consists predominately of light gray siltstones and claystones with thick intervals of gray, olive, or brown clayey to silty sandstone. Muddy sandstones in the lithofacies contain a variety of broken and abraded fossilized gastropod and clam shells. Oyster valves, though present, are very subordinate.

Bukry (1980) conducted preliminary investigations of coccolith assemblages from mollusc-bearing beds of this lithofacies. He concluded that the microfossils suggested that the rocks were a "shallower water" correlative of the Ardath Shale (mid-Eocene offshore deposits recognized in several localities of southwestern San Diego County). In 1983, calcareous nannofossils and benthic foraminifera from beds of this lithofacies were examined by Mark V. Filewicz and Al Almgren of Union Oil at Ventura, California. Filewicz (written comm., 1983) concluded that the nannofossils were of Middle Eocene age and specifically were from the zone of <u>Nannotetrina quadrata</u> (probable CP 13c of Okada and Bukry, 1980). A high stand of eustatic sea level occurred during the Middle Eocene (Vail and Hardenbol, 1979). Most of the foraminifera examined by Almgren indicated an outer neritic paleobathymetry with one species suggesting a possible upper bathyal depth.

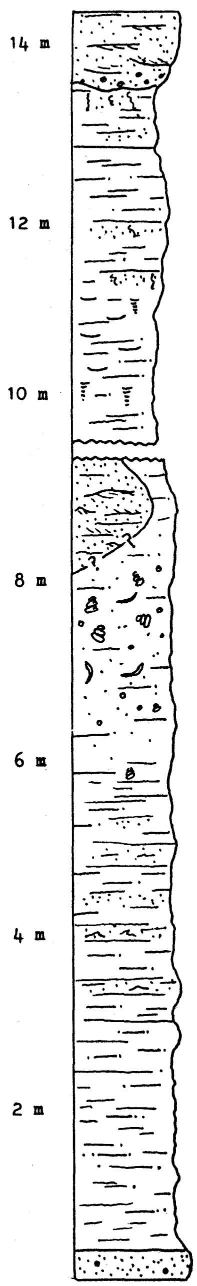
At the northern limits of this lithofacies, as it occurs in the sea cliffs, is a high angle fault that offsets portions of the unit. The fault juxtaposes an overlying cross-bedded sandy lithofacies (lithofacies H, Figure 10) which has a conspicuous lower erosional contact with gray mudstone and muddy sandstones of the offshore lithofacies exposed more extensively just to the south. Marine fossils contained within the sandy unit include <u>Ophiomorpha</u> and shark and ray teeth.

It is apparent that this facies was deposited under hydrologic conditions more typically found in near shore environments. It is most likely that these sandstones were deposited during the marine regression that immediately followed the main marine transgression.

A fairly continuous and remarkably extensive depositional history is contained in the rocks exposed in the sea cliffs along Cardiff-by-the-Sea, Encinitas, and Leucadia. The landward onlap of the various depositional environments during the mid-Eocene marine transgression left good deposits of lagoonal, barrier, and offshore settings recorded in the succession of the different lithofacies present. The succeeding marine regression is indicated by the uppermost lithofacies recognized. Lithologic correlatives to most of the lithofacies discussed in this paper can be recognized locally in outcrops inland of the sea cliffs. Study of the inland outcrops, coupled with the succession of lithofacies present in the sea cliffs, provides insight into the temporal and spatial distribution of the associated depositional environments.

Certain strata of the Torrey Sandstone exposed inland record progradation of thick gravelly alluvial fan-delta deposits into sandy back-barrier littoral environments. This paralic lithofacies is not developed in the sea cliffs of the study area. Absence of this lithofacies suggests that contemporaneous environments represented in the sea cliffs were in deeper-water settings removed from the influence of these progradational processes.

Figure 11 summarizes the depositional environments indicated by Eocene lithofacies of the study area and depicts a theoretical spatial distribution of those environments.



DESCRIPTION	INTERPRETATION
Light brown cross-bedded sandstone	
-Sharp erosional contact-	Base of lithofacies H
	LITHOFACIES G
Gray mudstone and bioturbated muddy sandstone	Finer-grained sediments deposited seaward of the outer fringes of the sandy barrier complex
Fault	
Interval of gray mudstone with poorly-defined lenses and layers of bioturbated muddy sandstone	Mudstones produced primarily by the settle-out of fines under lower lower flow regime
Interval is cut by many steeply-inclined faults having apparently minor offsets	
Wispy silty laminae	Infilled ripple troughs
Small stacks of concave-up thin laminae	Bivalve burrows (?)
Obscured by sea wall	
Large sandstone lense that tongues into, and is partially a lateral equivalent of, strata depicted below. Lense contains brown and brownish-gray fine- to medium-grained sandstone with ripple laminae and poorly-developed swaley (?) cross strata	Offshore sand ridge or subaqueous bar deposited under lower flow regimes probably between storm and fair weather wave base
Gray and greenish-gray poorly-sorted richly fossiliferous silty sandstone with scattered sand-supported subangular to subrounded granules and pebbles	Offshore storm deposits
Megascopic body fossils include a variety of gastropods and thick-shelled bivalves, many of which are broken and/or abraded	Fossil assemblage including transported shells
Laminated greenish-gray fossiliferous siltstone	
Light gray thin- to medium-bedded silty sandstone interlayered with medium- to thickly-bedded greenish-gray clayey siltstone	Suspension deposition of fines with periodic sand influx (distal storm layers ?)
Thin planar laminae and minor convolute or ripple laminae are present within individual beds	Lower lower flow regime
Dark gray silty claystone	Silts and clays deposited in low energy environments seaward of the outer fringes of the sandy barrier complex
Small (2± cm in diameter) chunk of amber (collected)	
Slightly fissile gray clayey siltstone	
-Sharp apparently conformable contact-	Base of lithofacies G
	Lithofacies F

Figure 9. LITHOFACIES G: representative stratigraphic column exposed in the sea cliffs of Leucadia Roadside County Park and Ponto Beach State Park.

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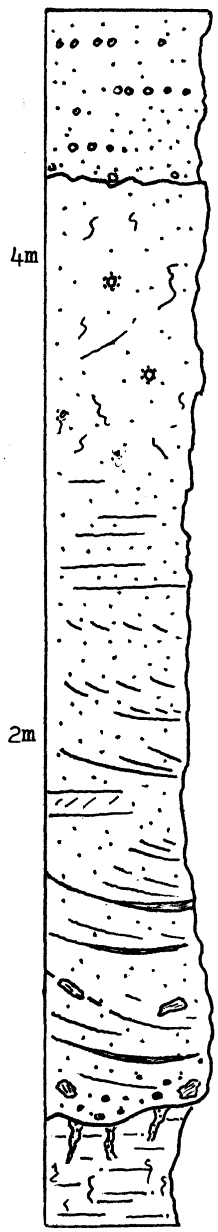


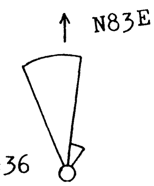
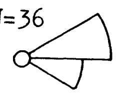
DESCRIPTION	INTERPRETATION
Poorly indurated brown sandstone with cobble stringers	Pleistocene beach sediments
	LITHOFACIES H
Sharp irregular contact	Erosional surface
Bioturbated sandstone with abundant *Ophiomorpha*	Intertidal sand flats
 N83E, N=36. Azimuthal distribution of trough axes	**East/west-oriented tidal currents**
Planar laminated sandstone with mud-laminae and ripple laminae	Very shallow channel fill
 N=36, S3E	**Point bar sequence from a southward migrated tidal channel**
Azimuthal distribution of cross beds	
Fine- to medium-grained sandstone with southward dipping epsilon cross bedding and east-west trending mud-draped troughs	Deep channel fill
Layer of mudstone cobbles, granules, and coarse-grained sand with marine macro-fossils including shark and ray teeth	Basal channel lag deposit
Sharp irregular contact	Erosional surface
Sand-filled burrows	Escape burrows
Bioturbated gray silty mudstone and muddy sandstone	Lithofacies G (offshore fines)

Figure 10. LITHOFACIES H: representative stratigraphic column of the rocks exposed in the sea cliffs at Ponto Beach State Park.

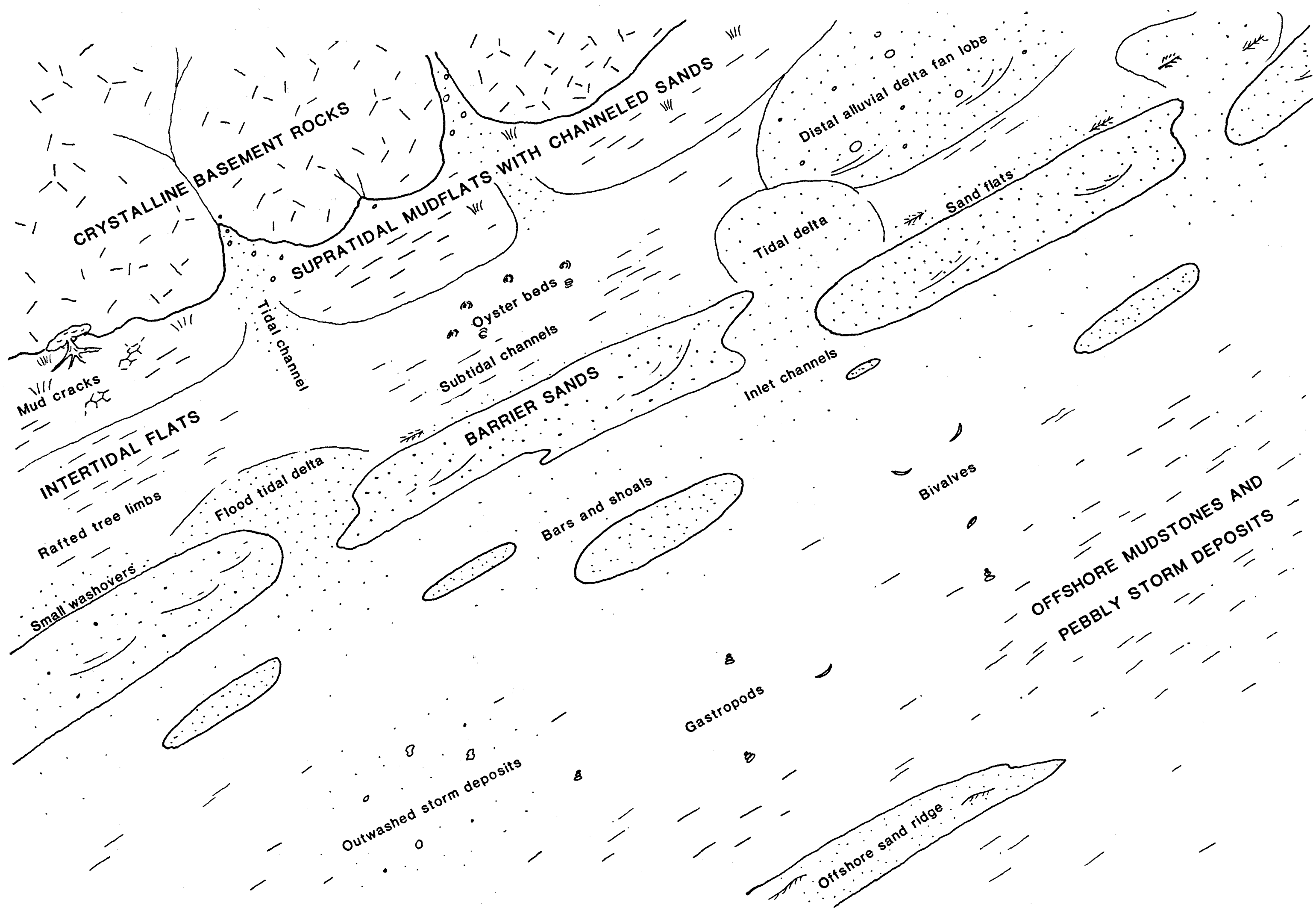


Figure 11. Cartoon showing the theoretical spatial distribution of the depositional environments indicated by the various lithofacies recognized.

PALEONTOLOGY AND BIOSTRATIGRAPHY OF MIDDLE EOCENE NEARSHORE MARINE SEDIMENTARY ROCKS, LEUCADIA, SAN DIEGO COUNTY, CALIFORNIA

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ABSTRACT

Sea cliff exposures of Eocene nearshore marine sandstones and siltstones at Leucadia, San Diego County, California contain a diverse and well-preserved assemblage of calcareous nannoplankton, benthic foraminifers, mollusks, ostracodes and fishes. Planktonic coccolith assemblages are correlative with the Middle Eocene Nannotetrina quadrata zone (CP13) and possibly with the Coccolithus staurion subzone (CP13C) dated at 45.0 to 46.5 million years old. This correlation is in conflict with a benthic foraminiferal-based late Early to early Middle Eocene Ulatisian Stage correlation and a mollusk-based Late Eocene "Tejon Stage" correlation. Comparison of these correlations corroborates the notion that Paleogene provincial benthic foraminiferal stages are facies controlled and time-transgressive. It is suggested that the same is true for Paleogene provincial molluscan stages. The coccolith-based Middle Eocene correlation suggests that the fine-grained Leucadia section is slightly younger than typical lower Middle Eocene exposures of the Ardath Shale near San Diego, to which it is provisionally assigned.

INTRODUCTION

The paleontology of the marine Eocene strata exposed near San Diego has been the subject of considerable prior study (see summaries in Hanna, 1927 and Givens and Kennedy, 1979). The majority of these earlier studies dealt with localities in and around Clairemont, La Jolla and Del Mar (Fig. 1). The present study represents a preliminary analysis of a rather unique fossiliferous site exposed in the sea cliffs at Leucadia. This site has yielded abundant and well-preserved remains of calcareous nannoplankton, foraminifers, octracodes, and mollusks as well as rare remains of bony and cartilaginous fishes.

The recovered fossil assemblage is significant as it represents one of the only shallow nearshore marine environments in this part of the Eocene San Diego embayment where lagoonal and brackish water environments predominate. In addition, the variety of fossil groups represented at Leucadia allows for fairly precise biostratigraphic correlations and age determinations and has the potential for cross-correlating provincial molluscan stages (Weaver et al., 1944) with benthic foraminiferal stages (Mallory, 1959) and deep sea nannoplankton zones (Okada and Bukry, 1980).

All of the fossil remains discussed in this paper have been deposited in the paleontological collections of the San Diego Natural History Museum (SDSNH).

STRATIGRAPHY

The sea cliffs along the San Diego County coast at Encinitas and Leucadia (Fig. 2) expose a gently dipping and locally faulted sequence of Eocene-aged sandstones, siltstones, claystones and oyster bioherms. Wilson (1972) assigned these sedimentary rocks in ascending order (south to north) to the Delmar Formation, the Torrey Sandstone, and the Santiago Formation and suggested that the stratigraphically higher Santiago Formation was in fault contact with the Torrey Sandstone. Based on better and more continuous outcrops due to sea cliff retreat, Eisenberg (1983) reevaluated the Leucadia part of the section and recognized a conformable relationship between the Torrey Sandstone and the overlying unit which he refers to the Ardath Shale. It is this "Ardath Shale"-"Santiago Formation" section that is the focus of the present study. Briefly the section (see Irwin, this volume: Fig. 9) consists of at least 13 m of dark gray, well-sorted, very fine- to fine-grained locally fossiliferous, biotite-rich lithic arkose and siltstone and dark gray-green, silty claystone. Fossils

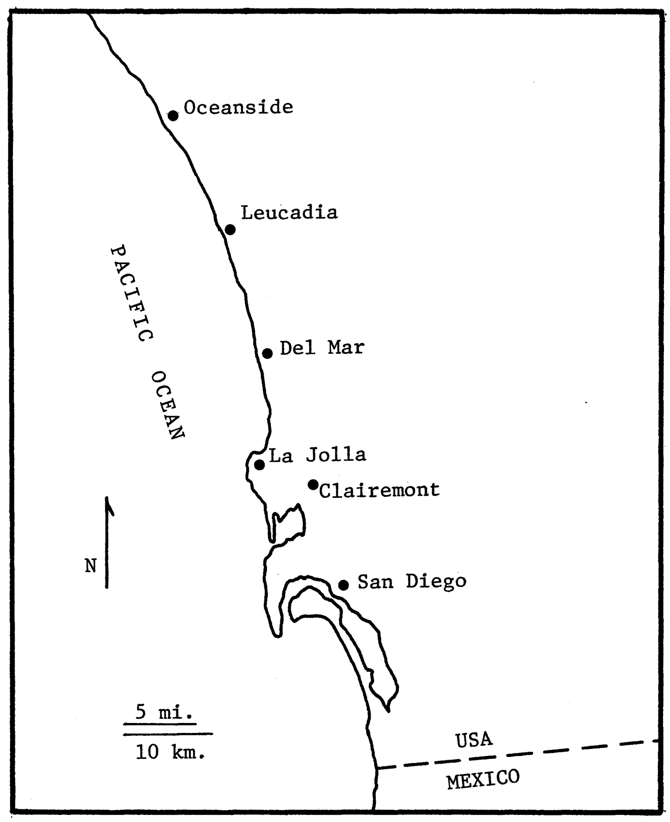

Figure 1. Index map of coastal San Diego County.

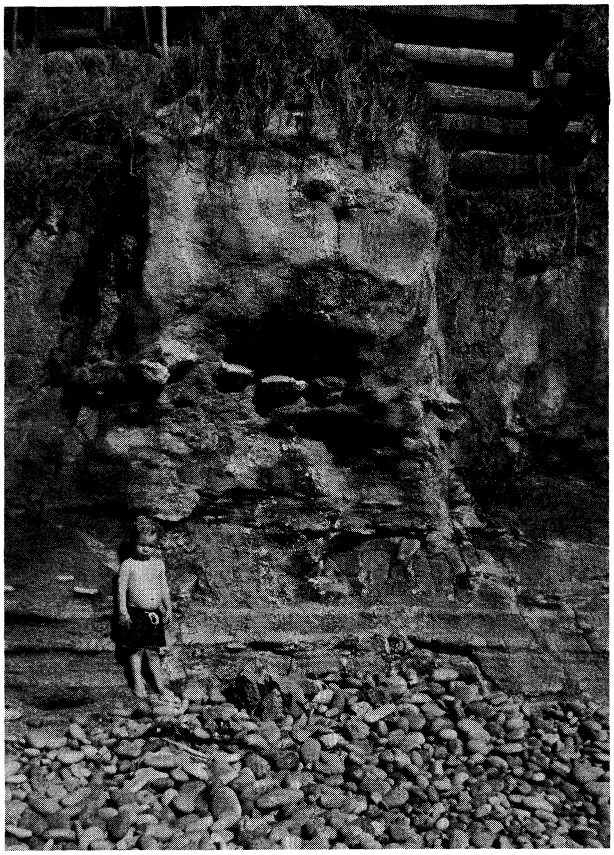

Figure 2. SDSNH locality 2961 as exposed in sea cliffs at Leucadia. Fossiliferous horizon is above child's head. (2.7 y.o. Evan for scale.)

are especially abundant within a 90-130 cm thick massive, dark gray, poorly sorted, fine-grained pebbly sandstone and siltstone bed. This bed (SDSNH locality 2961) lies approximately 7 m above the "Ardath Shale"/Torrey Sandstone contact (as interpreted by Eisenberg, 1983 and Irwin, this volume) and has yielded all of the fossil remains discussed in the present report.

The common occurrence of large, thick-shelled mollusks "floating" unoriented in the poorly sorted matrix is a striking characteristic of this otherwise massive unit. Occasional aggregates of fossils also occur, some with small gastropods (e.g. "Voluta") stuffed into the apertures of larger species (e.g. Pachycrommium). Many of the larger pelecypod specimens (e.g. Crassatella) display breakage and abrasion; no paired valves were noted. The majority of the macroinvertebrates occur as well-preserved body fossils composed of original aragonitic or calcitic shell material. Foraminifers are equally well-preserved with certain taxa (e.g. Eponides) displaying beautifully translucent chambers. Vertebrate remains, although extremely rare, are also well preserved.

PALEONTOLOGY

As briefly discussed already, SDSNH locality 2961 has yielded diverse and well-preserved remains of calcareous nannoplankton, foraminifers, ostracodes, mollusks and fishes. Table I summarizes the floral and faunal content of this diverse assemblage.

CALCAREOUS NANNOPLANKTON

Calcareous nannoplankton from SDSNH loc. 2961 have previously been studied by Bukry (1980) and Filewicz (in Eisenberg, 1983). Bukry recorded a low diversity assemblage (10 species) dominated by shallow water pentaliths and placoliths (e.g. Micrantholithus and Pemma). He also recorded the occurrence of several biostratigraphically important taxa including Helicosphaera lophota Bramlette and Sullivan and Sphenolithus spiniger Bukry. Filewicz recorded an additional nine taxa from this locality including Discoaster barbadiensis Tan Sin Hok, and Reticulofenestra umbilica (Levin). The combined nannoplankton assemblage is summarized in Table I.

FORAMINIFERA

Foraminifers are reasonably well represented in the samples collected from loc. 2961. No planktonic specimens occur in this material which is dominated by a benthic assemblage consisting primarily of species of Anomalina, Elphidiella, Eponides and Lenticulina. Biostratigraphically significant taxa in this assemblage include Caucasina sp. cf. C. schencki (Beck) and Elphidiella californica (Cook). Table I summarizes the total foraminiferal assemblage recovered from loc. 2961.

MOLLUSKS

A total of 31 molluscan taxa (15 pelecypod, 15 gastropod and 1 cephalopod) divided between 20 families are here recorded from SDSNH loc. 2961 (Table 1). A few of the more taxonomically or biostratigraphically interesting taxa are discussed below.

Pelecypoda

Carditidae

Several large well-preserved valves of Venericardia (Pacificor) hornii (Gabb) s.s. exhibit the cuneate elongate anterior cardinal tooth of the typical subspecies (Verastegui, 1953). This form is known only from the Late Eocene "Tejon" molluscan stage (Givens, 1974). A small carditid (10 mm long) is provisionally referred to Glyptoactis marksi (Verastegui) based on its rounded outline and rather blunt beak. This species also is known only from the Late Eocene "Tejon Stage" (Verastegui, 1953).

Crassatellidae

Because of its large size (up to 123 mm long) Crassatella uvasana Conrad s.s. is a conspicuous faunal element at Leucadia. Specimens of this species possess a nearly equilateral, triangular outline with broad prominent beaks and widely spaced concentric growth lines. These specimens are nearly identical to forms figured by Dickerson (1915: pl. 1, fig. 8; pl. 2, figs. 1a, 1b) from the type Tejon as Crassatellites grandis Gabb. According to Givens (1974), C. uvasana s.s. is only known from the "Tejon Stage".

Veneridae

Venerids are the most diverse pelecypod group at Leucadia being represented by five taxa (Table I). Four taxa, Pitar (Calpitaria) uvasanus (Conrad) s.s., Callista (Costacallista) hornii (Gabb), Callista (Macrocallista) conradiana (Gabb) are recorded only from the "Transition" and "Tejon" molluscan stages (Givens, 1974).

Gastropoda

Turritellidae

A few incomplete specimens of Turritella uvasana Conrad s.l. are provisionally referred to T. u. neopleura Merriam. These specimens exhibit a regularly convex whorl profile and numerous nearly equal-sized principal spiral ribs which display a tendency of becoming beaded posteriorly. This form from Leucadia is very similar to turritellas from a locality in the Scripps Formation (SDSNH loc. 3144). Givens (1974) records T. u. neopleura only from the "Transition" and "Tejon" stages.

Volutidae

Numerous well-preserved specimens of a medium sized volute (up to 38 mm high) are conspecific with "Voluta" martini Dickerson from the type Tejon. The Leucadia specimens possess four columellar folds, a short twisted anterior canal and seven prominent nodes on the body whorl (eight on the penultimate whorl). The nodes are positioned one third of the whorl length from the indistinct suture. Besides the nodes, the body whorl is decorated by growth lines only. "Voluta" martini has previously been recorded only from the "Tejon" (Dickerson, 1915) and the "Domengine" (Bremner, 1932). To this scant record can be added a single juvenile specimen from a locality in the Mission Valley Formation (SDSNH loc. 2962). The macroinvertebrate assemblage from this "Tejon" correlative has been preliminarily described by Demere et al. (1979).

Cephalopoda

Cymatoceratidae (?)

A body chamber fragment of a large, thick-shelled nautiloid is provisionally referred to this family based on the shell thickness and evenly convex lateral outline of the aperture.

OSTRACODES

Well preserved but rare remains of ostracodes were encountered but not identified in the samples collected from loc. 2961.

VERTEBRATES

A single large shark vertebra and a partially abraded bony fish otolith are recorded from this locality.

BIOSTRATIGRAPHY AND AGE

Bukry (1980) noted that the great dissimilarities between early Middle and late Late Eocene shallow-water coccolith assemblages are not evident at Leucadia (SDSNH loc. 2961), and that the presence of Helicosphaera lophota Bramlette and Sullivan and Sphenolithus spiniger Bukry suggested a stratigraphic level no higher than Middle Eocene. He further implied a possible correlation between the Leucadia section and the Ardath Shale, which he notes is correlated with the early Middle Eocene portion of the Discoaster sublodoensis zone of Bukry (1973). Filewicz (in Eisenberg, 1983) in his examination of a more florally diverse sample from SDSNH loc. 2961 suggested a slightly younger correlation with the Middle Eocene Nannotetrina quadrata zone of Bukry (1973) and possibly with the Coccolithus staurion subzone of that zone. Okada and Bukry (1980) suggest an absolute age estimate of 45.0 to 46.5 million years for this subzone.

Benthic foraminiferal assemblages from Leucadia indicate a correlation with the Ulatisian Stage of Mallory (1959). The co-occurrence of Caucasina sp. cf. C. schencki (Beck) and Elphidiella californica (Cook) further suggest correlation with the upper part of that stage. The upper Ulatisian stage may range from the later part of the Early Eocene to the early part of the Middle Eocene following the data of Warren (1980). Some caution, however, must be used in the strict application of early to middle Tertiary benthic foraminiferal ranges. Paleoenvironmental effects may extend or shorten a particular species' stratigraphic range depending on the locality (Steineck and Gibson, 1971).

The Leucadia section contains several molluscan taxa indicative of the provincial Late Eocene "Tejon Stage" of Weaver et al. (1944) as interpreted by Givens (1974) and Givens and Kennedy (1979). These include Crassatella uvasana Conrad s.s., Venericardia (Pacificor) hornii (Gabb) s.s. and Callista (Microcallista) conradiana (Gabb). Additional taxa are restricted to the "Transition Stage"-"Tejon Stage" biostratigraphic interval while other species range throughout the Eocene. Based on these ranges a correlation with the "Tejon Stage" is here tentatively proposed. Wilson (1972) suggested a similar correlation based on a more taxonomically limited molluscan assemblage from Leucadia.

Comparison of the various biostratigraphic correlations indicated by the Leucadia microfossil and macroinvertebrate assemblages reveals some significant discrepancies. Relying on the data of Warren (1980: fig. 3) the Middle Eocene Nannotetrina quadrata zone is correlative with the provincial Late Eocene Narizian Stage of Mallory (1959) and not with the older Ulatisian Stage. This problem of correlating planktic nannofossil zones with those established for benthic foraminifers has been discussed by Steineck and Gibson (1971, 1972) and Gibson and Steineck (1972). These workers suggest that the California Paleogene benthic foraminiferal stages of Mallory are facies controlled and time transgressive, a conclusion which explains the Leucadia data. Interestingly, the Late Eocene "Tejon Stage" molluscan-based correlation at Leucadia suggests that molluscan stages are probably also facies controlled and time transgressive.

Concerning the question of the stratigraphic correlation of the fine-grained Leucadia section with either the Upper Eocene Santiago Formation (Wilson, 1972) or the lower Middle Eocene Ardath Shale (Bukry, 1980), it appears from coccolith evidence that the Leucadia section represents a slightly younger Middle Eocene nearshore portion of the Ardath Shale.

Table I. Faunal and floral list of fossils collected from SDSNH locality 2961.

CALCAREOUS NANNOPLANKTON
- Braarudosphaera bigelowii (Gran & Braarud)
- B. discula Bramlette and Riedel
- Chiasmolithus grandis (Bramlette & Sullivan)
- C. solitus (Bramlette & Sullivan)
- Discoaster barbadiensis Tan Sin Hok
- D. elegans
- D. tani Bramlette & Riedel
- Helicosphaera lophota Bramlette & Sullivan
- Micrantholithus basquensis Martini
- M. flos Deflandre
- M. parisiensis Bouche
- Nannotetrina cristatus (Martini)
- Pemma rotundum Klumpp
- Reticulofenestra callida (Perch-Nielsen)
- R. samudorovi (Hay, Mohler & Wade)
- R. umbilica (Levin)
- Sphenolithus spiniger Bukry

FORAMINIFERA
- Anomalina sp. indet.
- Caucasina sp. cf. C. schencki (Beck)
- Elphidiella californica (Cook)
- Eponides yeguaensis Weinzierl & Applin
- E. minima Cushman
- E. sp. indet.
- Florilus sp. cf. F. florinensis (Cole)
- Lenticulina inornata (d'Orbigny)
- L. sp. cf. L. kreyenhagensis (Mallory)
- L. spp. indet.
- Massilina sp.

PELECYPODA
- Brachidontes (Brachidontes) cowlitzensis (Weaver & Palmer)
- Callista (Costacallista) hornii (Gabb)
- C. (Macrocallista) andersoni (Dickerson)
- C. (Microcallista) conradiana (Gabb)
- Callocardia (Nitidavenus) sp. indet.

PELECYPODA (Continued)
- Corbula (Caryocorbula) parilis Gabb
- Crassatella uvasana Conrad
- Gari hornii (Gabb)
- Glycymeris (Glycymeris) perrini Dickerson
- G. (G). sagittata (Gabb)
- Glyptoactis sp. cf. G. marksi (Verastegui)
- Ostrea idriaensis Gabb
- Pitar (Calpitaria) uvasansus (Conrad) s.s.
- Trigonodesma hornii (Gabb)
- Venericardia (Pacificor) hornii (Gabb) s.s.

GASTROPODA
- Calyptraea diegoana (Conrad)
- Cerithiopsis sp. indet.
- Conus hornii Gabb s.l.
- Conus sp. indet.
- Ectinochilus (Cowlitzia) sp. indet.
- Euspira? sp. cf. E.? nuciformis (Gabb)
- Mitra sp. indet.
- Pachycrommium? clarki (Stewart)
- Pleurofusia sp. cf. P. lindavistaensis (Hanna)
- Polinices hornii (Gabb)
- Ranellina? sp. indet.
- Strepsidura ficus (Gabb)
- Surculites sp. cf. S. sinuata (Gabb)
- Turritella uvasana neopleura Merriam
- "Voluta" martini Dickerson

CEPHALOPODA
- Cymatoceratidae? gen. et sp. indet.

OSTRACODA
- unidentified ostracodes

VERTEBRATA
- Chondrichthyes
- Osteichthyes

PALEOENVIRONMENT

As noted by Bukry (1980) the Leucadia site contains common shallow-water nannoplankton including Braarudosphaera bigelowii (Gram and Braarud), B. discula Bramlette and Riedel, Micrantholithus basquensis Martini, M. flos Deflandre and Pemma rotundum Klumpp.

Foraminifers at Leucadia clearly indicate a shelf environment (probably inner to middle), following the models of Ingle (1980).

The shallow-water inner to middle shelf environment indicated by microfossils is supported by analysis of the Leucadia molluscan assemblage. In addition the majority of the molluscan taxa further indicate the presence of sandy substrates and normal marine salinities.

The sedimentology of the fossil bed at Leucadia, with granules and pebbles of batholithic origin floating in a primarily silty fine-grained sandstone matrix together with large, unpaired and unoriented pelecypod valves, suggests that the fossils (and pebbles) were transported to the site of deposition. Eisenberg (1983) has suggested that this transport was the result of a storm-return surge (Hayes, 1967) sweeping coarse material out onto the shelf.

SUMMARY

1) Diverse and well-preserved marine microfossil and molluscan assemblages have been recovered from a single bed within the Eocene section at Leucadia.

2) These assemblages represent nearshore inner to middle shelf environments.

3) Planktic coccoliths indicate a correlation with the Middle Eocene Coccolithus staurion subzone of the Nannotetrina quadrata zone (approximately 45.0 to 46.5 million years B.P.).

4) Benthic foraminifers indicate a correlation with the late Early to early Middle Eocene Ulatisian stage.

5) Mollusks indicate a correlation with the Late Eocene "Tejon Stage".

6) Comparison of these correlations suggests that the provincial benthic foraminiferal and molluscan stages are facies controlled and time transgressive.

7) Planktic coccolith zones apparently are the most temporally reliable.

8) This biostratigraphic analysis also suggests that the fine-grained Leucadia section is slightly younger than typical lower Middle Eocene exposures of

the Ardath Shale near San Diego, to which it is provisionally assigned.

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Conglomeratic stringers of Poway rhyolite clasts spread by major flood event from a fan-delta lobe over the Eocene lagoonal bottom topography.

DEPOSITIONAL PROCESSES IN THE LANDWARD PART OF AN EOCENE TIDAL LAGOON, NORTHERN SAN DIEGO COUNTY

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INTRODUCTION

Along the San Diego County coast, Upper Cretaceous, Eocene and Pleistocene strata are preserved in a narrow strip between Mesozoic basement hills and the sea. The basement hills are formed from Upper Jurassic metavolcanic rocks and from Cretaceous intrusive rocks. The metavolcanic rocks are part of the Santiago Peak Volcanics and consist largely of andesitic agglomerates, breccias, flows and tuffs (Larsen, 1948; Adams, 1979). Some of the sedimentary rocks interbedded with the volcanic rocks contain marine fossils whose presence suggests a latest Jurassic (Portlandian) age (Fife and others, 1967). Cretaceous rocks are in intrusive contact with the metavolcanics and consist largely of tonalite and granodiorite with lesser amounts of gabbro and granite.

Santiago Peak Volcanic rocks were the product of a Jurassic island arc system in which thousands of feet of volcanic material were deposited, primarily in marine environments. Lulls in the volcanic regime allowed the intercalation of some volcaniclastic marine deposits (Balch, 1981). Subduction in an accompanying trench generated the numerous igneous bodies which are now in intrusive contact with the Santiago Peak Volcanic rocks and which make up the Peninsular Ranges batholith (Gastil and Higley, 1977).

After an interval of exposure and erosion, Upper Cretaceous alluvial fan and marine rocks were deposited over older rocks along a high relief erosion surface. Kaolinitic paleosols formed on these Cretaceous sedimentary rocks, as well as on metamorphic and plutonic basement rocks. These paleosols suggest that exposure and erosion occurred while a hot and humid climate prevailed over the San Diego region. Medial middle and younger Eocene rocks suggest that the climate was semi-arid (Peterson and Abbott, 1979).

The arrival of exotic, rhyolitic Poway-suite clasts accompanied the start of Eocene deposition in the San Diego area (Kies, 1982; Kies and Abbott, 1983). These exotic clasts were derived from volcanic rocks in Sonora, Mexico and were transported westward to San Diego via a fluvial system which crossed over a yet-to-be-uplifted batholithic terrain. These rhyolitic clasts found their way into Eocene deposits in many types of environments, including alluvial fan, fan-delta, lagoonal delta and submarine canyon and fan (Minch, 1972; Abbott and Smith, 1978; Link and others, 1979).

Alternating transgressions and regressions fashioned the Eocene stratigraphic sequence in the San Diego area from a submarine fan-slope-shelf-barrier-lagoon depositional megasystem, with each advance and retreat of the sea stacking the deposits of each depositional environment sequentially above those beneath.

Eocene strata are nearly flat-lying and rest on older rocks along a high relief erosion surface. Eocene and younger deposition took place without much erosion of the pre-existing basement topography. This topography has been partly exhumed by recent erosion and now forms a portion of the modern topography (Peterson and Nordstrom, 1970). The hills of Jurassic metavolcanic and Cretaceous plutonic rocks looming above the San Diego coastal mesas look much as they did 40 million years ago. Younger Tertiary deposits, now eroded away, must have buried these hills beneath a protective cover.

During the Pleistocene, numerous marine terraces were incised into the rocks along the coast. Many of these terraces are preserved along the San Diego County coastline and the marine and non-marine deposits which mantled the terraces underlie much of the coastal strip.

Along the northern San Diego County coast between Carlsbad and Solana Beach (Figure 1), Eocene rocks were deposited in a barrier bar-tidal lagoon depositional setting. The record of this depositional system is well exposed in numerous canyons and roadcuts. These excellent exposures allow a rather complete view of the Eocene section in the horizontal as well as the vertical dimension. Eocene rocks are practically undeformed and nearly flat-lying and rest on the underlying rocks essentially as they were laid down in Eocene time. Thus the record of lateral and vertical facies changes and depositional processes and history in the Eocene section is laid bare.

This paper discusses some of the depositional processes and influences active in the landward part of the tidal lagoon during Eocene time.

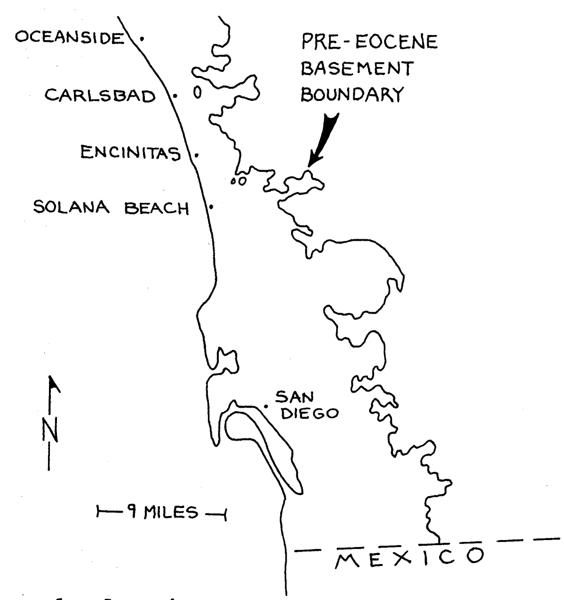

Figure 1. Location map.

DEPOSITIONAL SETTING

The depositional setting of the Eocene rocks preserved along the coast between Carlsbad and Solana Beach was essentially that of a barrier and tidal lagoon system; the sediments deposited in the varied environments of this system make up the lion's share of the Eocene section. Deposits of alluvial, fluvial/deltaic and nearshore marine environments are interspersed within the barrier-lagoon rocks and form the remainder of the Eocene section.

Deposition began in the earliest middle Eocene with the formation of a barrier-tidal lagoon system along and roughly parallel to the position of the present coastline. The formation of this system was associated with the advent of a worldwide transgressional episode in the early middle Eocene that was to last through most of the rest of the middle Eocene.

On the seaward side of the barrier, sand was deposited in environments such as the seaward side of tidal inlets, in ebb-tidal deltas, and in longshore bars and troughs. These sands often were burrowed by robust crustaceans able to hang on in the shifting substrate. Along the barrier itself beach and upper shoreface sands piled up along the shore, dunes capped the barrier island and back-barrier sands spilled down into the lagoon. Landward of the barrier, sands accumulated in the lagoonward side of tidal inlets, flood-tidal deltas, and subtidal and intertidal channels and bars. Deposits in these shifting environments interfingered on their landward side with intertidal flat sands (Figure 2).

As is typical in tidally-influenced depositional systems the sand that was deposited along the barrier gradually was replaced in the land direction by silt and mud. Around a barrier, tidal currents are strong enough to move sand and winnow mud but further landward, away from tidal inlets currents weaken and mud and silt will accumulate (Evans, 1965; Klein, 1971; De Jong, 1977; Boothroyd, 1978). These silts and muds were deposited in intertidal creeks and flats and supratidal marshes along the landward edge of the lagoon where it abutted the hilly coastline.

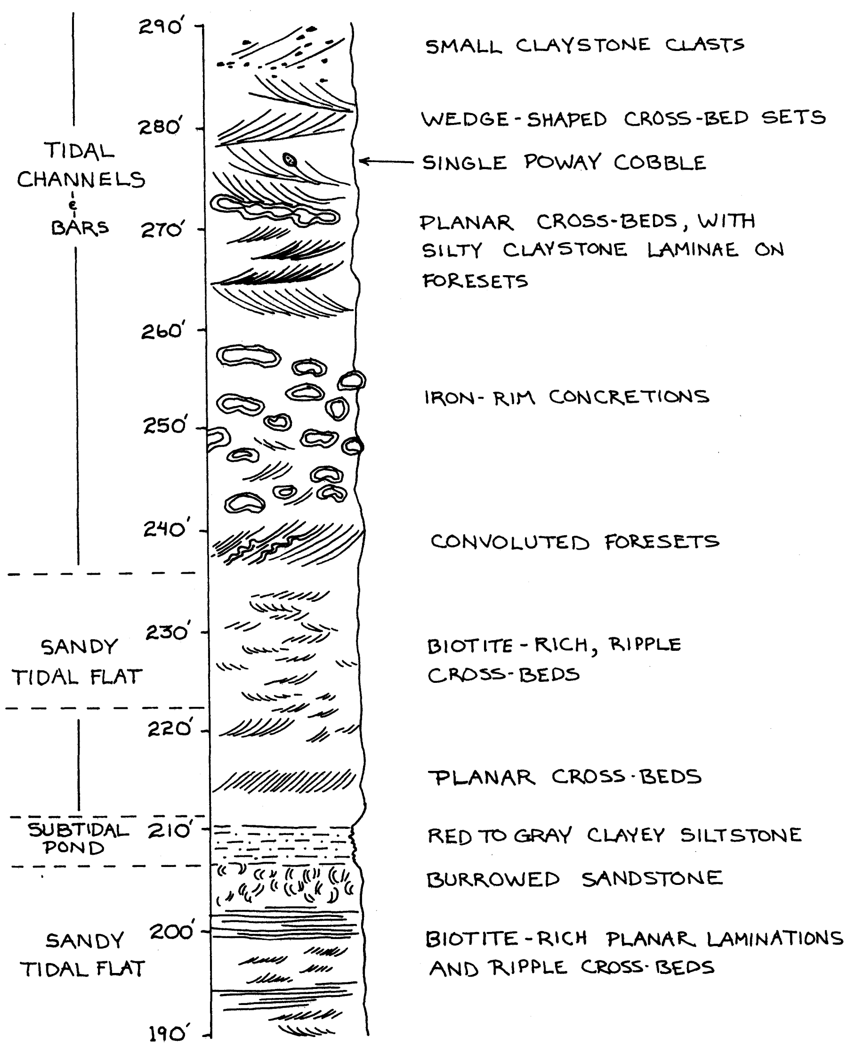

Figure 2. Interfingering lithologies and depositional environments in sandy outer tidal lagoon strata. Outcrop section in north-facing bluff 3,000 feet S25°W from intersection of Olivenhain Road and Rancho Santa Fe Road. Section drawn against elevation.

At times of increased runoff or major storms, coarse sand and gravel washed down from the precipitous hills and into the lagoon. These coarse sediments cut through and overlaid the muddy sediments at the back edge of the tidal lagoon. Locally the coarse sediments were built into small deltas. The focus of deposition moved around the edge of the delta as the main delta distributary first filled and then abandoned its channel for a new one. As distributary channels filled they accumulated finer and finer sediments. Often these channels were overlaid by and interfingered with muddy sediments that accumulated beyond the edge of the delta (Figure 3).

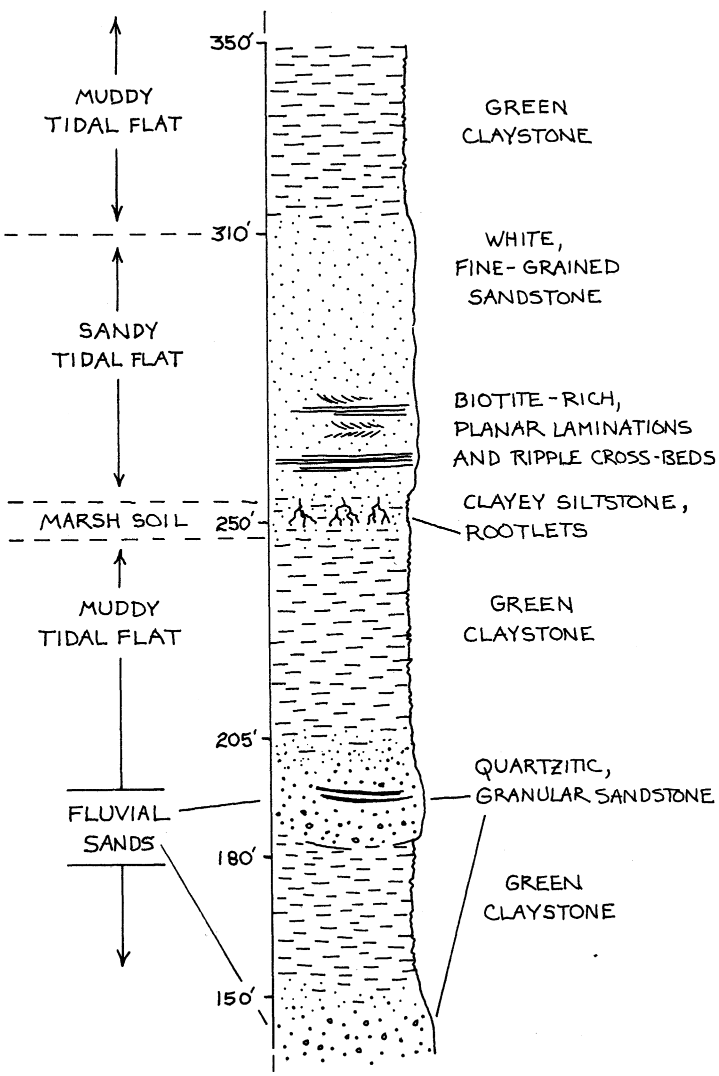

Figure 3. Interfingering lithologies and depositional environments in muddy inner tidal lagoon strata. Composite outcrop section from southwest of intersection of La Costa Ave. and Rancho Santa Fe Road. Section drawn against elevation.

As transgression continued through the early middle Eocene the various environments shifted landward, with more seaward deposits accumulating over successively more landward ones. As the sea advanced, surf action along a narrow zone near the base of the barrier shoreface planed off sediments deposited in upper shoreface, beach and dune environments of the barrier. Within the lagoon, sandy outer tidal lagoon sediments overran muddy inner tidal lagoon sediments.

As the sea continued to transgress it eventually became impeded in its landward advance by the coastal hills. This steep paleoshoreline topography caused deposition to become confined against the coastal hills. This compressed the various tidal environments against the coastal hills and caused them to maintain a nearly constant position relative to the shoreline as sediments continued to pile up. The result of this confinement was a pronounced buttress unconformity between Eocene strata and basement rocks, and a relatively steep depositional contact between sandy outer tidal lagoon sediments and muddy inner tidal lagoon sediments.

In addition to the intermittent incursions of gravel and sand from the immediately surrounding coastal hills a different suite of gravels reached into the lagoon. These gravels came from a larger gravelly system to the south and east which was part of the Poway-suite conglomeratic environment centered in the San Diego area. A northerly arm of this system advanced into Rancho Santa Fe and delivered Poway-suite gravels through a braided-bar fluvial distributary into the sandy, deepest parts of the tidal lagoon. Intermittent floods spread the Poway-suite gravels northwestward across the uneven floor of the lagoon.

The maximum advance of the sea toward the land occurred in the medial middle Eocene, and the deposition of nearshore marine sand, silt and mud reached just to the position of the present coastline. A slight regression after this transgressive peak caused the various environments to shift back seaward, and the nearshore marine deposits became wedged underneath the advancing sands of the barrier system. Although transgression and a high sea stand continued through the middle Eocene the depositional environments and corresponding deposits continued to prograde in response to a slowing of subsidence and/or an increase in sedimentation. Eventually inner lagoon sediments overran outer lagoon sediments and a complete transgressive-regressive barrier and lagoon sedimentation cycle was completed. Figure 4 is a diagrammatic cutaway view of Eocene tidal deposits of the first transgressive-regressive sedimentation cycle.

Regression and transgression followed in the late Eocene but little of this sedimentation cycle is preserved in the area between Carlsbad and Solana Beach. Only in the far southeastern corner of this area, east of Rancho Santa Fe across the San Dieguito River, is the record preserved. The late Eocene regression is recorded in a thin wedge of alluvial fan and fluvial braided-bar Poway-suite conglomerate. This conglomerate prograded over muddy inner tidal lagoon sediments. The following transgression is recorded in a poorly exposed, possibly estuarine sandstone that conformably overlies the conglomerate.

The Eocene rocks along the coast between Carlsbad and Solana Beach have been assigned to units of the La Jolla Group (Eisenberg, 1983). Figure 5 shows a diagrammatic summary of the nomenclature and stratigraphic relations of Eocene rocks in this area.

DEPOSITIONAL PROCESSES IN THE LANDWARD PART OF THE EOCENE LAGOON

The middle Eocene barrier-lagoon system appears to have been a bit out of the ordinary in that it formed along a coast with a narrow shelf and a

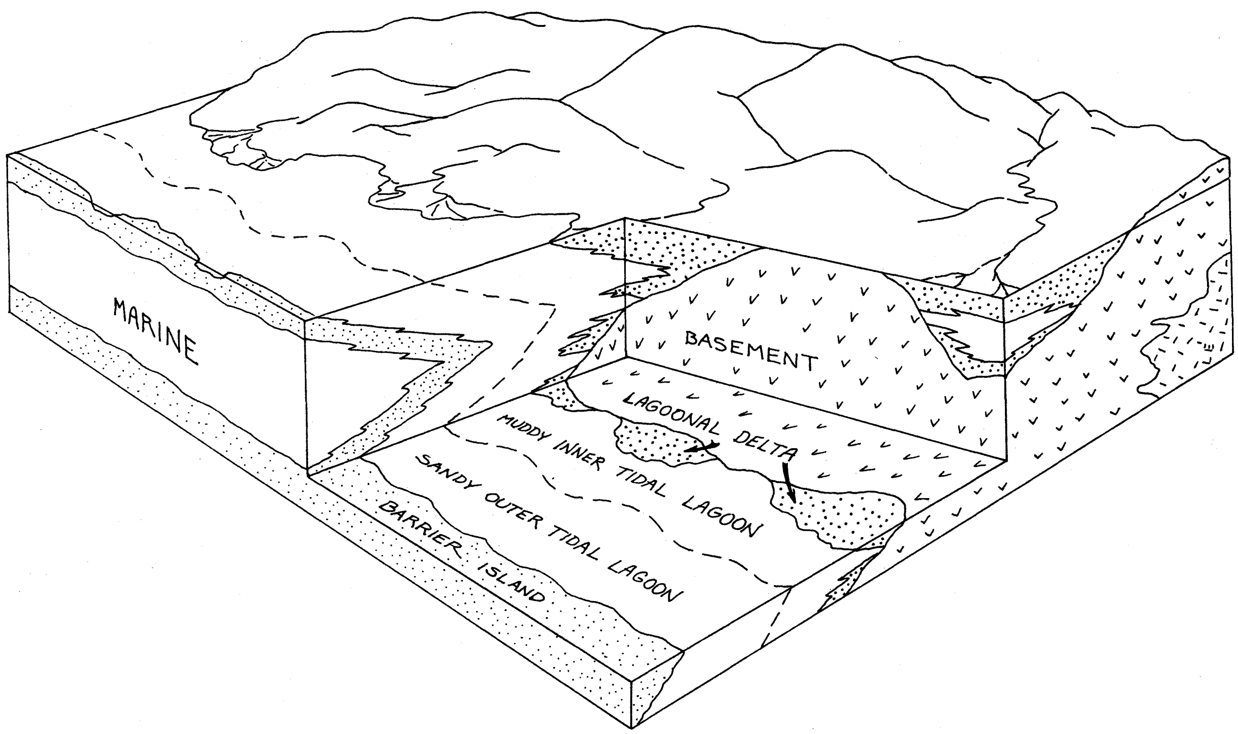

Figure 4. Diagrammatic cut-away view of middle Eocene stratigraphy between Carlsbad and Solana Beach. View is to the northeast.

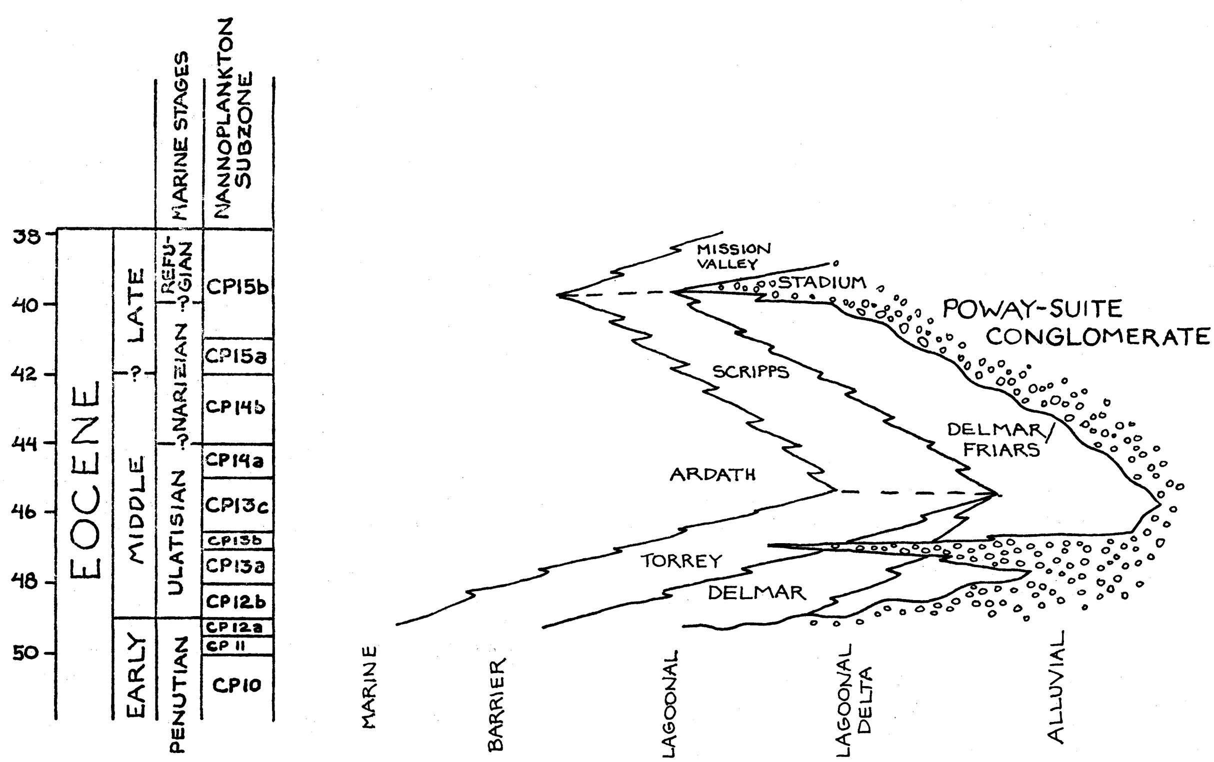

Figure 5. Diagrammatic summary of nomenclature and stratigraphy in Eocene section between Carlsbad and Solana Beach.

precipitous coastal topography. The narrowness of the shelf is based on the fact that submarine canyon and fan deposits occur nearly along depositional strike to the south at Torrey Pines (May, 1982). Barrier islands are more typical along coasts with wide shelves and a coastal topography of low relief such as those found along the Gulf of Mexico or the U.S. Atlantic coast (Inman and Nordstrom, 1971). The precipitous shoreline topography had a significant influence on the depositional history of the barrier lagoon. In its modifying role on the normal lagoonal depositional process of tide and storm the coastal topography helped produce a notable suite of depositional features.

The steep coastal topography made for a short distance of transport from the sediment source to the final point of deposition. This is reflected in the immaturity and composition of the barrier and lagoon sediments. They contain a high percentage of feldspar and volcanic, plutonic and metamorphic rock fragments. These sediments, commonly coarse and angular, did not travel very far and were not extensively reworked before final deposition.

This lack of sediment reworking and the presence of intermediate plutonic bodies nearby accounted for a plentiful supply of biotite in the sediment supplied to the barrier-lagoon system from the coastal hills. In the Eocene lagoon, biotite evidently had a depositional character similar to that of mud in that it was kept in suspension or winnowed by strong currents and would deposit under very slow moving or still water conditions. In tidal settings, mud characteristically will be thinly intercalated within sandy sediments as a direct result of the changing strength of tidal currents. Sand is moved and deposited in stronger tidal currents but during intervals of weak or slack tidal currents mud may accumulate. With the return of stronger (but not too strong) currents the mud may be covered by sand. The sedimentary structures produced include flaser, wavy and lenticular bedding and interlaminated sand and mud bedding (Reineck and Singh, 1980).

In much of the sandy cross-strata, thin laminae of clay are found rhythmically interbedded with sand along the base of cross-strata sets and along foresets. This clay often contains abundant biotite. Much of the cross-stratification is without clay or biotite but some of it contains biotite-rich laminae rhythmically intercalated with sand along foresets. In addition biotite is rhythmically intercalated in planar-laminated sandy sediments.

In particular one facies of tidal lagoon sediments is characterized by abundant biotite-rich laminae. This sandstone facies occurs between sandy outer tidal lagoon sediments and generally muddy inner tidal lagoon sediments and records deposition on sandy intertidal flats. Currents in this environment were evidently strong enough to exclude muddy sediment. However, at times of weak or slack tidal currents biotite settled from suspension on sandy planar and ripple foresets surfaces. In effect biotite replaced mud as the deposit from suspension. A considerable thickness of biotite built up on some ripple foresets (up to 1/8 inch thick) during tidal cycles with a particularly long period of weak currents. In a tidal cycle these weaker currents would coincide with the several day period surrounding a minimum in tidal range. In this way biotite flasers and planar laminations in this facies and in others formed when current conditions were consistently strong enough to exclude mud but just weak enough at times to allow biotite build-up.

In other facies of this same Eocene tidal lagoon and in estuaries of the modern Dutch North Sea, complete tidal cycles are recorded in cross-stratified sediments as rhythmic changes in foreset thickness. During days of stronger current strength more sediment is deposited along the ripple slip-face, while during periods of weaker current strength less sediment is deposited. Thus the repeating tidal cycle of stronger to weaker and back to stronger currents can be preserved in the sedimentary record (Clifton, 1979; Sieganthaler, 1982; Eisenberg, 1983). Several consecutive middle Eocene tidal cycles have been nicely preserved in a biotite-flaser-bedded sandstone. Biotite daily collected in thicker and thicker ripple foreset laminae during the weakest portion of each tidal cycle, but biotite became quite sparse during intervals of stronger current strength (Figure 6).

Figure 6. Tidal cycles recorded in biotite-rich ripple cross-laminae. Road cut on east side of County Haul Road 1,200 feet west of intersection of Encinitas Blvd, and Manchester Ave.

Figure 7. Claystone-filled tidal channels in sandstone. House pad outcrops northeast of intersection of Cerro St. and Avenida de las Adelsas, Encinitas.

On a larger depositional scale a relatively sudden, widespread and more pronounced drop in water energy occurred at times in parts of the Eocene lagoon. This is recorded in the several tabular claystone beds that drape over depositional features of the sandy outer tidal lagoon facies. These claystones are broadly lenticular over a distance of a mile or two. At several localities the claystone fills up tidal channels below the tabular body of claystone or maintains a constant thickness down into and back out of a channel (Figures 7 and 8).

These claystones were the product of a temporary abandonment of the prevailing depositional regime from a portion of the sandy tidal lagoon. Once the strong currents of a sandy outer lagoon were displaced, mud settled from suspension, draping the uneven sandy bottom. The most likely causes for this displacement of depositional regime were the blockage of a tidal inlet by a storm, the migration of a tidal inlet and beheading of the corresponding tidal creek system, or avulsion and stranding of a major branch of a tidal creek system. The limited areal extent of these claystones seems to favor the last process.

The return of sandy outer tidal lagoon depositional conditions often resulted in the erosion of a tabular claystone (Figure 9) or the isolation of a mud-filled tidal channel within sandy tidal deposits.

Figure 8. Draping claystone beds in sandy outer tidal lagoon strata. Roadcuts on south side of Encinitas Blvd. opposite Rosebay Drive and Delphinium Street. View is to the southwest. Lowermost claystone is two feet thick.

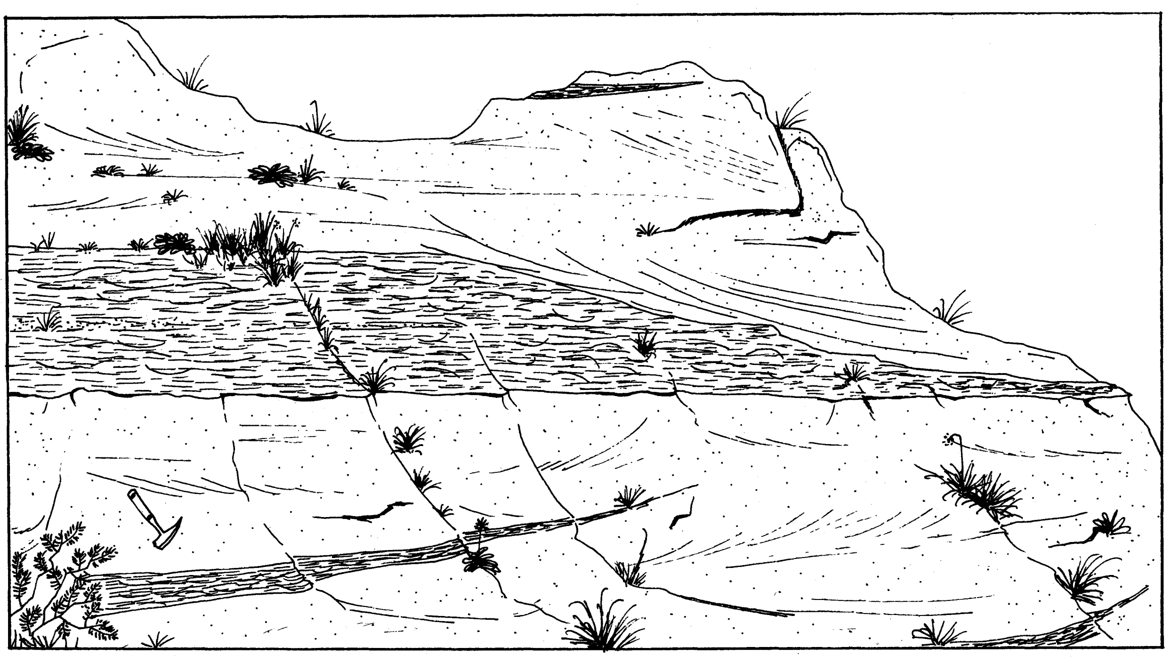

Figure 9. Eroded claystone in sandy outer tidal lagoon strata. East-facing outcrop 1,000 feet due west of intersection of El Camino Real and Manchester Ave. Elevation 280 feet.

Occasionally a record of an isolated event in the life of the Eocene lagoon was preserved in the sedimentary record. Up to around the medial middle Eocene the climate had been hot and humid and mangrove, palm and other tropical trees grew around the lagoon (Link and others, 1979; Wosika, 1975). From about the medial middle Eocene onward the climate became drier and a savannah type of climate prevailed (Peterson and Abbott, 1979; Carr, 1975). Late Eocene terrestrial vertebrate fossils, including tree-dwelling marsupials, indicate that riparian habitats and open savannah forests existed around the lagoon. On occasion, perhaps during periods of storm and floods, one of these trees would pull loose from the hillside above the lagoon and, still clutching cobbles and small boulders in its roots, wash down into the lagoon. One by one the clasts dropped from the tree's grasp as it floated about in the lagoon. Eventually the tree rotted away, but a few of the waterlogged pieces dropped to the sandy lagoon floor and were buried quickly enough to be preserved. One of these dropstones is exposed in sandy tidal deposits near Palomar Airport Road in Carlsbad. Next to the dropstone, in the same stratigraphic horizon, is a large piece of silicified wood, perhaps from the same tree that dropped the stone (Figures 10 and 11).

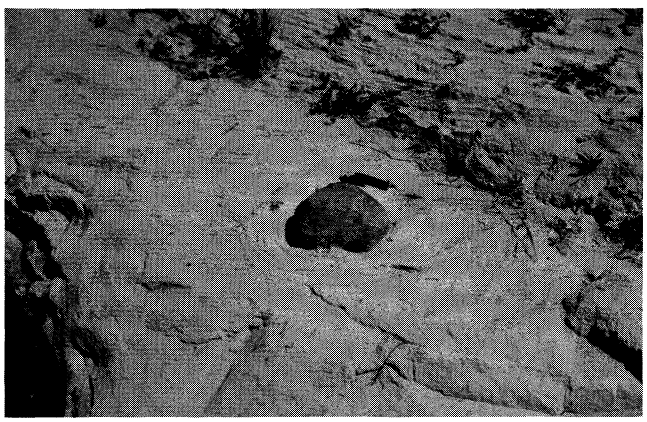

Figure 10. Volcanic clast probably dropped from the roots of a tree floating above sandy outer tidal lagoon sediments. Creek bed outcrop on the south side of Canyon de las Encinas east of Laurel Tree Road, Carlsbad.

Figure 11. Silicified wood adjacent to volcanic clast shown in Figure 10.

EARTHQUAKES

Earthquakes are another type of isolated event that were recorded in the lagoonal stratigraphic record. Some of the coarser-grained cross strata in sandy outer tidal lagoon deposits are disrupted by spectacular convolutions. These convolutions are up to three feet high and are upright or overturned in the direction of dip of the cross strata. The folding is not accompanied by fracturing and the contorted cross beds remain nearly parallel through the fold. Beds above and below the convolution are undisturbed. Deformation probably took place before deposition of overlying sediments (Figure 12).

North of San Elijo lagoon several of these convolutions occur on or very near the same stratigraphic horizon. The cross strata probably were deposited in sandy tidal channels or on bars. The convolutions may have been produced soon after deposition of the cross strata when the sediment underwent liquefaction and was thrown into a fold by the shock of an earthquake. Similar convolutions in Cretaceous arkoses in Nigeria are thought to have had the same origin (Jones, 1962).

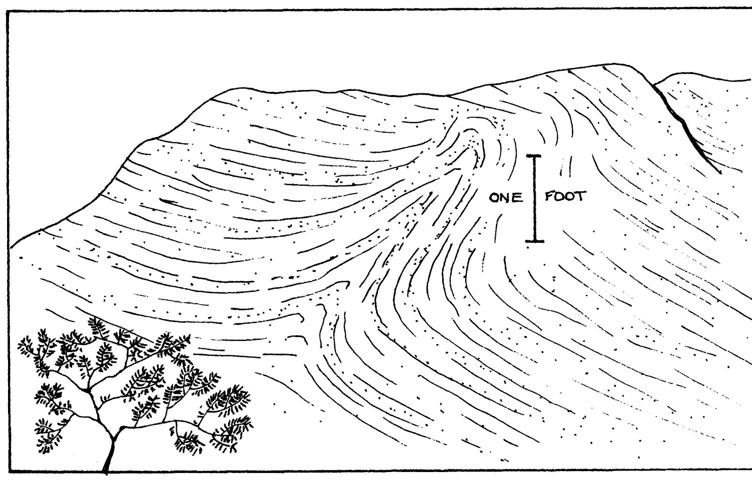

Figure 12. Convolution in cross strata of sandy outer tidal lagoon deposits. Outcrop 100 feet southeast of Ruddy Duck Court, Cardiff. View is to the east.

Alternatively, these convolutions may have been the result of dewatering and deformation in rapidly deposited and water-logged sand. The coarse-grained nature of the cross strata suggest deposition in strong currents may have piled up cross strata rapidly and then have helped to initiate their deformation.

An earthquake probably was the cause of a ball and pillow structure seen in outcrop in Lomas Santa Fe. Founded, oblong masses of sandstone are suspended in one of the broadly lenticular claystones (Figure 13). The sandstone masses appear to have been detached from the overlying sandstone. Kuenen (1965) produced a ball and pillow structure experimentally by applying a shock to a layer of mud overlain by a layer of sand. The shock caused the overlying sand to break up into oblong masses which then sank into the mud. A middle Eocene earthquake probably provided the shock in the case of the Lomas Santa Fe ball and pillow structure.

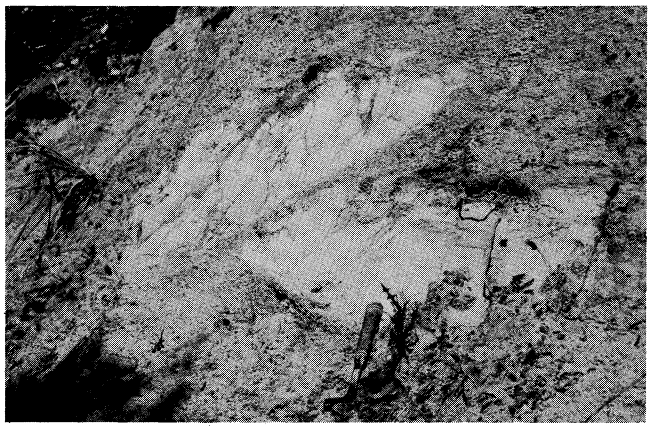

Figure 13. Ball and pillow structure. Road cut on east side of Santa Helena 500 feet north of the intersection with Sun Valley Road, Lomas Santa Fe.

COASTAL TOPOGRAPHY

The rugged coastal hills played a significant modifying role in the depositional history of sediments deposited in the Eocene tidal lagoon. During periods of high runoff and flood, coarse sand and gravel were washed down from the hills and out into the lagoon. The rugged topography of the coastal hills resulted in stronger, coarser and more abrupt sediment influxes than would have been the case with a more subdued coastal topography.

Initial influxes of coarse sediment into the lagoon were evidently abrupt and locally erosive events. Along Palomar Airport Road in Carlsbad the basal, poorly-sorted, coarse, pebbly sandstone of a lagoonal delta rests on a non-planar surface above sandy tidal flat and creek sandstone. Coarse and granular sandstone-filled burrows project downward from the base of the coarse deltaic sand into the underlying tidal flat and creek sandstone. These escape burrows formed when small crustaceans feeding peacefully on the lagoon bottom fled their mucus-lined dwellings during a sudden influx of coarse sediment (Figure 14).

Figure 14. Escape burrows at the contact between coarse lagoonal delta and outer tidal lagoon sandstone. Road cut on the north side of Palomar Airport Road 400 feet east of Laurel Tree Road.

At the same locality pebbles, cobbles and large, subangular blocks of green silty claystone occur suspended within the poorly-sorted, coarse and pebbly sandstone a few feet above the contact with the tidal flat sandstone. These claystone pebbles and blocks were probably derived from muddy tidal sediments deposited further north, toward the basement hills of the paleoshoreline, in the landward margin of the lagoon. (Basement rocks crop out 2000 feet to the northeast and the coarse-grained sandstone pinches out to the south within 1000 feet).

The first floods of coarse material poured off the basement hills and into the lagoon. They first eroded and then built out over muddy sediments at the lagoon margin and extended onto sandy sediments further into the lagoon. The coarse sands channeled the muddy sediment or occupied and eroded pre-existing tidal creeks in the muddy sediments. In either case muddy channel walls were undercut and then collapsed into the flood of coarse sediment. The resulting muddy clasts and blocks were transported out into sandy parts of the lagoon where their sudden arrival with the coarse, pebbly sands caused the above-mentioned crustaceans to flee their burrows (Figure 15).

The coarse-grained pebbly sandstones typically fine upward from an erosive base to fine-grained sandstone and green silty claystone. At localities near the basement paleoshoreline the top of this sequence is the erosive base of another fining-upward sequence. At a locality east of Rancho Santa Fe at least one half dozen of these fining-upward sequences are stacked one on top of the other (Figure 16). These sequences record autocyclic depositional events around the perimeter of a coarse-grained lagoonal delta. The erosive base and basal coarse sandstone with claystone clasts represent an initial abrupt sedimentation pulse. Subsequent deposition under more normal conditions lowered the gradient of the distributary and filled it with finer and finer sediment. Avulsion shifted the distributary mouth to different parts of the delta. The inactive parts then received muddy lagoonal sediments until the reestablishment of a distributary brought back erosion and coarse-grained sand, and the cycle started all over again. At the San Dieguito River locality east of Rancho Santa Fe, continuous subsidence helped to preserve the record of at least one half dozen of these delta distributary shifts.

At times smaller pulses of coarse-grained, pebbly sand extended further out into the fringing muddy lagoonal sediments. These pulses channeled the muddy sediment or occupied and eroded pre-existing muddy tidal creeks. The pebbly products of the erosion of the muddy sediments frequently are incorporated into the basal, coarse, channel-fill sandstones that occur isolated in muddy tidal lagoon deposits (Figure 17). Renewed deposition of muddy sediments buried these coarse, channel-fill sands. In outcrop they may appear as half-lenses floating within green, silty claystone (Figure 18).

Another delta-like body extended into the tidal lagoon during the middle Eocene but this one was derived from a different, larger conglomeratic system to the south, not from the nearby coastal hills, and built out along the deeper, sandy part of the lagoon rather than being built-up locally along the hilly paleoshoreline. Clasts of the southerly-derived system belong to the Poway suite of clasts, while clasts of the lagoon-edge deltas belong to the Peninsular Ranges suite.

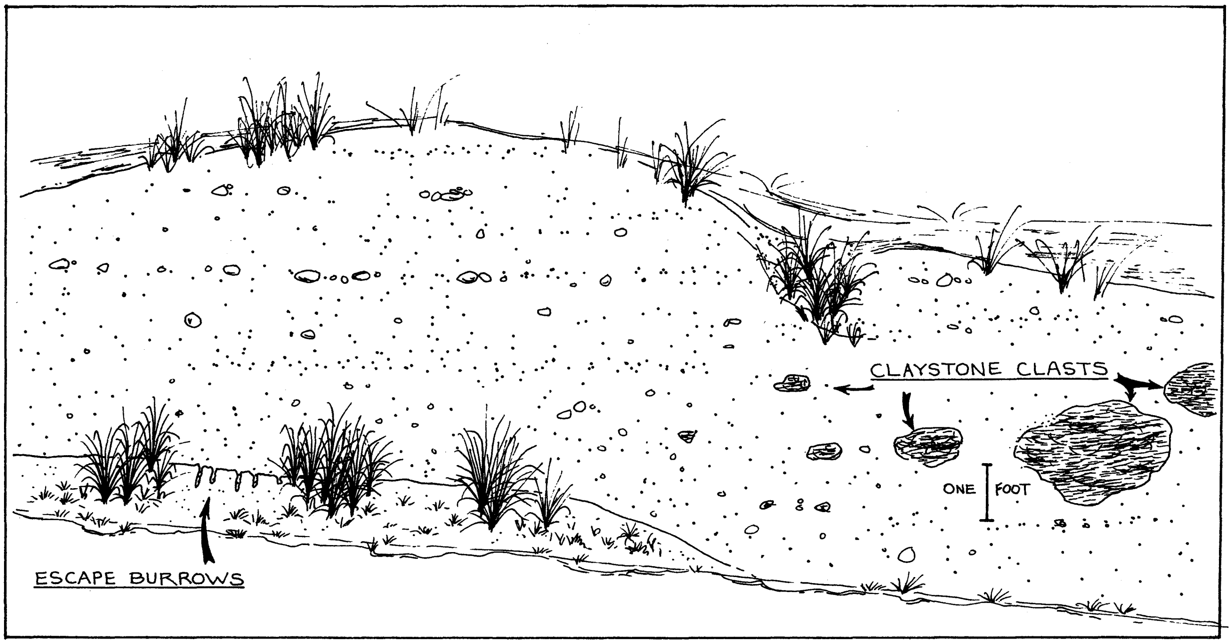

Figure 15. Large claystone clasts in coarse, lagoonal delta sandstone. Same site as Figure 14.

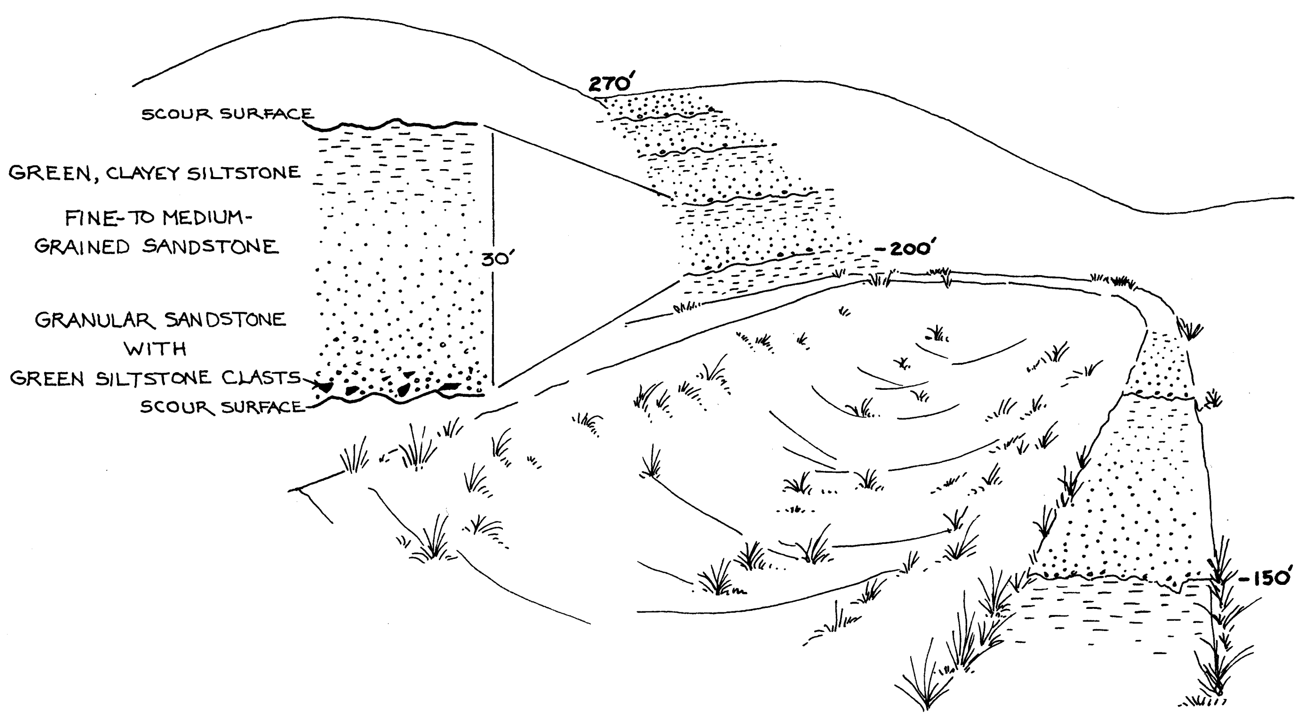

Figure 16. Stacked fining-upward sequences. Outcrops 3000 feet southeast of intersection of El Escondido Del Dios Highway and Camino de Estrellas.

Figure 17. Claystone clasts at base of coarse, channel-fill sandstone in claystone. South end of San Elijo State Beach. Scale is six inches.

Figure 18. Half-lense of coarse sandstone wholly enclosed within green claystone. Road cut along Access Road of Wiggens Ranch.

The Poway-suite clasts arrived from the south via a braided bar, fluvial type of distributary. As this distributary extended northerly along the deeper sandy bottom of the lagoon thick deposits of conglomerate interspersed with thin sandstone lenses were left behind. During exceptional flood periods Poway-suite pebbles and cobbles were spread beyond the mouth of the distributary and were thinly scattered over a large portion of the sandy lagoon floor.

These thinly scattered gravels commonly occur in outcrop as laterally continuous, one- or two-cobble-thick, clast-supported conglomerate stringers spaced every 5 to 20 feet within sandy outer tidal lagoon deposits. Locally the stringers may suddenly thicken into three- or four-foot-thick lenses. Many stringers appear planar in outcrop but others appear to undulate through an outcrop. Some stringers possess all of these characteristics (Figure 19).

These gravel stringers appear to have been spread across the uneven floor of the lagoon when fluvial processes superceded tidal processes during major floods. Pebbles and cobbles in a tidal depositional system typically concentrate along the floor of a tidal inlet or channel (Kumar and Sanders, 1974; Moslow and Heron, 1978), but these gravel stringers were deposited on sandy tidal flats and along the upper margins and walls, as well as on the floor, of tidal channels and creeks. The gravels also collected along the sandy lagoon bottom in small depressions, and on the top and along the sides of low mounds. Evidently the gravels were rolled and pushed along by the current over a lagoon bottom patterned by pre-existing tidal features and probably some just-formed fluvial channels, sand bars and ripples. At some obstructions, either depressions or mounds, the gravel was stranded and formed thicker accumulations (Figure 20). At other obstructions the current left little or no gravel.

The deposition of one gravel stringer probably took place over a time span of a few hours or less. The abruptness of the initial influx is demonstrated by the presence of escape burrows. At a locality east of Encinitas six-inch to one-foot-deep cylindrical depressions are filled with Poway-suite

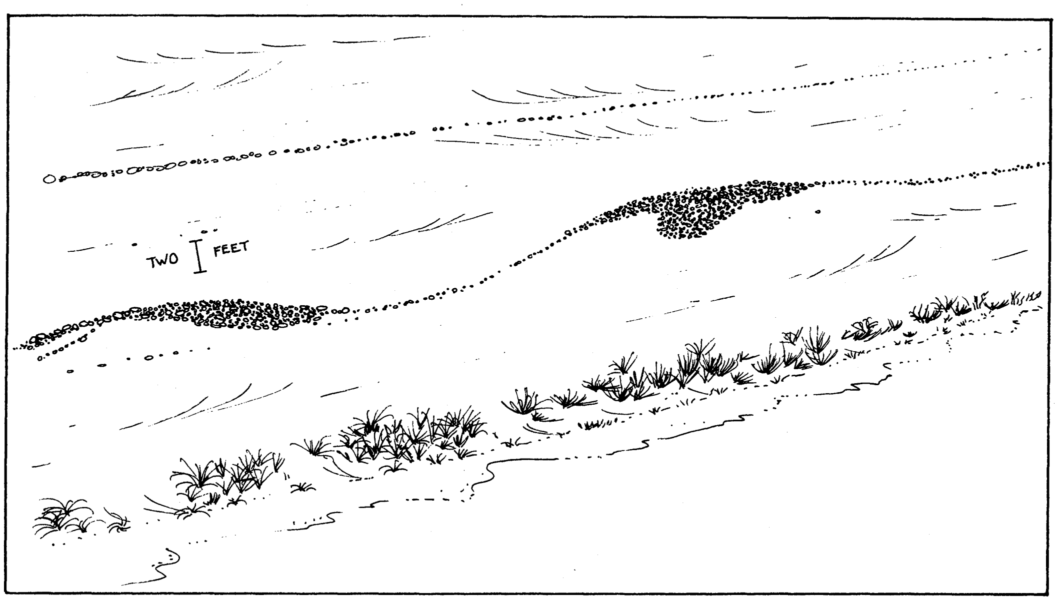

Figure 19. Pinch-and-swell conglomerate stringer. East-facing road cut along County Haul Road. Same locality as Figure 6.

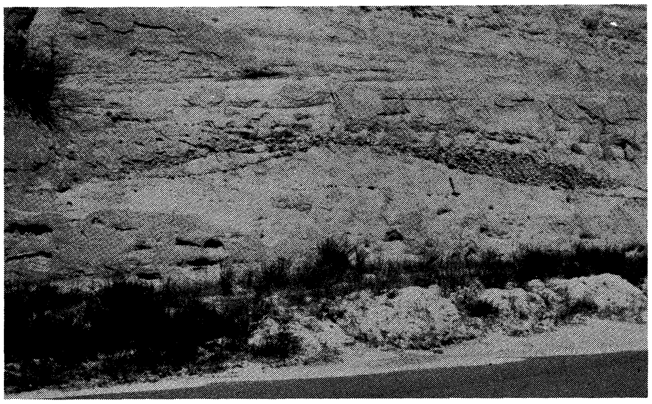

Figure 20. Gravel stranded at obstruction. Same locality as Figure 19.

conglomerate from the immediately overlying gravel stringer (Figure 21). These conglomerate-filled depressions are without question a primary sedimentary feature. They are probably depressions or burrows excavated by large crustaceans which were later abandoned by their inhabitants during a sudden influx of gravel.

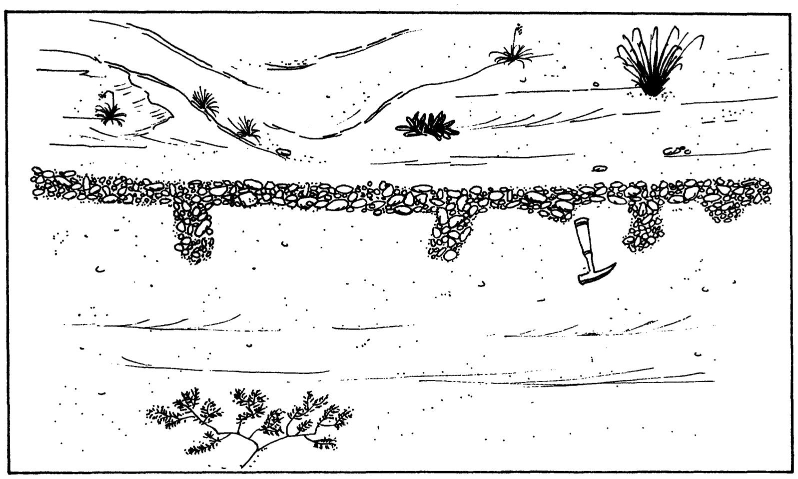

Figure 21. Poway-suite-conglomerate-filled escape burrows. South-facing bluffs 2,000 feet west of intersection of Encinitas Blvd. and Manchester Avenue.

Although the scale of burrow is a bit different, these escape burrows and those recognized along Palomar Airport Road show that the various types of gravel that invaded the Eocene tidal lagoon did not work their way slowly across the lagoon but spread rapidly over the lagoon floor in short-lived depositional events.

Portions of some of the Poway-suite conglomerate stringers are matrix-supported although still part of a well-defined, thin, planar conglomeratic unit. These portions and conglomerate thinly scattered along the floor of some tidal channels or toward the margins of some conglomerate stringers probably record reworking by tidal and wave action when normal depositional processes returned to the lagoon.

There are probably less than twenty separate conglomerate-bearing stratigraphic horizons within less than 80 feet of section. Each conglomerate-bearing horizon records the effects of a major storm, a closely-spaced series of storms, or a seismic sea wave. This suggests that over a time span of several hundred thousand to possibly one or two million years there were less than two dozen gravel depositing events. The flood conditions during which the gravel was deposited occurred, roughly, only every 10,000 to 100,000 years.

The storms were probably immense tropical cyclones. In temperate climates frontal cyclones are the norm, but in hot and humid or winter-dry coastal savannah climates such as those that prevailed over the San Diego area in the Eocene, tropical cyclones are the norm (Haurwitz and Austin, 1944).

A storm surge from a tropical cyclone occurs when the bulge of water beneath the very low pressure center of the cyclone comes ashore. The surge may be enhanced by wind-driven water piled up along the coast and storm waves (Petterssen, 1969). The backwash, or storm return surge can pick up sand, gravel, shells and wood fragments from a barrier lagoon and carry them offshore via tidal inlets or passages cut through the barrier by the storm (Pierce, 1970). A similar return surge could result from the arrival and subsequent backwash of a seismic sea wave. A few of these return surge deposits have been recognized in sea-cliff exposures from Leucadia to Solana Beach.

At a locality in Leucadia the return surge deposit appears as a few one-clast thick, sparse, but laterally persistent stringers that are composed of subrounded, poorly-sorted, Peninsular Ranges-suite pebbles, cobbles and boulders as well as bits and several-inch-long blocks of wood. The largest clasts are almost one foot in diameter (Figure 22). The sandstone matrix is mostly poorly-sorted, coarse-grained, granular and pebbly. Little in the way of

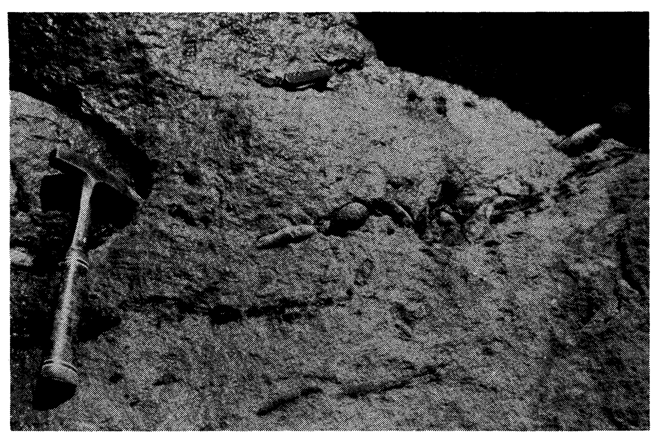

Figure 22. Poorly-sorted cobbles, boulders and wood fragments in a return surge deposit. Sea cliff outcrop 1,500 feet south of the Leucadia Blvd. beach access stairway.

bedding features exist, but the semi-planar outcrop pattern of the stringers suggests a traction deposit. In mass-flow deposits the clasts would appear to be floating in the matrix (Reading, 1978). This conglomerate, wood and coarse sandstone bed is found within a sandstone that was deposited in environments just seaward of the barrier island (Eisenberg, 1983). In the section above this bed, at S.D.S.N.H. locality 296, another return surge deposit has been recognized in strata that were deposited somewhat further offshore. This deposit consists of large, thick-shelled gastropods and bivalves, pebbles and granules of vein quartz and some coal. These clasts float within a matrix of fine-grained sandstone and siltstone. The macrofossils are part of a nearshore marine assemblage (Wilson, 1972) although microfossils indicate deposition in shallow marine (Bukry, 1980) to outer neritic waters (A. Almgren, pers. comm. in Eisenberg, 1983). The return surge carried pebbles and wood from the lagoon, picked up nearshore marine macrofossils at the barrier and deposited the whole mess in a churned-up mixture with nearshore marine fine-grained sand and silt. The fact that the clasts float within a homogeneous, fine-grained matrix suggests that this is a mass-flow deposit. Return surge depositional processes also have been recognized in Eocene deposits in Solana Beach (Boyer and Warme, 1975).

The return surges of tropical cyclones and seismic sea waves were an important depositional factor in the Eocene barrier lagoon, and their influence was probably enhanced by the rugged topography of the coastal hills. These hills would have formed a barrier to landward movement of any storm or seismic sea wave surge. Compared to a low relief coastline the hills would have acted to gather more surge water over a smaller area closer to the shoreline. This situation probably would have acted to concentrate and strengthen the return flow.

Large tropical storms played an important role in the depositional history of the Eocene barrier lagoon, but seasonal storms played a role as well. Besides contributing to the normal runoff these seasonal storms contributed to the outbuilding of lagoon-edge deltas. In addition they appear to have influenced the deposition of a small but interesting accumulation of sand and shells along the landward margin of the lagoon.

Along Palomar Airport Road in Carlsbad small bivalves are stacked into a distinctive mound. The shells are uniformly small, less than one inch in length, are mostly whole and unabraded or bored. No articulated valves are present. Both left and right valves are predominantly oriented with the concave-side down and parallel to the base of the mound. The fauna is composed of a single species of oyster, *Ostrea* cf. *crandalli* and a much smaller proportion of *Anomia mcgoniglensis*.

The valves are arranged in single-valve-thick, planar, parallel beds spaced one to two inches apart. These beds are stacked into a symmetrical, flat-based mound 70 feet across at the base and about five feet high at the crest. The shelly layers do not drape over the crest or sides of the mount but extend horizontally out to the mound margin. The matrix consists of moderately- to poorly-sorted, fine- to coarse-grained lithic arkose. Sediment within the valves is identical to the matrix. Subangular pebbles of yellowish, fine-grained sandstone are present along some of the shelly beds. Beds below the western end of this mount dip slightly to the west and are truncated at the base of the mount (Figure 23). Basement outcrops occur about 2,000 feet to the northwest.

Anomia mcgoniglensis is one of the most abundant and characteristic brackish water elements of the middle Eocene Delmar Formation fauna (Hanna, 1927; Givens, unpublished data in Givens and Kennedy, 1976; Givens and Kennedy, 1979). Its occurrence here with large numbers of small, possibly stunted oysters suggests that that the shell mound accumulated in or near a brackish water environment.

The type of fauna present in the mound, the coarseness and poor sorting of the matrix, the presence of sedimentary clasts, the uniform spacing of the shelly beds and the consistent valve orientation all suggest that the shell mound was built near the edge of the lagoon as periodic, probably seasonal floods swept shells and sand into a delta-like accumulation near the mouth of an intermittent fresh-water distributary. The slight truncation below the mound may have occurred as slightly older sediments were scoured and overlain by coarser, shell-rich sediments deposited at a slightly different slope orientation along the front of the small delta-like accumulation.

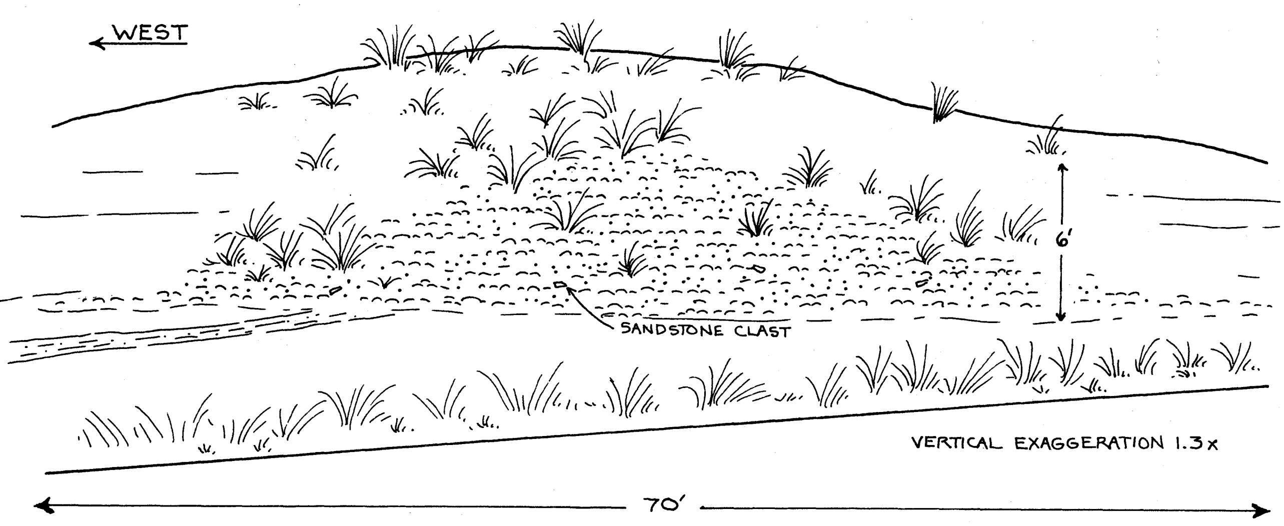

Figure 23. Shell mound. Road cut on north side of Palomar Airport Road, 800 feet east of the intersection with Palomar Oaks Way, Carlsbad.

SUMMARY

The normal depositional processes active in the Eocene barrier lagoon were modified by the presence of a rugged coastal topography and occasionally were superceded by depositional processes of storms and earthquakes.

During normal, tidal depositional conditions a landward-fining sedimentary sequence was established in the lagoon, and the sediments were patterned with the typical sedimentary features of tidal channels, flats and marshes. Tidal channels left trough, planar and longitudinal cross-strata, tidal flats left ripples and planar laminae and marshes left mudcracks. Abandonment of a part of the lagoon by higher energy tidal processes allowed the draping of thick muds over the higher energy lagoon bottom. Earthquake shocks caused sandy masses to sink into these draping muds and threw newly deposited cross-strata into convolutions.

The rugged coastal topography and nearby plutonic outcrops provided an abundant supply of biotite to the lagoon. The biotite was incorporated into flasers and planar laminae during periods of slack tidal currents.

The coastal topography also produced a fringing residuum of coarse sediment around the landward margin of the lagoon. Floods washed coarse sediment from the coastal hills and from a different conglomeratic system to the south into the lagoon and occasionally out into the sea beyond the barrier. The coarse sediment commonly scoured the lagoon floor and forced panic-stricken crustaceans to flee their burrows.

The return surge of tropical cyclones and of seismic sea waves was enhanced by the confining coastal hills, and this served to increase the number and intensity of gravel depositing events.

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A MEDIAL EOCENE MACROFLORA FROM THE TORREY SANDSTONE AT DEL MAR

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INTRODUCTION

The discovery of an extensive fossil macroflora in the Torrey Sandstone at Del Mar enables interpretation of local climate, geography, and vegetation during medial Eocene time. Climates of the early Paleogene are interpreted to have been wet in the southwestern California region (Peterson and Abbott, 1979). By the late Eocene, though, fossil and geologic evidence indicates that the climate had become semi-arid. Floristic composition of the Torrey Sandstone documents a gradual drying trend throughout the medial Eocene. This resulted in a southward shift of the tropical savanna vegetation which covered the region during the Paleocene (Axelrod, 1980), and its replacement by dry tropical forest vegetation characterized by deciduous taxa. Modern floras of similar composition are found in the coastal Rio Mayo region of Sonora, Mexico.

Right-lateral strike slip motion along the San Andreas fault system has displaced the Torrey flora about 275 km north relative to the North American craton (Abbott and Smith, 1978). Trace-element comparison of conglomerate clasts from the late Eocene Poway Group in San Diego with rhyolitic source terranes in Sonora led to the suggestion that present-day San Diego and Tajitos, Sonora were adjacent during late Eocene time. Approximately the same configuration can be assumed for the medial Eocene as well. However, western North America lay approximately eight degrees of latitude north of its present position during the early Paleogene. Thus, San Diego, now at 32-1/2° N latitude, lay at about the modern latitude of San Francisco during the medial Eocene (Peterson and Abbott, 1979).

The abundance of North American fossil floras of Paleogene age (including those described by Berry, 1916, 1930; Chaney and Sanborn, 1933; Brown, 1962; and MacGinitie, 1941, 1969, 1974) provides a detailed picture of the floristic evolution of much of the continent during that interval of time. The age assigned to many of the collections is subject to debate, as are the methods used to obtain paleoclimatic information from them (Axelrod and Bailey, 1969; Wolfe, 1970); however, some general conclusions are inescapable, regardless. The composition of most North American floras of Late Cretaceous to early Eocene age is similar at the generic and often even to the species level. Evidently, floristic connections between the east and west as well as between the north and south existed on the continent throughout this time. Additionally, climatic belts must have been broad. By the medial Eocene, local endemic floras became common, suggesting an interval of climatic deterioration. Axelrod (1980) showed that temperate rain forest covered western North America north of the present 35°N latitude line during the Eocene, while southern regions had a dry tropical forest vegetation. Tropical savanna and rain forest vegetation (which characterizes the Paleocene Elsinore flora of the Santa Ana Mountains, California) apparently had retreated southward by this time. By the early Miocene, plant communities of southern California came to be dominated by sclerophyllous woodland vegetation in response to increasing aridity accompanied by climatic cooling. The Torrey collection contains leaf forms and taxa typical of both dry tropical forest and sclerophyllous woodland environments. This study will evaluate both floristic and geological evidence to interpret the climate and paleoecology of the San Diego region during medial Eocene time.

GEOLOGY

The Torrey Sandstone at the fossil locality north of Black Mountain Road, Del Mar, consists of interbedded mudstones and cross-bedded sandstones. Sand sequences range from nearly four m to a single grain in thickness, while the thickness of mudstone beds does not exceed 20 cm. The sandstone consists of angular to subangular, fine to coarse grains. Sorting is good and matrix nearly lacking. Quartz grains make up nearly 60 percent of the sand with the remainder mostly composed of feldspar and lithic fragments. Heavy minerals, granule-sized mudstone rip-up clasts, and fragments of charcoal make up less than one percent of the sandstone. Most of the sandstone beds are massive, but a few 5-15 cm thick, fining-upward graded cycles were observed. Mudstones were deposited non-gradationally upon sandstone beds. Very thin, pure clay laminae occur abundantly within the mudstones. Thin beds of pure sand, commonly only a single grain thick, interrupt the mudstone sequences, and pockets of coaly organic material generally less than two cm thick and of short lateral extent also are found within the mudstone beds.

Large-scale, trough cross beds characterize the Torrey Sandstone at the Black Mountain Road outcrop. Although the small size of this outcrop makes detailed analysis difficult, cross-bed wavelengths appear to be as great as 10 m. Two paleocurrent readings taken from cross-bed orientations reveal an eastward direction of transport at this locality. Foreset angles are steep, averaging 29°. Such steep foreset angles are found in sub-aqueous dunes deposited in tidal channels. These structures have wavelengths of the same magnitude as those observed in the Torrey Sandstone, as well. The lack of biological structures in the sandstone, with the exception of a few sub-vertical Ophiomorpha, suggests rapid deposition of the thick sandstone sequences, perhaps as products of high current energy in tidal channels associated with storm events which produced high rainfall.

Mudstone sequences were deposited as non-gradational drapes upon the cross-bed surfaces. The beds vary in thickness laterally and appear to fill hollows between the large subaqueous dunes. In many instances, mud layers terminate erosionally at the base of thick overlying sandstone beds. Planar lamination of the muddy intervals was rarely disturbed by biogenic activity, although both horizontal and sub-vertical burrows are common. These penetrate both downward from the mudstone into underlying sand beds and downward from the upper surface of the mud beds. The burrows are simple with the exception of a few horizontal sand-filled Domichnia which thicken and thin in a random pattern. The iron-stained sand which fills all of the burrows appears to have passivelyfiltered downward from overlying sand beds.

The moderate degree of biological modification of the mudstone beds suggests that deposition of the thick sandstones was infrequent, and that periods of low energy mudstone deposition persisted for long periods of time between sandstone depositional events. Mudstone deposits, then, may reflect periods of "normal" deposition between high energy storm events of short duration.

While the sandstone sequences are for the most part massive, mudstone beds consist of variable lithology indicating fluctuations in depositional energy. Thin sand laminae are common and suggest pulses of moderate energy, while claystone interbeds indicate periods of quiescence. Such variable current strengths characterize fluvial processes. The mudstone sequences contain the fossil leaf material which must have been transported by stream to the site of deposition.

FLORISTIC COMPOSITION

The Torrey collection includes a diverse assemblage of dicot and monocot angiosperms, and at least one fern. The majority of taxa have not yet been identified and this discussion must be considered an overview of on-going work. Leaf specimens are referred to genus based on their morphological similarity to modern taxa using the classification of leaf architecture by Hickey and Wolfe (1974) and Hickey (1979).

The assumption that plant species of the geological past have identical or similar ecological requirements to their modern counterparts has been questioned by Wolfe (1970) and others. However, general ecological interpretations based on this principle concur with the geological evidence in this case, enabling a discussion of climate and the environment of growth at the Torrey flora locality during medial Eocene time.

The most abundant fossil in the Torrey collection is a fern virtually identical in appearance to the living species Acrostichum aureum. Several dozen entire leaflets from Acrostichum fronds were found, many of these still attached to stipules and portions of the frond midrib (Figure 1). This excellent preservation suggests that the fern was not transported far from its growth locality. The lack of root casts in the surrounding sediments at the fossil locality indicates that some transport may have taken place, however. Fossil bivalved molluscs occur in beds containing Acrostichum, as do small pockets of coal. This association indicates that Acrostichum grew within or on the margin of an environment of standing marine or brackish water.

The modern distribution of Acrostichum is pantropical, with a northernmost occurrence in western North America of south coastal Nayarit, Mexico. The fern inhabits brackish-water estuaries and marshes, generally growing in standing water or boggy soil. Tryon and Tryon (1982) noted that Acrostichum is commonly a member of mangrove communities. Axelrod (1980) cited the occurrence of black mangrove pollen in the Torrey Sandstone which suggests that a mangrove-Acrostichum community may have existed at the site of deposition.

Brackish-water lagoons and estuaries occur in modern environments of moderate to high rainfall. Acrostichum can survive in a wide range of salinities, from fresh-water to marine, and thus persists in environments alternately dominated by fluvial and marine conditions. The interbedded assemblage of high and low depositional energy lithology indicates that conditions at the site of deposition were variable. Coaly horizons suggest standing brackish water, while the thick cross-bedded sandstones document rapidly moving currents. Associated fossils appear to be marine dwellers. Clearly the site of Acrostichum deposition experienced variable conditions of water salinity.

Three dicot genera have been tentatively identified in the Torrey collection. Many other forms of broadleaved plants occur as well, but have not yet been identified.

Two leaves related to the modern genus Persea (avocado) in the family Lauraceae were found in the Torrey collection (Figure 2). Persea is a broadleaved tree which produces new foliage in response to summer rainfall. The tree can be semi-defoliate during periods of water stress. Its occurrence is restricted to frost-less regions throughout the tropics and subtropics, and it is found in the Rio Mayo region of Sonora inhabiting moist canyon bottoms. Avocado does not reproduce well at mean yearly temperatures lower than about 16°C (Axelrod and Demere, 1984); frost-less climates having rather narrow fluctuations in daily temperature are required. Thus Persea is often found in coastal environments moderated by ocean air.

Persea's restriction to climates of convective summer rainfall concurs with the geological evidence at the site of deposition. Thick cross-bedded sand sequences may have been deposited during floods caused by heavy rainfall like that which occurs during summer storms in tropical and subtropical climates.

Well-preserved fossil leaves related to the genus Ficus (family Moraceae) also were identified in the Torrey collection (Figure 3). The modern distribution of Ficus (fig) extends from the tropics to summer-wet mediterranean climates, and thus does not indicate a specific climate. Ficus leaves in the Torrey Sandstone are rather small, typically less than 5 cm long and appear to have been thin and flexible. Such leaves typify members of the genus inhabiting drier subtropical regions where they are deciduous in response to summer drought. Gentry (1942) reported four species of Ficus in the Rio Mayo Basin, one of which (Ficus continifolia) inhabits moist canyon bottoms and is at times deciduous during drought. The leaves of Ficus continifolia appear similar to those of the Torrey collection Ficus, suggesting that the two may characterize similar environmental conditions.

Numerous specimens of leaves tentatively identified as Myrica (family Myricaceae) occur in the Torrey assemblage (Figure 4). Impressions of these leaves are deep, indicating a fairly thick growth morphology. The leaf margins are toothed and enrolled ventrally. Such adaptations typify sclerophyllous vegetation inhabiting semi-arid temperate climates. Modern members of the genus inhabit moist sites in subtropical and temperate regions of North America. Myrica was found in the middle Miocene Tehachapi flora described by Axelrod (1939). This flora grew in a frost-less climate with annual rainfall of about 64 cm that chiefly fell during the summer months. The presence of Myrica in the Torrey flora provides strong evidence that the assemblage contained a sclerophyllous component adapted to localities of modern aridity.

Figure 1. Acrostichum sp.: portion of a compound leaf showing leaflets attached to midrib.

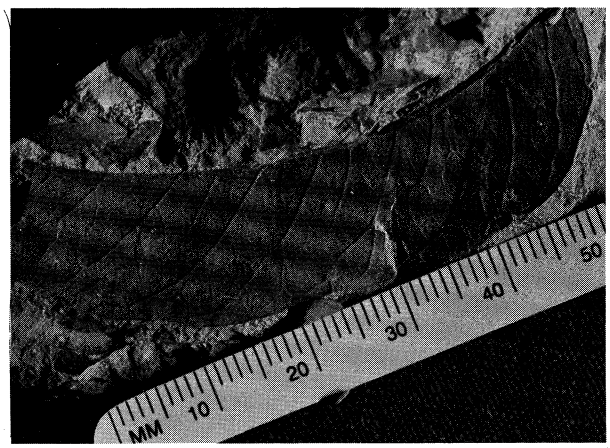

Figure 2. Persea sp.: fragment of leaf showing lower leaf surface.

Figure 3. Ficus sp.: fragment of leaf.

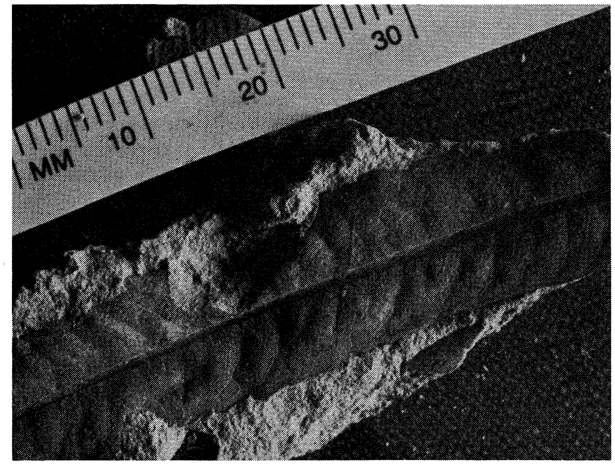

Figure 4. Myrica sp.: note teeth on leaf margin and ventrally curved leaf form.

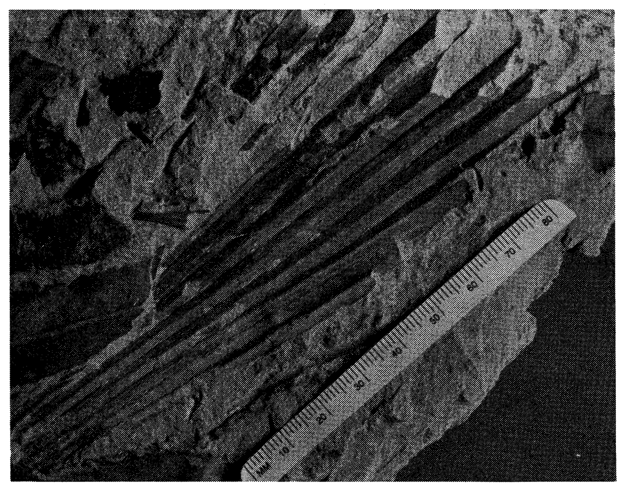

Figure 5. Fragment of a palm frond.

Figure 6. Reed fragments.

Recognizable among the monocot specimens are a single species of palm roughly similar to Sebal (Figure 5), and at least one species of reed (Figure 6). Reeds are common in marshy habitats, while palms frequently occur in perennially wet localities such as canyon bottoms. The abundance of palm and reed fossils in the Torrey collection suggests that both grew close to the site of deposition, perhaps lining the margin of an estuary or marsh.

VEGETATION

Gentry's (1942) description of the flora of the Rio Mayo Basin in Sonora includes taxa and morphological forms similar in part to those of the Torrey collection. Termed short-tree forest by Gentry, the Rio Mayo vegetation consists of an evergreen or semi-deciduous, moist canyon bottom community in which are found both Ficus and Persea, and a dry tropical forest of low stature consisting of deciduous broad-leaved taxa clothing steep hillsides at elevations between 300 and 900 meters. Taxa identified in the Torrey collection represent members of the valley bottom community. These forms comprise most of the collection, and are generally well preserved. This suggests a fairly short transport distance; and these taxa are interpreted to have grown on a coastal plain in broad river beds at the Torrey locality.

Also present in the Torrey flora are many unidentified leaves of broadleaf taxa. A diverse pollen flora identified by W. S. Ting (described in Axelrod, 1980) includes species which Axelrod assigned to short-tree forest vegetation. These include the following taxa in part: Juglandaceae (Carya), Fagaceae (Quercus), Ulmacaea (Celtis), and Moraceae (Ficus). Broadleaf forms in the Torrey collection probably belong in part to these genera. Short-tree forest probably covered slopes above the coastal plain in the San Diego region during the medial Eocene.

The presence of Myrica and other sclerophyllous leaf forms indicates that drier habitats occurred in the Torrey environment. South-facing slopes and drier sites in riparian communities may have been characterized by arid-adapted forms such as Myrica. Such a vegetation type had become dominant in southern California by the medial Miocene.

High energy depositional features in the Torrey Sandstone suggest that streams of the medial Eocene had rather high gradients. Highlands may have existed not far inland from the coastal plain. The presence of Pinus and Quercus (oak) pollen in Ting's flora from the Torrey Sandstone indicates that more mesic woodland sites existed at moderate elevations above the short-tree forest vegetation, as they do in the Rio Mayo Basin.

Finally, at the site of deposition there probably existed a mangrove-Acrostichum community inhabiting a marsh or estuary which also supported abundant reeds. Palms may have surrounded the estuary or grown in dry river channels on the coastal plain.

CLIMATE

The climate of the Rio Mayo Basin may be similar to that of the San Diego region during medial Eocene time, if we are to regard as similar the conditions under which allied modern taxa grow. Gentry (1942) described Rio Mayo climate in detail. Short-tree forests of the region experience moderate temperatures, which average 28°C during the summer growing season, but reach highs of 38°C; winter low temperatures rarely produce frost. While dry season temperature may fluctuate as much as 15°C, growing season temperatures rarely fluctuate as much as 7°C on a daily cycle. Rainfall is concentrated during the summer and winter seasons; about 50 cm of precipitation is normal, with 38 cm of this falling during the summer months. Summer rainfall normally occurs as brief, violent storms. Many streams draining high elevations surrounding the Rio Mayo basin are perennial as is the Rio Mayo itself. However, standing water in the form of brackish swamps, marshes, or estuaries is rare.

Paleotemperature interpretation of ancient floras can be conducted in two ways, either through analysis of leaf physiognomy (Wolfe and Hopkins, 1967; Wolfe, 1970), or by comparison with the requirements of allied living taxa (Axelrod and Bailey, 1969). Leaf morphology of Torrey collection taxa and geological evidence from the Torrey Sandstone together suggest a climate similar to that of the Rio Mayo short-tree forest. Features interpreted to represent adaptation to drought are abundant in the Torrey leaves. The size of angiosperm leaves and leaflets is small in comparison to that of rain forest plants, and the thin, fragile texture of many of the leaves suggests deciduousness. Other morphologies appear to be drought tolerant, as in the case of sclerophyllous taxa including Myrica. Such characteristics may be found in plants of more mesic sclerophyllous woodlands in subarid modern climates. Elongate apices on some of the broadleaf fossils resemble drip tips which serve to concentrate rainfall into a directed stream on the roots of the plant. The immature texture of the Torrey Sandstone reflects rapid deposition in a subarid climate. Finally, the presence of Acrostichum indicates that brackish standing water occurred at the site of deposition. Such features together suggest a moderately arid climate. However, the presence of standing water suggests a climate more moist than that of the Rio Mayo region. Precipitation was likely between 50 and 70 cm annually.

As discussed above, both geological and floristic evidence indicate that rainfall fell seasonally. Broadleaved taxa appear to have been deciduous in response to drought, and the interbedded mudstones and cross-bedded sandstones of the Torrey Sandstone at the leaf locality reflect alternating high and low energy deposition possibly in response to seasonal storms. The modern requirements of Persea specify summer rainfall, which by analogy may have characterized the environmmnt of the Torrey flora as well. Modern avocados are restricted to frost-free habitats with fairly equable temperatures. Such conditions may have existed at the Torrey locality during the medial Eocene. Average temperature likely averaged about 16°C or warmer, again by analogy with the modern requirements of avocado.

Wolfe (1970) and Wolfe and Hopkins (1967) proposed that the percentage of entire and toothed margined leaf forms present in a fossil flora provides an accurate indication of climate during the growth of the plants. For example, tropical rain-forest communities consist of species 80% or more of which have entire margins. Subtropical and warm temperate woodlands generally consist of about 50% entire margined species. Application of the Wolfe-Hopkins thesis requires that all taxa be present in the sample and that all separate species be recognized.

The Torrey collection is clearly an incomplete representation of local flora, with moist canyon bottom taxa dominating the assemblage. Wolfe (1970) observed that riparian vegetation generally shows a higher than expected proportion of toothed margin forms. Still, the proportion of toothed to entire margined leaves in the Torrey collection appears at first guess to be in the ballpark of 50%, which is typical of warm temperate and subtropical woodlands.

CONCLUSION

Paleobotanical and geological evidence suggests that the San Diego region experienced a mild, equable climate characterized by summer convective rainfall during the medial Eocene. Average annual temperatures were mild, exceeding 16°C and rarely falling below freezing. Proximity to the coast moderated the climate. At least 50 and probably closer to 70 centimeters of rain fell yearly, this primarily was concentrated in the summer months. Temperatures of the present are much colder and rainfall much greater than during medial Eocene time.

Axelrod (1975) proposed that during the Eocene, warm, moist tropical air masses travelled much further north than at present. Uplift of the Mexican highlands and southern Rockies during the Pliocene, along with a cooling of ocean temperature along the Pacific coast resulting from the development of the cold California current during the Oligocene, pushed the subtropical high pressure belt southward to a position at roughly the latitude of the Tropic of Cancer. Geological and paleobotanical evidence from the Torrey Sandstone indicate that this trend toward aridity began prior to medial Eocene time, producing a medial Eocene climate that was subarid in the San Diego region.

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Time out for the old Victorian pastime of hackysack.

EARLIER EOCENE? MICROVERTEBRATE FOSSILS FROM SAN DIEGO COUNTY, CALIFORNIA: A PRELIMINARY REPORT

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ABSTRACT

Several very fragmentary microvertebrate fossils have been collected from a roadcut outcrop on Morena Boulevard in San Diego. The fossil-bearing unit was mapped by Kennedy (1975) as the Upper Cretaceous Cabrillo Formation and by Kies (1982b) as the upper Paleocene "upper estuarine facies" of the Mount Soledad Formation. The "estuarine facies" is suggested to be at least in part of earlier Eocene (Wasatchian or Bridgerian) age on the basis of ?paramyine rodent and anguid lizard fossils.

INTRODUCTION

Kies (1982a, b) mapped several outcrops in the La Jolla 7 1/2-minute quadrangle as the "upper estuarine facies" of the Mount Soledad Formation (Figure 1). All of these outcrops were previously mapped by Kennedy (1975) as the Upper Cretaceous Cabrillo Formation. For brevity, these outcrops will hereafter be referred to as the "estuarine facies". This term is synonymous with Kies' "upper estuarine facies" in the sense that it is used to designate an informal lithostratigraphic unit characterized by whitish or light greenish-gray muddy sandstones and conglomerates that lack Poway rhyolite clasts. Despite the environmental connotation of the term we do not mean to imply that all outcrops of this unit were necessarily deposited in an estuarine environment.

Kies (1982b) described the Morena Boulevard outcrop of the "estuarine facies" as containing, in part, muddy coarse sandstones, occasional reddish sandy mudstone beds with root-cast horizons, common kaolinitic clastic debris, and sparse conglomerates that lacked Poway clasts. Kies removed the "estuarine facies" from the Cabrillo Formation and suggested a late Paleocene age on the basis of lithological and sedimentological evidence. Following the articles by Kies, Walsh began to prospect the Morena Boulevard outcrop of the "estuarine facies" in an attempt to obtain direct fossil evidence for the age of this unit. A few fragmentary, yet age-significant, microvertebrate fossils have been recovered as a result of screen washing the muddy sandstones and sandy mudstones of this outcrop.

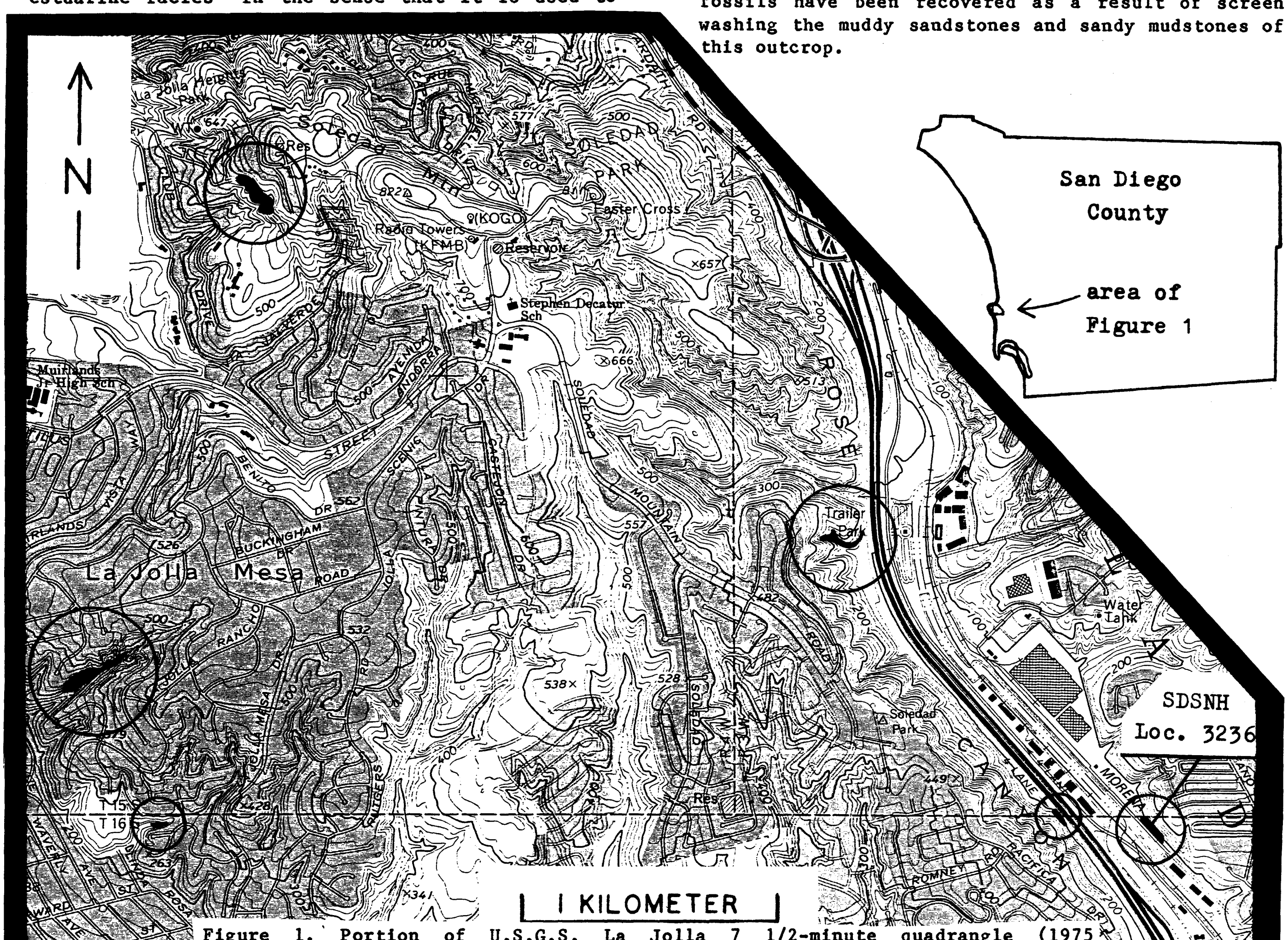

Figure 1. Portion of U.S.G.S. La Jolla 7 1/2-minute quadrangle (1975 photorevised edition) showing currently recognized outcrops of the "estuarine facies" in black, circled for clarity.

METHODS

All microvertebrate specimens discussed in this paper are housed in the San Diego Natural History Museum (SDSNH) and were collected from SDSNH Locality 3236, the "Morena Boulevard Cut" (Figure 2). All specimens were obtained by screen washing using a 10" diameter test sieve with a 0.7 mm opening. About 400 kg of bulk matrix has been washed, and all resulting concentrate greater than 1.2 mm in size has been examined. Much of the concentrate between 0.7 mm and 1.2 mm in size has yet to be sorted. The largest bone fragment yet recovered is 9 mm long, while the total mass of fossil material collected is about 0.6 grams. The fossils range from relatively soft to quite hard in preservation and from pale red (10 R 6/2) to dark reddish brown (10 R 3/4) in color. Bone fragments are commonly abraded and appear to occur throughout the exposed section of the "estuarine facies" at the "Morena Boulevard Cut". A large volume of concentrate is currently being collected from SDSNH 3236 for future processing by a heavy liquid separation technique.

All measurements of microvertebrate specimens were made on an Ehrenreich Photo-Optical Industries Shopscope using a computer program developed by the Life Sciences electronics laboratory at SDSU. Dental terminology employed is that of Wood and Wilson (1936) and Wood (1962), with modifications explained in the text.

Color descriptions accompanied by numerical designations are based on comparison with the Rock Color Chart distributed by the Geological Society of America. Usage of the term "Poway clast" follows the recent definition of Kies and Abbott (1983).

Figure 2. View northeast across Morena Boulevard toward SDSNH Locality 3236. Base of left five-gallon bucket marks site of SDSNH 26224. Right bucket straddles the sandy mudstone bed that yielded SDSNH 26225, 26227, 26228, and 26229. Meter stick between buckets for scale.

SYSTEMATIC PALEONTOLOGY
MAMMALIA Linnaeus, 1758
RODENTIA Bowditch, 1821

Rodentia, genus and species undetermined
(Figure 3, left)

Material: SDSNH 26226, a left upper incisor fragment.

Description: SDSNH 26226 preserves the wear surface of the tooth and is 4.9 mm in maximum length. The anteroposterior diameter of 2.22 mm was measured at the anterior end of the tooth, perpendicular to the tangent to the anterior face. The maximum transverse width of 0.97 mm was also measured at the anterior end of the tooth, perpendicular to the anteroposterior diameter.

The anterior face is rounded and merges gradually into the lateral face. The enamel cap is of moderate thickness and is restricted in its medial and lateral extent. The pulp cavity is small, narrow, irregular in outline as exposed on the wear surface, and uniformly oval in outline as exposed on the broken posterior end.

Discussion: This tooth is notable for its low transverse width/anteroposterior diameter ratio of 0.44, a value that is slightly less than the same ratio for any of the Paleogene upper incisors described by Wood (1962, 1973, 1974). SDSNH 26226 seems to represent a rodent taxon significantly smaller than that represented by SDSNH 26224 (see below). However, the anteroposterior diameter of the former specimen increases slightly toward the posterior end, suggesting that it may have been from a juvenile. While SDSNH 26226 almost certainly represents one of the smaller Paleogene rodents, a more precise taxonomic identification of this specimen is not attempted.

PROTROGOMORPHA Zittel, 1893
ISCHYROMYOIDEA Wood, 1937
ISCHYROMYIDAE Alston, 1876
PARAMYINAE Simpson, 1945

?Paramyine, unidentified genus and species
(Figure 3, right)

Material: SDSNH 26224, a right M^3.

Description: The tooth shows no dental attrition, but is somewhat battered, possibly as a result of transport and/or the screen washing process. The enamel is pitted over much of the tooth, and a large piece has been broken away from the posterior face. The enamel is uncrenulated and is dark reddish brown (10 R 3/4) in color. The tooth has a rounded subtriangular occlusal outline, with a slight indentation at the posterolingual margin. All roots have been broken away.

The protocone is bulbous, much larger than the paracone, and slightly elongated in the anteroposterior direction. The paracone is conical and slightly taller than the protocone. A weak and somewhat undulating protoloph connects the labial base of the protocone to the lingual base of the paracone. A protoconule is absent. Much of the anteroloph is broken away, but remnants of this structure indicate that it was well-developed and curved in an anteriorly-convex arc from the anterior base of the protocone to the anterior base of the paracone. A protostyle and parastyle appear to be absent, although the original presence of the latter structure cannot be ruled out owing to damage to the anteroloph.

A hypocone and distinct metacone are absent, although there is a slight swelling of the posterior marginal crest near the posterolabial edge of the tooth in the region where a metacone would be expected. The term "posterior marginal crest" refers to the well-developed semicircular ridge that encloses the posterior half of the tooth and is continuous from the posterior base of the protocone to the posterior base of the paracone. Two slight

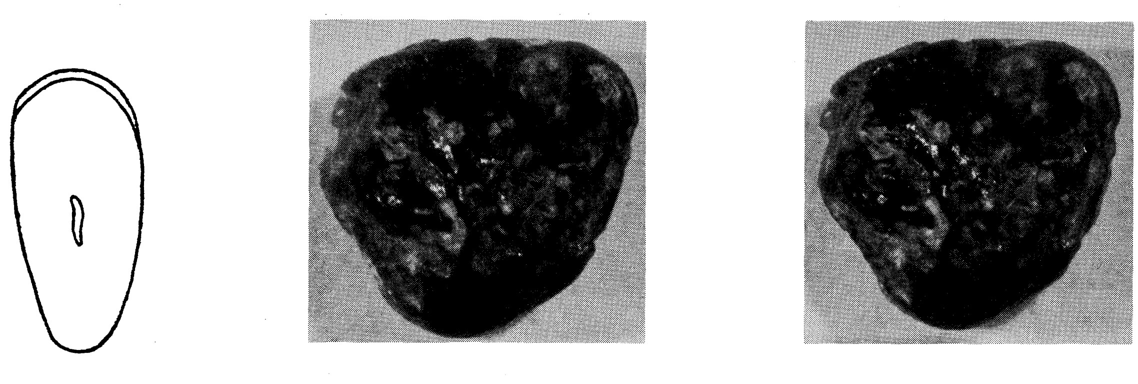

Figure 3. Left, projection of the wear surface of SDSNH 26226 (rodent left I^1) viewed perpendicular to the anteroposterior diameter. Lateral surface to right, anterior toward top of page. Bar equals 1 mm. Right, stereophoto in occlusal view of ?paramyine right M^3 (SDSNH 26224). Anterior to right, labial toward top of page. Bar equals 3 mm.

bumps are present on the labial portion of the posterior marginal crest, the most pronounced and anterior of which may represent a very small mesostyle.

The term "posterior basin" is used below to refer to the essentially circular basin that is completely enclosed by the protocone, protoloph, paracone, and posterior marginal crest. A distinct metaloph extends posterolabiad from its fusion with the base of the protocone to merge with the posterior marginal crest at the edge of the posterior basin after making a distinct posteriad turn. The metaloph thus divides the posterior basin into two parts, with the labial portion much larger than the lingual. The center of the metaloph has been expanded slightly anteriad and distinctly posteriad to form a small metaconule.

The anteroposterior length of 2.93 mm was measured from the posterior-most edge of the posterior marginal crest to the anterior-most edge of the anteroloph, in a direction parallel to a line connecting the apex of the paracone and the center of the swelling on the posterior marginal crest near the posterolabial edge of the tooth. The width of 2.81 mm was measured perpendicular to the length from the lingual-most face to the labial-most face of the tooth.

Discussion: SDSNH 26224 is assigned to the Ischyromyidae (as diagnosed by Black, 1971) on the basis of its brachyodonty, tritubercular nature, and complete lack of a hypocone. Identification of SDSNH 26224 beyond the family level is hampered by the relatively undiagnostic nature of most ischyromyoid M^3's. The specimen can be excluded from the Ischyromyinae on the basis of its poorly developed crests and complete lack of a hypocone. The specimen cannot be excluded with certainty from the Paramyinae or Reithroparamyinae. However, it appears that SDSNH 26224 is not referable to any genus included by Black (1971) in the Reithroparamyinae, as discussed below.

The specimen differs from species of *Reithroparamys* for which the M^3 is known in its possession of a distinct metaloph and lack of a distinct metacone, and from *Franimys* in its better-developed metaloph, lack of a metacone, and lack of a significant posterior elongation (see Wood, 1962:124, 142). The specimen can probably be excluded from *Microparamys* and *Lophiparamys* (as both are diagnosed by Wood, 1962:158, 167) on the basis of its lack of crenulated enamel, lack of accessory ridges and crestlets, and relatively large size. The M^3 of *Janimus* is currently unknown, prohibiting direct morphological comparison with SDSNH 26224. However, the animal represented by the San Diego tooth seems to be significantly larger than the only known species of *Janimus*, based on the relatively small size of the lower teeth of the type and only known specimen of this taxon. In addition, SDSNH 26224 lacks the crenulated enamel of the latter specimen (see Dawson, 1966:102-104). Thus, SDSNH 26224 does not seem referable to any known reithroparamyine genus.

A tentative assignment of SDSNH 26224 to the Paramyinae is compatible with Black's (1971) diagnosis of that taxon, but a more precise identification is not attempted here. SDSNH 26224 can be excluded from most of the genera included by Black (1971) in the Paramyinae on the basis of size and/or morphological differences. It most closely resembles certain species of *Paramys* and *Mytonomys*. For example, the specimen resembles the homologous tooth of the Wasatchian *Paramys c. copei* figured by Wood (1962, fig. 14C) in general morphology, although the San Diego tooth has a relatively smaller metaconule and mesostyle, and is somewhat smaller than this specimen. SDSNH 26224 resembles the M^3 of the Wasatchian *Paramys c. bicuspis* figured by Wood (1962, fig. 16B) in the arrangement of the metaloph and metaconule, but differs from this specimen in its lack of a protoconule, lack of a transversely elongate mesostyle, and lack of accessory spurs extending labiad from the protocone. The San Diego tooth resembles the M^3 of the Uintan *Mytonomys robustus* figured by Black (1968, fig. 2) in general morphology, but differs from this specimen in its much smaller size and lack of a protoconule and mesostylar loph. Other paramyine taxa for which the M^3 is described do not seem to show great morphological similarity to SDSNH 26224.

REPTILIA Linnaeus, 1758
SQUAMATA Oppel, 1811
ANGUIMORPHA Furbringer, 1900
ANGUIDAE Gray, 1925
GLYPTOSAURINAE Marsh, 1872

Glyptosaurine, genus and species indeterminate
(Figure 4)

Material: SDSNH 26225, keeled scute (now essentially destroyed); 26227, unkeeled scute; 26228, jaw fragment with two tooth positions.

Description: SDSNH 26225 0.7 mm wide, 1.3 mm long; exterior scute surface with oblique keel and a sculpture of incipient tubercles, grooves, and pits; smooth gliding surface 0.3 mm long; lateral bevel slightly angled, roughened; free scute margin chipped; interior scute surface smooth. SDSNH 26227 0.9 mm wide, 1.3 mm long; edges more rounded, keel absent, sculpture of vermiculate ridges and pits, no tubercles. SDSNH 26228 with two closely spaced smooth tooth bases.

Discussion: The keeled scute is characteristic of that of anguid lizards based on the rectangular shape, gliding surface, and lateral bevel. Presence of tubercles in the sculpture pattern indicates a member of the Glyptosaurinae, which ranges from the Late Cretaceous into the Miocene (Estes, 1983). Generic identification of this specimen is not possible owing to lack of diagnostic characters in the scutellation of such lizards. Most glyptosaurines have fully tuberculate scutes, and the incipient tuberculation of this specimen most closely resembles that of *Proxestops jepseni*, which ranges from the early Paleocene through early Eocene of New Mexico, Wyoming, and Montana. Part of the diagnosis of *P. jepseni* includes such incipient tubercles (Gauthier, 1982). The high relief of the scute sculpture in this extremely small specimen indicates that larger individuals would have more definitively marked tubercles, because there is size (ontogenetic?) variation in tubercle development in glyptosaurines. This specimen would have come from a lizard with an approximate snout-vent length of as little as 40 mm. Keeled scutes are lacking in *Proxestops* so far as known (Gauthier, 1982; Estes, 1983), and in this feature the specimen most closely resembles Eocene or later glyptosaurines. Presence of keels in glyptosaurines may vary depending on position in the body or on the taxon, but at present, no keeled glyptosaurine scutes have been

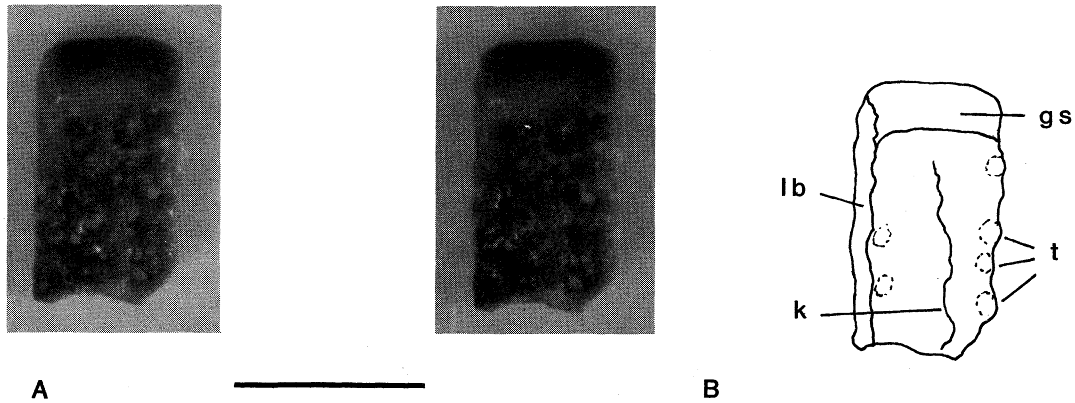

Figure 4. A, Stereophoto of keeled glyptosaurine anguid lizard osteoscute (SDSNH 26225). B, outline of same specimen identifying morphological features. Abbreviations: g = gliding surface; k = keel; lb = lateral bevel; t = tubercles. Bar equals 2 mm.

recovered prior to the early Eocene, where they occur in a number of glyptosaurine taxa (e. g. Xestops, Arpadosaurus).

SDSNH 26227 quite possibly belongs to the same taxon as 26225 because taxa with keeled scales on some parts of the body may have smooth ones elsewhere, or it may have belonged to a different anguid taxon. SDSNH 26228, a jaw fragment, is compatible with reference to Anguidae but is not diagnostic beyond that level. It is included here for completeness but is too fragmentary to determine whether it came from an anguid or a non-anguid taxon.

Schatzinger (1975) described similar keeled anguid scutes (probably from a different taxon) from the later Eocene Mission Valley Formation in San Diego, and glyptosaurines are relatively common lizard fossils in the Early Cenozoic of western North America (Estes, 1983).

REPTILIA?

Material: SDSNH 26229, scute.

Description: Scute eroded, fragmentary; elongated, deep longitudinal keel present; sculpture of weak pits and ridges. Maximum length 1.6 mm; maximum width 1.03 mm.

Discussion: The general aspect of this scute is quite different from the scutes discussed above; it is possibly a fragmentary crocodilian scute although there is also the less likely possibility that it comes from a fish. It is too poorly preserved for further comment.

Other Fossils from the "Estuarine Facies"

A few unidentifiable bone fragments similar in preservation and color to those from SDSNH 3236 have been collected by screen washing about 20 kg of light greenish-gray muddy coarse lithic sandstone from a roadcut outcrop of the "estuarine facies" on the west side of Interstate 5, about 1.6 km northwest of SDSNH 3236, at the letter "k" in the words "Trailer Park" on the photorevised (1975) edition of the U.S.G.S. La Jolla 7 1/2 minute quadrangle, at 32°49'40"N, 117°13'57"W., at an elevation of about 140 feet. Unfortunately, difficulties in access may prevent large-scale collecting at this outcrop.

Sparse, poorly preserved fossil plant fragments occur in a 0.4 m-thick pale brown (5 YR 5/2) sandy carbonaceous shale bed on the north side of "La Cañada Canyon" (32°49'20.1" ± 0.2"N., 117°15'57.2" ± 0.2"W.) at an elevation of about 280 feet (Figure 5). Unfortunately, no identifiable specimens have yet been found. This carbonaceous shale is interbedded with whitish muddy sandstones and conglomerates that lack Poway clasts. Outcrops in this vicinity are assigned here to the "estuarine facies" on the basis of their lithological similarity to other outcrops of this unit. Samples of this carbonaceous shale and the microvertebrate-bearing sandy mudstone bed at the Morena Boulevard Cut were analyzed for fossil pollen by Fuchit Hart of Micropaleo Consultants. Unfortunately, both samples were barren, containing only "coaly debris" (Hart, written comm., 1985).

AGE OF THE "ESTUARINE FACIES"

The minimum age of the "estuarine facies" is established by its stratigraphic position. This unit underlies an erosional surface that occurs below both the lower Middle Eocene Ardath Shale (Bukry and Kennedy, 1969) and early Uintan Friars Formation. Lillegraven (1980) suggested that the vertebrate faunas of the Friars and Mission Valley formations probably represent the interval of time near the boundary of the Bridgerian and Uintan Land Mammal Ages. Thus, a pre-Uintan age for the "estuarine facies" seems probable.

LITHOLOGICAL EVIDENCE

Kies (1982b) proposed a Paleogene rather than Cretaceous age for the "estuarine facies" because it contained kaolinitic detritus that was apparently derived from a presumably Paleogene laterite (Peterson and Abbott, 1979). Kies further suggested a late Paleocene rather than Eocene age for the "estuarine facies" on the basis of its lithological and presumed depositional similarity to the upper Paleocene Silverado Formation of the Santa Ana Mountains (Schoellhamer et al., 1981), as well as its lack of Poway clasts, which (according to Kies,

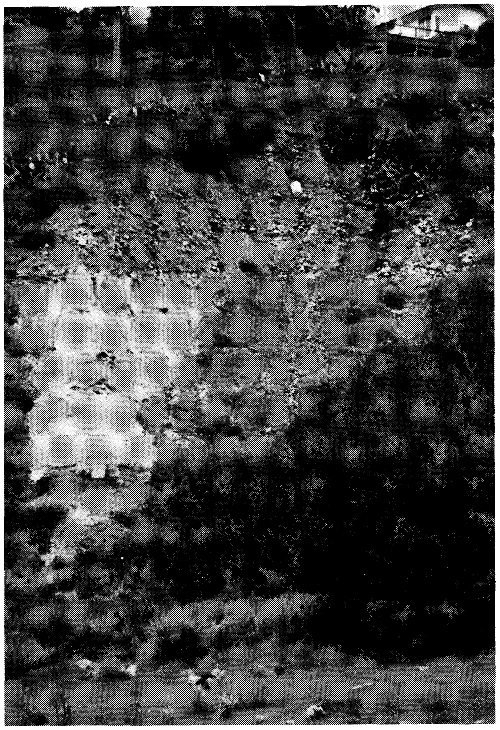

Figure 5. View north of newly recognized outcrop of the "estuarine facies" on the north side of "La Cañada Canyon". Lower five-gallon bucket marks contact between pale brown plant-bearing carbonaceous shale bed and overlying whitish muddy sandstone. Upper bucket lies among conglomerates whose clast content is similar to that of the Cabrillo Formation in the False Point area.

1982a) were present in the southern California Borderland only as early as the late Paleocene or earliest Eocene. While it is possible that the "estuarine facies" could be in part of late Paleocene age, the lithological evidence is not conclusive.

MICROVERTEBRATE EVIDENCE

The beginning of the North American Clarkforkian Land Mammal Age is currently defined in part by the first appearance of the Rodentia (Rose, 1980). If it is assumed that the first appearance of rodents in the San Diego and Rocky Mountain areas was essentially simultaneous, the occurrence of rodent material at the Morena Boulevard cut strongly indicates a Clarkforkian (latest Paleocene-earliest Eocene) or younger age for this outcrop. A post-Clarkforkian age is weakly suggested by SDSNH 26224, which most closely resembles post-Clarkforkian taxa of the Rocky Mountain region. The keeled glyptosaurine lizard scute is a second resemblance to post-Clarkforkian taxa in that region (Estes, 1983), at least from the standpoint that at present, no keeled scutes of this taxon have been recovered from earlier strata.

As a result of the microvertebrate and stratigraphic evidence presently available, the Morena Boulevard outcrop of the "estuarine facies" is tentatively suggested to be of earlier Eocene (Wasatchian or Bridgerian) age. Although the Wasatchian is assigned to the Eocene by most vertebrate paleontologists, some marine biostratigraphers (e.g. Costa et al., 1978) prefer to assign the Sparnacian Stage of Europe to the Paleocene. The Sparnacian and the Wasatchian are considered to be essentially contemporaneous by most vertebrate paleontologists on the basis of their highly similar mammalian faunas. Thus, if the Morena Boulevard outcrop of the "estuarine facies" is Wasatchian in age, it may be time equivalent to what some workers would consider to be upper Paleocene in the marine sequence. In any case, the Paleogene age for this outcrop proposed by Kies is corroborated. In terms of geochronologic age, this outcrop could range from about 47.5 to 55 mybp, based on the correlations proposed by Berggren et al. (1978).

It must be emphasized that the earlier Eocene age suggested above applies strictly only to the Morena Boulevard outcrop of the "estuarine facies". The three currently recognized outcrops of this unit in Rose Canyon show important lithological differences from some of the outcrops of this unit west of Rose Canyon, and it is conceivable that the latter could be significantly older or younger than the Morena Boulevard exposure.

REGIONAL SIGNIFICANCE OF THE MICROVERTEBRATE FOSSILS

As sparse as they are, the fossils from the "estuarine facies" are apparently the first earlier Eocene (or late Paleocene) terrestrial vertebrates to be reported from California (see Savage and Russell, 1983:45,85,99). Middle(?) Paleocene (Torrejonian) vertebrates occur about 320 km north of San Diego in the Goler Formation of the Mojave Desert (e.g. West, 1970), and probable early Eocene (Wasatchian) vertebrates are present about 550 km south-southeast of San Diego near Punta Prieta in Baja California (Flynn and Novacek, 1984).

There are several shallow-water or nonmarine rock units in California of late Paleocene and earlier Eocene age that appear to be grossly similar in lithology to the "estuarine facies"; none of these, apparently, has yielded any terrestrial vertebrates. These include the Paleocene Silverado Formation of southern California (Schoellhamer et al., 1981) and the lower and/or middle Eocene Tesla and Ione formations of the central part of the state (Huey, 1948; Allen, 1929, respectively). All of these formations contain frequent white quartz-rich sandstones, residual or transported kaolinitic material, and common carbonaceous shales or lignites.

It is possible that the tropical climate and severe weathering that was presumably responsible for some of these lithological features also served to hamper the preservation of vertebrate fossils. On the other hand, a thorough paleontological survey of these formations using screen washing techniques might reveal some important new Paleogene vertebrate localities.

STRATIGRAPHIC STATUS OF THE "ESTUARINE FACIES"

Formational assignment of the "estuarine facies" is problematical. Based on marked differences in clast content between this unit and the Mount Soledad Formation (as originally characterized by Kennedy and Moore, 1971), as well as the presence of an erosional surface between these units, assignment of the "estuarine facies" to the Mount Soledad Formation is questioned. However, it should be noted that a unique outcrop currently assigned to the Mount Soledad Formation may be partially time-equivalent to the "estuarine facies". This "deltaic facies" was suggested by Kies (1982a) to be of late Paleocene or earliest Eocene age. The possible time-equivalency of these rocks and the "estuarine facies" is indicated in Figure 6.

In clast content the "estuarine facies" resembles typical outcrops of the Cabrillo Formation in La Jolla. It differs from such outcrops, however, in its whitish or light greenish-gray muddy sandstones, common kaolinitic debris, presumed estuarine environment of deposition, and apparently much younger age. Reassignment of the "estuarine facies" to the Cabrillo Formation would thus introduce significant lithological, depositional, and temporal inhomogeneities in the current concept of the latter unit. For this reason, reassignment of the "estuarine facies" to the Cabrillo Formation is inappropriate.

Establishment of the "estuarine facies" as a new formation may eventually prove to be advantageous. However, such an action is currently unjustified, owing to the small areal extent of this unit, the unknown nature of its lower boundary, and its unclear stratigraphic, depositional, and temporal relationships to similar but unstudied rocks in the Mount Soledad area.

As a result of the above considerations, the formational assignment of the "estuarine facies" is left in doubt. A confident decision regarding the stratigraphic status of the "estuarine facies" must await further geological and paleontological investigations into both this unit and many of the outcrops in the La Jolla area that were mapped by Kennedy (1975) as the Cabrillo Formation.

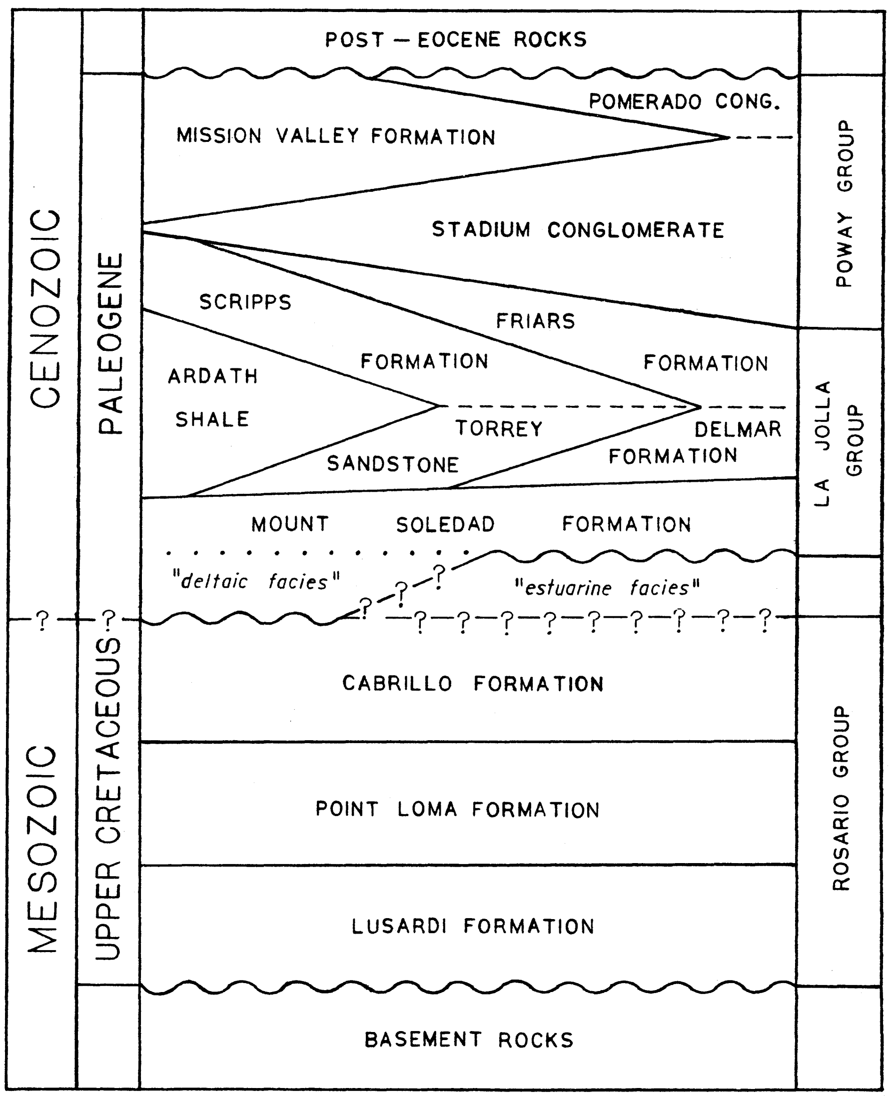

Figure 6. Partial geologic column for the San Diego area showing stratigraphic position of the "estuarine facies". Queried dashed lines represent unobserved contacts. Queried position of the Cretaceous-Paleogene boundary reflects uncertainty over the minimum age of the Cabrillo Formation. In part after Givens and Kennedy (1979).

CONCLUSIONS

Fragmentary microvertebrate fossils were collected from a roadcut outcrop on Morena Boulevard in San Diego. The fossil-bearing unit was mapped by Kennedy (1975) as the Upper Cretaceous Cabrillo Formation, and by Kies (1982a, b) as the upper Paleocene "upper estuarine facies" of the Mount Soledad Formation.

The "estuarine facies" is pre-medial Eocene and probably pre-Uintan in age, because it stratigraphically underlies an erosion surface that occurs below both the lower middle Eocene Ardath Shale and the Friars Formation of early Uintan age. The occurrence of rodent material in the "estuarine facies" strongly indicates a Clarkforkian (latest Paleocene-earliest Eocene) or younger age, while the presence of a keeled glyptosaurine anguid osteoscute suggests a post-Paleocene (no later than Miocene) age. The Morena Boulevard outcrop of the "estuarine facies" is therefore tentatively suggested to be of earlier Eocene (Wasatchian or Bridgerian) age based on the known material. In any case, the Paleogene (vs. Cretaceous) age proposed for this outcrop by Kies (1982a, b) is corroborated. As sparse as they are, the fossils from the "Morena Boulevard Cut" are apparently the first late Paleocene or earlier Eocene terrestrial vertebrates to be reported from California.

Further geological and paleontological investigations into both the "estuarine facies" and lithologically similar outcrops in the La Jolla area will be required to resolve the stratigraphic status of this unit with confidence.

ACKNOWLEDGEMENTS

The comments and criticisms of P. L. Abbott, J. D. Archibald, C. C. Black, T. A. Deméré, E. D. Milow, G. L. Peterson, and M. A. Roeder are gratefully acknowledged. A. E. Wood provided important technical information. P. L. Abbott, J. D. Archibald, and C. C. Black reviewed all or part of the manuscript. We thank Fuchit Hart and Hideyo Haga of Micropaleo Consultants for preparing and analyzing samples.

LOCALITY DESCRIPTION

SDSNH 3236, the "Morena Boulevard Cut"

Southwest-facing roadcut in the "estuarine facies" on the northeast side of Morena Boulevard, San Diego, San Diego County, California. U.S.G.S. La Jolla 7 1/2 minute quadrangle, 1967 edition. City of San Diego Topographic Survey Sheet 238-1701 (1:200 scale orthophoto map prepared from aerial photography dated 8/1/78).

The ?paramyine right M^3 (SDSNH 26224) was collected from light greenish gray (5 GY 8/1) muddy gravelly massive coarse-grained friable sandstone (volcanic sublitharenite). This site is located on the north side of a small southwest-draining gully about 6.5 m above road level, about 1 m below the base of the uppermost 0.4 m-thick mottled reddish and greenish sandy mudstone bed at this outcrop, directly across Morena Boulevard from a point 4 m southeast of the north corner of Buccola Showrooms (4330 Morena Blvd.), at latitude 32°49'02.3" ± 0.2"N., longitude 117°13'13.4" ± 0.2"W., at an elevation of about 95 feet.

All lower vertebrate specimens described in the paper (SDSNH nos. 26225, 26227, 26228 and 26229) were collected from the above-mentioned 0.4 m-thick mottled reddish and greenish sandy mudstone bed, about 1 m stratigraphically above the locality of SDSNH 26224.

The rodent left I^1 (SDSNH 26226) was collected from a mottled reddish and greenish sandy mudstone bed about 20 m northwest of and 3 m stratigraphically below the site of SDSNH 26224.

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ADDENDUM: Korth (1984, fig. 10A) referred an isolated M^3 from the Wasatch Formation (Early Eocene) of Wyoming to a new species of *Reithroparamys*, *R. ctenodactylops*. This tooth closely resembles SDSNH 26224 in general morphology, differing from it only in smaller size, relatively larger paracone and metaconule, and possession of a small hypocone. It is thus possible that SDSNH 26224 may be either reithroparamyine or paramyine. This decision changes none of the conclusions of our paper.

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GEOLOGY OF THE MORRO HILL AREA, NORTHWESTERN SAN DIEGO COUNTY, CALIFORNIA

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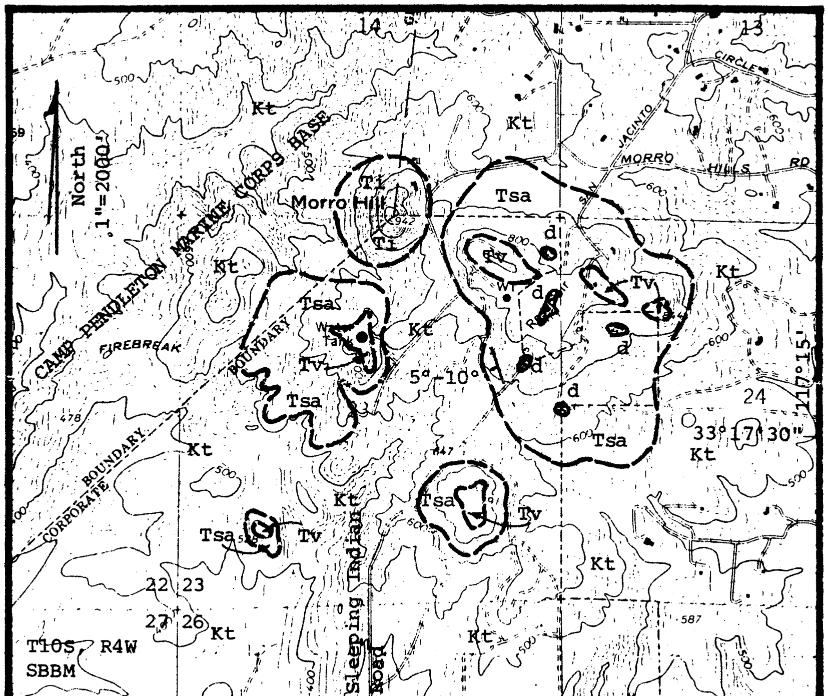
Urbanization in the Morro Hill area, northeast of Oceanside, and south of Fallbrook, has lead to the discovery of four outliers of sedimentary strata correlated with the Santiago Formation - Member A of Wilson (1972). The nonconformable contact with underlying Bonsall tonalite basement rock is well exposed in several road cuts. Indian Hill Volcanics (new name proposed herein) unconformably overlie the approximately 8 to 30 meters of thinly- to massively-bedded, well-indurated, unfossiliferous, olive-green claystone, tan to gray siltstone, and light gray to white sandstone. Bedding is inclined gently in a westerly to southwesterly direction on the order of 5 to 10 degrees. Geomorphic evidence for recently active landsliding is clearly apparent on stereographic aerial photographs and large-scale topographic maps. At least four closed or nearly closed natural depressions, along with sharp, arcuate headscarps and hummocky topography, define these nearly ubiquitous landforms. Land development, accompanied by imported water for domestic use and orchard irrigation, the presence of relatively weak clayey soils, and existing landslide deposits, are key ingredients which could result in a re-activation of sliding and other slope instability problems in this area known locally as "Sleeping Indian Hill."



EXPLANATION

Tv = Indian Hill Volcanics, probably acidic composition and accumulated as a series of flows and/or air falls. Post-Santiago Formation, possibly Miocene age.

Ti = Morro Hill volcanic plug or neck, probable source for the Indian Hill Volcanics.

Tsa = Santiago Formation - Member A, interbedded claystone, siltstone and sandstone. Eocene age.

Kt = Bonsall tonalite, and other undifferentiated basement rocks. Cretaceous age.

— — — = Approximately located geologic contact.

= Approximate dip and stike of bedding.

d = Closed or nearly-closed natural depression.

Reconnaissance geologic mapping and interpretation by W. J. Elliott, 1984-85, and modified after Rogers (1965).

Base map after U.S. Geol. Survey, Morro Hill 7½' Quad., 1968.

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Olivenhain
MEETING HALL

PLEISTOCENE FAULTS AND MARINE TERRACES, NORTHERN SAN DIEGO COUNTY

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INTRODUCTION

Marine terraces are wave-abrasion platforms that have been preserved from subsequent erosion. A marine terrace typically has a gently seaward-dipping offshore segment and a narrower, slightly steeper inshore segment which terminates against the old sea cliff. The line of intersection formed by the meeting of the old wave-abrasion platform and the old sea cliff is the terrace shoreline. The terrace shoreline closely approximates sea level at the time the terrace was formed (Bradley, 1957; Bradley and Griggs, 1976).

At least nine marine terraces are preserved along the stretch of coast from Carlsbad to Solana Beach (Plate 1 in back pocket). Relative seaward and landward directions at the time these terraces were cut are the same as those today. The shoreline of each terrace trends nearly parallel to the present shoreline, and each terrace maintains a nearly constant width along its length. The lowest and most seaward terrace shoreline is at an elevation of about 20 to 25 feet. The higher and more landward terrace shorelines are over 300 feet elevation. These spatial parameters impart a landward-climbing, stair-like pattern to the physical expression of the terraces.

Each marine terrace was cut during a Pleistocene sea-level high stand. Continuous slow uplift raised each terrace clear of wave attack during a subsequent sea-level rise, so that terraces decrease sequentially in age, elevation and in distance from the modern shoreline.

Each marine terrace is mantled by a regressive sequence of marine and non-marine strata that were deposited during sea-level high stand and retreat. Upper shoreface, beach and eolian beach-ridge deposits accumulated along a terrace shoreline during a sea-level high stand. These deposits prograded seaward a short distance with the subsequent retreat of the sea. This slight seaward shift left the terrace beach ridge very close to or directly above the seacliff at the landward edge of the terrace. These beach ridges form prominent topographic lineaments in many parts of coastal San Diego County and closely approximate the position of an old sea cliff. An old sea cliff is the topographic break between the landward margin of one marine terrace and the seaward margin of the next higher terrace (Peterson, 1970; Eisenberg, 1983; Kern, in prep.).

As sea level dropped after each high stand, sand and gravel were spread across the terrace surface by shoreline and alluvial processes. These coarse deposits form the most commonly observed rock type that rests directly on a terrace surface. Locally the coarse sediment covered small remnants of near-shore marine deposits.

Although no direct dates for marine terraces in the stretch of coast between Carlsbad and Solana Beach have been recorded (Lajoie and others, 1979; Karrow and Bada, 1980) a rough estimate of terrace ages can be made by using age estimates for associated estuarine deposits and the topographic continuity between terraces in this area and dated terraces in adjacent areas. Further speculations on the ages of marine terraces in this area can be made by a comparison of approximate terrace ages with the times of sea-level high stand recognized by Shackleton and Opdyke (1973).

As a first rough estimate older marine terraces were formed between 800,000 to 500,000 years B.P. Successively younger terraces were formed in the interval between 600,000 to 175,000 years B.P. The two youngest terraces correlate well with dated terraces nearby. The second youngest terrace probably formed during a sea-level high stand about 125,000 years B.P. The lowest, most seaward and youngest marine terrace probably formed during a sea-level high stand about 85,000 years B.P.

In the Carlsbad to Solana Beach area marine terraces have been referred where appropriate to previously named terraces in the San Diego area. Terraces not readily referrable or apparently original have been informally named for the locality where they are best exposed (Eisenberg, 1983). Table 1 lists the terrace names and shoreline elevations in order of age, with the youngest marine terrace at the top of the list. Figure 1 diagrammatically shows those marine terraces present in a coast-normal section near Encinitas. The distribution of Pleistocene marine terraces, stream terraces and Pleistocene terraces (undifferentiated) and points of measured elevation at terrace-bedrock contacts are shown in Plate 1 (in back pocket).

Table 1. Summary of Terraces and Corresponding Shoreline Elevation.

TERRACE	SHORELINE ELEVATION (IN FEET)
BIRD ROCK	20-25
NESTOR	65-70
PALOMAR	~120
MAGDALENA	~150
QUAIL	~170
BULRUSH	220-225
MARVIEW	275-280
CLAIREMONT	315
TECOLOTE	350-375

FAULTING AND PLEISTOCENE MARINE TERRACES

Pleistocene faulting and folding disrupted Pleistocene marine terraces in the San Diego area (Peterson, 1970; Ziony, 1973; Kennedy and others, 1975; Gastil and others, 1979; Kern, 1973; Kern, 1977; Schmalfuss, 1981; Kern, 1983). However,

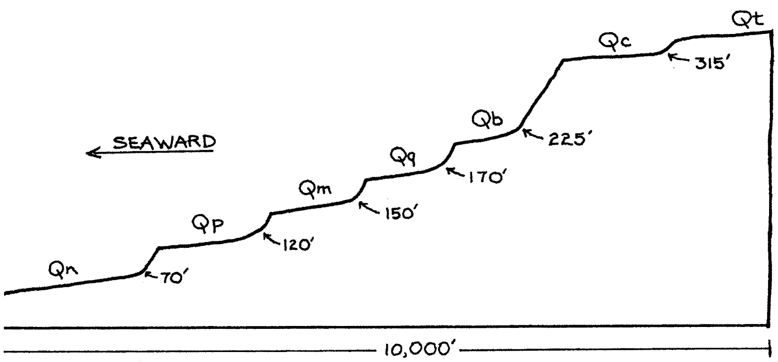

Figure 1. Diagrammatic cross section through Pleistocene marine terraces across the central part of the field area.

between Carlsbad and Solana Beach only one Pleistocene marine terrace is unquestionably faulted. The northeast-trending La Costa Avenue fault cuts a marine terrace surface but the immediately overlying terrace strata are draped over the fault (Figure 2). The deformation evidently was a growth fault. The La Costa Avenue fault may be a secondary feature produced by simple shear in association with strike-slip movement on the Rose Canyon fault (Adams and Frost, 1981). This faulting, as dated by its relationship with the terrace surface and terrace deposits, had its last movement probably between 400,000 and 175,000 years B.P. Other faults in the area, also possibly related to Pleistocene movement on the Rose Canyon fault, include a north-south trending fault set and an east-northeast trending fault set. None of these faults unquestionably cuts a Pleistocene terrace (Eisenberg, 1983). There is one intriguing possibility, however.

Figure 2. Looking southeast at the La Costa Avenue fault. Road cut on the south side of La Costa Avenue, 800 feet east of Interstate 5 in Leucadia.

One of the north-south trending faults, here referred to as the Encinitas Beach fault (Fault D of Wilson, 1972), coincides with an abrupt break in the elevation of the marine terrace - Eocene bedrock contact that is continuously exposed in the sea cliffs from northern Leucadia to Swami's Point in Encinitas. The fault and the topographic break occur 2,400 feet south of the Leucadia Boulevard beach access stairway (Plate 1, in back pocket). North of this N5°E-trending fault the terrace-bedrock contact elevation remains constant at about 20 feet for nearly two miles. For one mile south of this fault the elevation of the terrace-bedrock contact remains constant at 30 feet. An eroded gap less than 100 feet wide exists across the topographic break in terrace elevation. The fault is exposed on the north side of the eroded gap and clearly separates the underlying Eocene strata.

Several interpretations of the scene at the Encinitas Beach fault are possible. One interpretation is that only one marine terrace is present and that it has been disrupted by down-to-the-northwest separation along the fault. Another interpretation is that two separate terraces are present and that strike-separation along the fault has juxtaposed the topographically higher, seaward margin of an older marine terrace against the topographically lower, landward margin of a younger marine terrace. Still another possibility is that the two terraces exist, neither of which have been faulted.

Correct interpretation of this problem would suggest an age for the most recent faulting in this area. The youngest unquestionable faulting in the area is probably no younger than about 175,000 years B.P. If the Encinitas Beach fault has disrupted a marine terrace along the coast the deformation could be much younger than 85,000 years B.P. This paper discusses the questions of: 1) whether one or two separate terraces are present, and 2) whether young Pleistocene marine terraces have been faulted.

ONE TERRACE VS. TWO

The scene at the Encinitas Beach fault could be interpreted to require the presence of only one Pleistocene marine terrace. As mentioned above the elevation of the marine terrace - Eocene bedrock contact remains nearly constant for a considerable distance north and south of the fault. Across a narrow eroded gap at the fault zone the elevation of the terrace-bedrock contact drops from 30 feet on the south to about 20 feet on the north. In addition, north and south of the fault the basal beds of the Pleistocene terrace deposits are strongly iron stained and Pleistocene beach deposits mantle the terrace surface. Also, the small bit of fault splinter exposed in the underlying Eocene rocks shows a sense and amount of separation similar to the sense and amount of drop in terrace-bedrock contact elevations. These observations imply that a single, faulted terrace is present.

On the other hand strong evidence suggests that two marine terraces are present. Several features show that the segment of terrace south of the fault is probably the seaward margin of one marine terrace and that the segment of terrace north of the fault is the landward margin of another, separate marine terrace. First, a prominent beach ridge runs continuously along the top of the coastal bluffs from northern Leucadia to Swami's Point in Encinitas. South from Leucadia the crest of the beach ridge moves progressively closer to the coastal bluff until above the Encinitas Beach fault the ridge crest resides almost directly above the present sea cliff. A bit further south, at Moonlight State Beach, the beach ridge is in fact only half a ridge. In this area and elsewhere in San Diego County each beach ridge resides above an old sea cliff that marks the landward edge of one marine terrace and the seaward edge of the next higher terrace. The presence and trend of the beach ridge above the coastal bluffs strongly suggests that the old sea cliff that marks the topographic break between two marine terraces occurs in the vicinity of the Encinitas Beach fault.

Second, surge channels are a common feature along the Pleistocene terrace - Eocene bedrock contact north of the Encinitas Beach fault. Surge channels are linear troughs cut perpendicular to a shoreline by the grinding action of aligned cobbles in sand-filled depressions (Figure 3). They occur adjacent to shorelines and seacliffs (Bradley and Griggs, 1976). They are locally abundant on the modern marine abrasion platform in the Leucadia area just seaward of the modern sea cliff. Here surge channels on a modern abrasion platform and a late Pleistocene marine terrace can be compared (Figure 4). The surge channels exposed along the terrace-bedrock contact north of the Encinitas Beach fault suggest that the sea cliff at the landward limit of the terrace is present immediately landward of the sea-cliff outcrop. More seaward portions of the terrace have been eroded away.

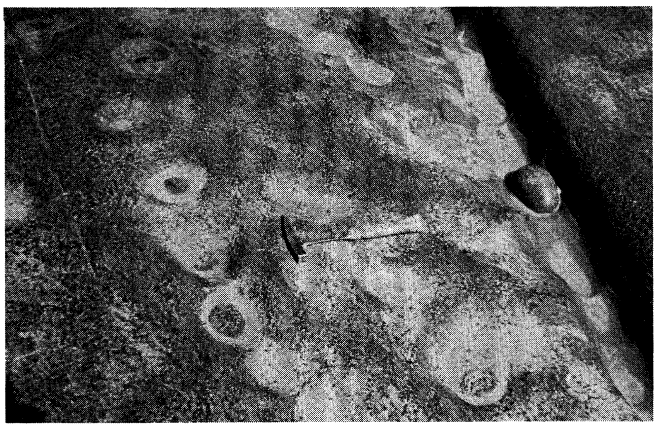

Figure 3. Cobbles resting in sand-filled depressions of incipient surge channels on the modern marine abrasion platform 400 feet north of the Leucadia Boulevard beach access stairway.

Pleistocene surge channels are also present further south in the sea cliffs at Solana Beach County Park. The seaward margin of the Nestor terrace crops out in the sea cliffs at a near constant elevation of 29 feet northward to a point about 500 feet north of the Solana Beach County Park beach access area. At that point the terrace-bedrock contact drops to about 20 feet along a gently northward-sloping, 300 foot-long stretch of the terrace-bedrock contact. Northward of this gentle slope the terrace contact stays at an elevation of about 20 feet and represents the landward margin of the Bird Rock terrace. Surge channels are common along the sloping interval that separates the two terraces. The sloping interval represents a highly oblique cut through the topographic break between the seaward margin of the Nestor terrace and the landward margin of the Bird Rock terrace. The surge channels indicate the position of the Bird Rock terrace shoreline along the sloping portion of the Pleistocene-Eocene contact.

It should be noted that a prominent beach ridge exists at the northern tip of Solana Beach. This beach ridge sits above the topographic break between the Nestor and Bird Rock terraces. Less than 1000

Figure 4. Looking southwest from the Grandview Street beach access stairway at surge channels cut into the Pleistocene terrace segment north of the Encinitas Beach fault (left) and the modern marine abrasion platform (right).

feet to the south the beach ridge is partly truncated by a slight landward bend of the modern coastline. About one-third of a mile further south, and on line with the trend of the beach-ridge crest, the sloping outcrop of the topographic break between the Nestor and Bird Rock terraces appears in the sea cliffs. The relationship between the coastal beach ridge crest, the modern shoreline and the topographic break between terraces at Solana Beach is strikingly similar to that at Encinitas Beach. It also should be noted that the elevation of the Bird Rock terrace sea-cliff outcrop (20 feet) and the Nestor terrace outcrop (29 feet) at Solana Beach are nearly identical to that observed for the two segments of terrace exposed north and south of the Encinitas Beach fault.

Third, beach sediments are well developed above the terrace contact north of the Encinitas Beach fault, and they locally dip seaward up to 5°. These beach deposits also suggest proximity to the landward margin of the northern terrace section. Beach deposits are also present south of the Encinitas Beach fault but they are probably deposits left on the seaward margin of the higher terrace on a minor terrace platform. Beach deposits are found on the higher terrace at an elevation of 30 to 35 feet in railroad cuts immediately north and south of Batiquitos Lagoon, but these beach deposits are well landward of the coastal beach ridge and have no corresponding beach ridge above them. This implies an origin during a minor, short-lived episode rather than a major terrace-cutting event, especially in light of the well-defined relationship between beach ridges and sea cliffs apparent in this area. The beach deposits at Batiquitos Lagoon and those south of the Encinitas Beach fault probably have the same origin.

Finally, the iron staining of the basal Pleistocene deposits probably was a result of later ground-water movement along the fault trace. The iron-stained sandstone is concentrated near the fault and fades laterally. Staining could have occurred in the basal sands of two separate Pleistocene terraces where they approach the fault trace.

Although not obvious at the fault outcrop the evidence shows that two separate terraces are exposed in the sea cliffs north and south of the Encinitas Beach fault. The southern and higher marine terrace outcrop probably represents the seaward margin of a terrace with a shoreline much further inland. The northern and lower marine terrace segment probably represents the landward margin adjacent to the old sea cliff of a separate, younger terrace. The topographic similarities and beach ridge continuity between areas suggest that the southern terrace outcrop is the seaward margin of the Nestor terrace and that the northern terrace outcrop is part of the Bird Rock terrace (Plate 1, in back pocket).

TO FAULT OR NOT TO FAULT?

Two marine terraces are present on either side of the Encinitas Beach fault. Therefore the coincidence of the fault and the topographic break between the two terraces must be either the result of strike separation and juxtaposition of the terraces, or a fortuitous occurrence, the fault just by chance coinciding with the topographic break between the terraces.

The scene at the fault superfically suggests that faulting has occurred. The abruptness of the topographic break in terrace elevations is quite striking. The terrace elevations are nearly constant for a considerable distance north and south of the fault but change 10 feet across the narrow, eroded gap that coincides with the fault trace. At a different scale, strike-separation faulting of the terraces also would seem to agree with the style of faulting suggested by the pattern of differential erosion on the modern marine terrace that can be seen in an aerial photo obtained where the differential erosion seen on either side of the Encinitas Beach fault as it heads offshore suggests right-lateral separation (Seitz, 1983). Right-lateral separation along the Encinitas Beach fault would have brought the higher, seaward edge of the Nestor terrace against the lower, landward part of the Bird Rock terrace on the southern and northern sides, respectively, of the Encinitas Beach fault.

However, there is convincing evidence that faulting has not disrupted the Pleistocene terraces. Where the Encinitas Beach fault is exposed, just to the north of the eroded gap, it is clearly truncated by the Pleistocene marine terrace (Figure 5). Unless fault splinters just north of and within the eroded gap moved before and after, respectively, the cutting of the lower marine terrace, an occurrence that seems highly unlikely, faulting must have taken place prior to 85,000 years B.P. It also is highly unlikely that the Encinitas Beach fault could have juxtaposed the terraces by faulting the Nestor terraces but not faulting the Bird Rock. The age of faulting must be older than 125,000 years B.P.

The Encinitas Beach fault is probably one of several related north-south trending faults that are exposed in the sea cliffs northward through Leucadia. None of these faults can be seen to cut the Pleistocene marine terrace. A younger set of east-northeast trending faults occurs in the same area but again none of these faults cuts the Pleistocene terrace. This indirect evidence also suggests that the terraces are unfaulted.

Finally, the elevation of the landward margin of the Bird Rock terrace and the seaward margin of the Nestor terrace at the Encinitas Beach fault exactly match the elevation of the corresponding parts of the same terraces at Solana Beach County Park. The seaward margin of the Nestor terrace can be traced nearly continuously from Solana Beach to Encinitas Beach County Park, and there can be little doubt that the 29 foot-elevation terrace outcrop at Solana Beach is the southward continuation of the terrace outcrop on the southern side of the Encinitas Beach fault. The correlation of the 20 foot-elevation terrace outcrop in Solana Beach and north of the Encinitas Beach fault is also very good, although not as continuously traceable. The exact match of terrace elevations over a distance of seven miles also strongly suggests that no faulting of the terraces at Encinitas Beach has occurred, especially in light of the fact that where exposed the Encinitas Beach fault clearly shows down-to-the-northwest separation of Eocene strata.

Figure 5. The Encinitas Beach fault. The fault splinter at the five-foot-long staff separates Eocene strata down to the northwest but is truncated beneath basal Pleistocene marine terrace deposits.

CONCLUSION

A continuous outcrop of a Pleistocene terrace - Eocene bedrock contact occurs in the sea cliffs in the vicinity of the Encinitas Beach fault. The contact segment south of the fault represents the low, seaward edge of the Nestor marine terrace. The Nestor shoreline, at about 70 feet, is a little less than one-half mile further inland. The contact segment north of the fault represents the high, landward part of the Bird Rock marine terrace. Only a thin slice of the Bird Rock terrace is preserved. If this were removed the seaward edge of the Nestor terrace would be revealed.

North-south trending, synthetic strike-slip faulting occurred in conjunction with movement along the Rose Canyon fault prior to the cutting of the Nestor terrace about 125,000 years B.P. One of the faults is the Encinitas Beach fault. After the formation of the Nestor terrace and while the Bird Rock terrace was being cut, about 85,000 years B.P., the trace of the north-south trending Encinitas Beach fault happened to coincide with the topographic break between the seaward edge of the Nestor terrace and the landward edge of the Bird Rock terrace. The geomorphic expression of the fault probably served to localize the topographic break between the terraces even closer to the trace of the fault. Recent erosion along the fault trace has left a gap in the seacliff that coincides with the topographic break between the terraces.

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On the road again.

Listed below are more stops than can be reached during the logistically cumbersome San Diego Association of Geologists field trip. All localities are numbered on the maps. Some of the unvisited localities described may be visited later or the whole course could be run during a quickly paced day by motivated individuals. In planning a trip a word of caution should be voiced about the tides; stops 6, 7, 8, 9 and the lengthy stop 13 all require low tides in order to be inspected. Examination of the tide tables during trip planning will allow coastal outcrops to be visited at low tide and inland outcrops to be viewed at high tides.

STOP 1. Railroad cut north of intersection with Miramar Road. See paper by May for geologic description.

STOP 2. North Torrey Pines Road (highway S-21) about halfway down grade through Torrey Pines State Reserve. An impressive 24 m vertical bank of Eocene and Pleistocene deposits flank the road. Parking is legal at a turn-out on the east side of the road only. No digging or sampling is allowed in the State Reserve.

The Torrey Sandstone is exposed in the north end of the outcrop. A varied lithology of amalgamated pebbly sandstone and channelized sandstone of weakly graded to massive sandstone is indicative of deposition in a submarine canyon tributary. A south-dipping laterally continuous erosional surface lies 16.4 m below the north corner of the outcrop as the unit pinches out near the north end of the Reserve.

A gray to orange-brown interbedded sandstone, siltstone and silty mudstone up to 10 m thick within the Torrey Sandstone, dips 8^{o} to the south. A regional south dip of $3\text{-}4^{o}$ results in a probably paleoslope of $4\text{-}5^{o}$ to the south. Broad shallow troughs of sandstone, a lag of fine shell hash, a microcrystalline sulfurous coating and worm bioturbated siltstones indicate modest impulses of sediment followed by quiet periods in deep water. The interbedded unit may be overbank levee deposits or interchannel deposits of a tributary canyon system. The upper sharp contact is non-erosional except at the upper north end where a scoured channel formed.

A highly bioturbated silty sandstone and mudstone overlies the Torrey Sandstone. An erosional undulatory surface is overlain by a cobble conglomerate lag, poorly graded sandstone, and poorly bedded silty sandstone and mudstone. A regression to nearshore deposits is indicated.

A conformable trough cross-bedded clean sand with several pebble stringer deposits and ripple cross beds is indicative of subtidal channels that may be on either side of the barrier.

STOP 3. In Del Mar, park near the intersection of Carmel Valley Road and the coastal highway, S-21. There are three nearby areas of interest: A) Del Mar Canyon Park, B) the road cut immediately north of the intersection, and C) the road cut immediately east of the intersection including outcrops exposed along Torrey Point Road to the northeast.

(A) Del Mar Canyon Park, an unimproved park, may be reached by walking north 260 m along the highway and then down its axis by steep foot path. A large culvert at the base of the canyon allows access to the well-exposed coastal bluffs. The lower 20.6 m is Delmar Formation. The lower 9 m includes channelized sandstone and claystone with a subaerial red claystone bed with apparent sand-filled mud-cracks. The middle 19 m is Torrey Sandstone subtidal channels, sand flat and bar deposits. <u>Ostrea idriaensis</u> shells are found as reworked deposits. A thin intertidal deposit is exposed in the upper portion of the outcrop on both sides of the highway.

(B) Immediately north of the intersection, the road cut exposes a subtle transitional phase between the Delmar Formation and the overlying Torrey Sandstone. A general coarsening-upward trend exposes bioturbated sand flat and shallow channel deposits to large cross-bedded nested channels with cobble lag deposits and festooned channel fill. The cobble-to very coarse sand-filled large channels indicate a probable storm outwash fluvial influence.

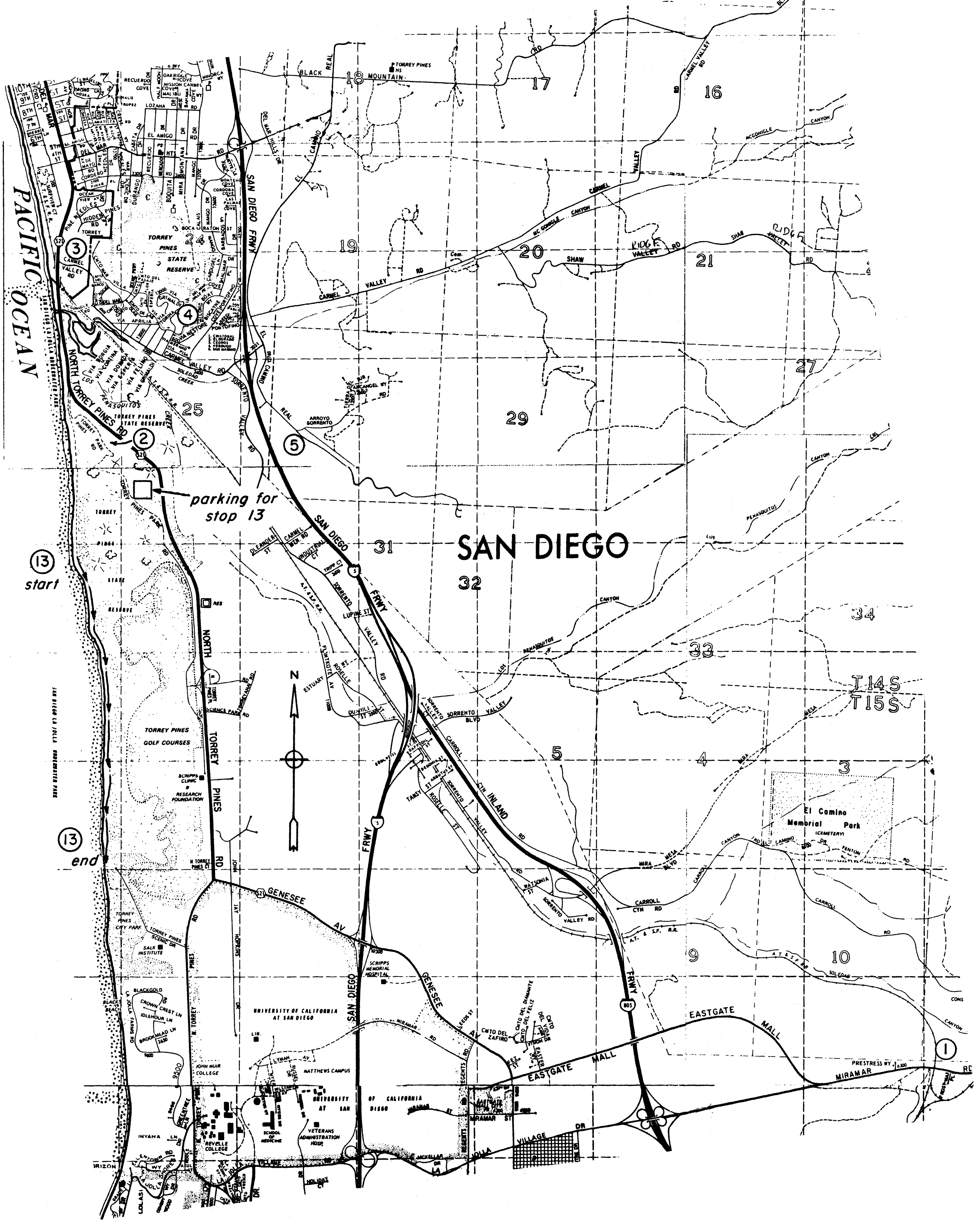
(C) The road cut east of the intersection has been upthrown relative to the north bank and the fault trace can be seen in the eastern portion of the north bank. The east bank is the type locality for the Delmar Formation. Outcrops to the northeast also expose the Delmar Formation along Torrey Point Road.

The lower 2 m of the bank is fossiliferous interbedded and interlaminated muddy sandstone to claystone. The overlying deposits are a thick sequence of bioturbated tabular beds that repetitively fine-upwards and are capped by thin muddy siltstone to claystone. Primary structures are rarely preserved trough cross beds in the sandstones and faint laminations in the siltstones. <u>O. idriaensis</u> shells are randomly exposed as lag deposits and one well developed biostrome is exposed along Torrey Point Road.

These three areas indicate a transgressive shift from back lagoonal supratidal-intertidal deposition to subtidal channel deposition and storm outwash channels near the barrier.

STOP 4. Continue east on Carmel Valley Road and turn north on Portofino Road. Turn west on Long Boat Way and west again on Long Boat Cove. At the end of the court walk along a foot path 30 m to the crest of a ridge. Look out for the steep cliffs.

Distinctive sand waves, all uniformly oriented in a southeasterly direction, are up to 2 m hig each, in excess of 100 m wide and occur in a repetitive sequence 14 m thick. Similar deposits also occur 450 m to the northwest that are in excess of 20 m thick. The sand waves are overlain by large longitudinally cross-bedded pebbly to coarse sandstone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TORREY PINES STATE RESERVE
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13 end
TORREY PINES GOLF COURSES
SCRIPPS CLINIC & RESEARCH FOUNDATION
SALK INSTITUTE
UNIVERSITY OF CALIFORNIA AT SAN DIEGO
SCRIPPS MEMORIAL HOSPITAL
JOHN MUIR COLLEGE
REVELLE COLLEGE
SCHOOL OF MEDICINE
VETERANS ADMINISTRATION HOSP.
MATTHEWS CAMPUS
GENESEE AV
EASTGATE MALL
MIRAMAR RD
LA JOLLA VILLAGE DR
CARMEL VALLEY RD
SORRENTO VALLEY RD
BLACK MOUNTAIN RD
El Camino Memorial Park (CEMETERY)
T14S
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channels. Several horizontal one-pebble conglomerate stringer lag deposits can be observed and are indicative of sheet flood deposits. The outcrop suggests a subsiding flood tidal delta or major flood channel bar system.

STOP 5. Continue east on Carmel Valley Road and turn south on El Camino Real. A locked gate crosses the road 300 m south of Arroyo Sorrento where a 120 m vertical section is exposed along the road cut as it climbs to the top of the mesa.

The lowest portion of the outcrop is of lagoonal Delmar interbedded and interlaminated muddy sandstone to silty mudstone. The overlying cross-bedded Torrey Sandstone is punctuated by cobble conglomerate deposits of nested channels and bars. The conglomerate and the overlying coarse sandstone occur as longitudinally cross-bedded broad channels with steep banks which indicate a strong fluvial influence from a delta distributary lobe.

Above the fluvial deposits a significant lithologic change occurs. Channelized sandstone with siltstone lithoclasts and rare primary troughs that have a poorly graded lag deposit indicate submarine canyon tributary deposits. At the crest of the ridge, 3 m blocks of interbedded sandstone and siltstone can be observed where they were torn from the channel flanks.

Nearshore interbedded sandstone and siltstone suddenly become a fining-upward sequence of nearshore coarse-grained sand waves and channels, siltstone draped bars and storm-outwash channels, and shelf interbedded and interlaminated sandstone, siltstone and mudstone. This is indicative of a middle Eocene minor regressive/transgressive sequence.

A progradational or slight regressive phase occurred as the deposits coarsen-upward and the shelf deposits become nearshore storm outwash channels and interbeds of medium sandstone and siltstone. Feeding burrows and hummocky cross stratification can be observed at the last turn before the top of the mesa.

STOP 6. Cardiff. Southern end of San Elijo State Beach. Park along coast highway or in State Park parking lot. Good exposure of lithofacies 2, channeled claystone, representing the lowest and most landward depositional facies of the Eocene section exposed along the coast. Next three stops are progressively further up-section.

STOP 7. Encinitas. Moonlight State Beach. Park in beach parking lot. South on beach 1000 feet to contact between lithofacies 3 (Delmar) and lithofacies 4/5 (Torrey). Lithofacies 3 green claystone and sandstone with abundant sedimentary structures of muddy and sandy inter/subtidal flats and channels. Moving north to northward-dipping Tt/Td contact, and into lithofacies 4 (sandy tidal flat) and then lithofacies 5 (sandy tidal channels) of lithofacies which make up lower part of Torrey sandstone. From south to north past the parking lot area the clay content of tidal channels decreases, indicating a shift barrierward. A few hundred feet past the parking area the sea cliffs contain broad channels, lacking clay and with very sparse cobble lag, indicating tidal channel/tidal inlet? just south of ill-defined boundary between lithofacies 5 and overlying lithofacies 6.

STOP 8. Encinitas. Seaside Gardens County Park. Beach walk 3/4 mile north to Leucadia Blvd. beach stairs. From stone steps continue northward past lithofacies 6 (Torrey ss) burrowed cross bedding to Encinitas Beach fault. Fault cuts Eocene but not overlying Pleistocene strata. Moving northward burrows decrease in size, indicating quieter depositional conditions higher in the section. Torrey/Ardath contact. Northward through Ardath Shale (lithofacies 7) to fossil locality (S.D.S.N.H. 296). Marine micro- and macro-fossils with possibly flood-derived gravels. Microfossils date locality as middle Eocene.

STOP 9. Leucadia. Ponto State Beach. Walk 200 feet south of stairs to faulted contact between Scripps and Ardath. Scripps (lithofacies 5) north of down-to-north fault contains regressive tidal channel deposits with basal lag of claystone clasts and shark's teeth.

STOP 10. Carlsbad-La Costa. Alga Road east of El Camino Real, 600 feet west of Almaden Lane on north side of Alga Road. Lithofacies 2-4 adjacent to Jurassic Santiago Peak Volcanics basement. Examine the buttress unconformity. Go south of Batiquitos lagoon on El Camino Real, east on Olivenhain, south on Rancho Santa Fe Road through Olivenhain. View of green claystone (Delmar/Friars) to the east of El Camino and steep, cliff-forming cross-bedded sandstone (Torrey) to the west of El Camino. Juxtaposition is not fault controlled, but rather is a depositional feature caused by transgression/subsidence along a coastline with a rugged, steep profile that resulted in a strong component of vertical stacking of depositional facies.

STOP 11. Carlsbad. Palomar Airport Road to Laurel Tree Road. N.B. This locality is just north of the index map coverage. Park along Laurel Tree Road. North-facing cuts east of Laurel Tree Road expose lithofacies 5 overlain by lithofacies 1 and 3. Flaser bedding, silicified wood, dropstone in sandy tidal deposits, coarse Peninsular Ranges-suite conglomerate in lithofacies 1 tidal lagoon with invading delta. Across Palomar Airport Road lithofacies 1 contains giant claystone blocks derived from collapse of muddy tidal creek banks during flood conditions.

STOP 12. Encinitas. Encinitas Blvd. and Candy Lane. The section exposed along Encinitas Blvd. and the County haul road includes lithofacies 3 (muddy/sandy tidal-Delmar) overlain by sandy tidal (lithofacies 5) sandstones, overlain by subfacies 5b conglomerate stringer sandstone, which represents an influx of


BATIQUITOS LAGOON
LA COSTA
T 13 S
LEUCADIA
PACIFIC OCEAN
SAN DIEGO COUNTY
CARLSBAD
RANCHO ENCINITAS
ENCINITAS
CARDIFF BY THE SEA
OLIVENHAIN
SAN ELIJO LAGOON
RANCHO
ALGA RD
LA COSTA AV
SIERRA VISTA RD
ALTA VISTA RD
RANCHO SANTA FE RD
ENCINITAS BLVD
SANTA FE DR
SAN DIEGO FRWY
EL CAMINO REAL
MANCHESTER AV
BIRMINGHAM DR
LEUCADIA BLVD
NORMANDY AV
CARDIFF BEACH STATE PARK
SAN ELIJO BEACH STATE PARK
QUAIL BOTANIC GARDENS
ENCINITAS BEACH
MOONLIGHT BEACH
SEA CLIFF PARK
Glen Park
EL MIRLO
AVENIDA ALONDRA
LA NORIA
LAS FLORES
EL SECRETO
AVENIDA MARAVILLAS
CIRCLE DR

Poway-clast conglomerate into the Eocene tidal lagoon.

STOP 13. Beach walk from Bathtub Rock to Indian Trail Canyon. Cliffs expose lagoon (Delmar) and tidal flat (Torrey) deposits cut into by a submarine canyon tributary that flowed southerly. Stroll down beach leads into deeper portions of submarine canyon until Indian Trail Canyon (on north end of glider port atop cliffs). At Indian Trail Canyon, severely weathered Mt. Soledad Fm. paralic facies are overlain by Delmar lagoonal deposits which were ripped asunder by sediment-gravity flows within Eocene submarine canyon. See article by May for more details.