

THE NEOGENE SAN DIEGO BASIN:
A REVIEW OF THE MARINE PLIOCENE SAN DIEGO FORMATION

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ABSTRACT

The San Diego Formation was deposited during a marine transgression of the Neogene San Diego Basin. This basin, like other on-shore sedimentary basins in southern California is structurally related to the transtensional tectonics of the continental borderland. Deposition of the San Diego Formation began in the Late Pliocene and extended into the Early Pleistocene accumulating some 75 m of marine and 9 m of nonmarine sedimentary rocks. The formation can be informally subdivided into a "lower" member characterized by massive, fine-grained, friable sandstone with occasional thin conglomerate layers and containing an inner to outer shelf molluscan assemblage. Characteristic species include *Patinopecten healeyi*, *Pecten stearmsii*, *Lucinoma annulata*, and *Opalia varicostata*. This "lower" member also contains a rich marine vertebrate fauna which includes whales, dolphins, sea lions, sea cows, birds, bony fishes, and sharks. An "upper" member consists of interbedded fine-grained and coarse-grained, friable sandstones with more common and thicker units of conglomerate. The marine invertebrates indicate a shallower facies of littoral to inner shelf character and include the following characteristic taxa: *Pecten bellus*, *Argopecten hakei*, *Nucella lamellosa*, and *Dendraster ashleyi*. The "upper" member becomes nonmarine upsection completing the picture of a successively shallowing and sediment-filled basin.

In terms of provincial correlation the "lower" member is equivalent to the Niguel Formation and the upper Fernando Formation in the southeastern Los Angeles Basin, the Careaga Sandstone in the Santa Maria Basin, and the San Joaquin Formation in the San Joaquin Basin (Upper Pliocene). The "upper" member correlates with the lower Santa Barbara Formation in the Ventura Basin (Upper Pliocene or Lower Pleistocene).

The meager microfossil control available suggests that the San Diego Formation may be no older than N-21 (approximately 3.0 million years B.P.) and at least as young as the *Emiliania annula* Subzone (approximately 1.5 million years B.P.).

INTRODUCTION

Marine Neogene deposits in the southern California area occur in a series of on-shore sedimentary basins which are structurally related to the transtensional tectonics of the continental borderland. The majority of these on-shore basins, including the Santa Maria, Ventura, and Los Angeles Basins, are filled with deep-water Miocene and Pliocene marine sedimentary rocks. A fourth and less well-known basin occurs in the southwestern corner of San Diego County and contains only shallow-water (shelf) Pliocene marine deposits. This basin, herein referred

to as the Neogene San Diego Basin, occupies a north to northwest trending graben which extends southward from Pacific Beach and Mission Bay beneath much of metropolitan San Diego, National City and Chula Vista and into northwestern Baja California, Mexico, as far south as Rosarito Beach (fig. 1).

The San Diego Formation (Dall, 1898; Arnold, 1903; Hertlein and Grant, 1944) was deposited in the San Diego Basin during a marine transgression that began in the Late Pliocene and extended into Early Pleistocene time, accumulating at least 75 m of marine and 9 m of nonmarine sedimentary rocks. The overall stratigraphic sequence suggests successively shallowing and filling of this basin. It is now apparent that extensional tectonics have controlled both the initial deposition as well as the present outcrop distribution of this rock unit.

The purpose of this paper is to summarize previous geologic and paleontologic work on the San Diego Formation and to offer an interim report on more detailed work in progress on the lithostratigraphy, biostratigraphy, and age of this deposit. Direct reference to depositional models and to sedimentary facies have been purposely omitted pending completion of additional field and laboratory work. Also, the present paucity of basin-wide microfossil control injects an obvious and inherent weakness into the proposed age assignments. Unless specifically referenced, the data and interpretations presented here are the result of recent work by the author, a preliminary report of which was given in Deméré (1982).

BACKGROUND

The first published reference to these rocks was made by Dall (1874) in his description of molluscan fossils recovered from the "old San Diego well" in Balboa Park (fig. 1). In a subsequent paper Dall (1878) added fossils from the Pacific Beach sea cliff section (fig. 1) to this Pliocene molluscan fauna. Later (Dall, 1898) he combined the fossiliferous well section and sea cliff section with exposures at nearby Mount Soledad, establishing the "San Diego Beds" as a stratigraphic unit. However, Dall's concept of this unit seems to have been more time-stratigraphic than rock-stratigraphic.

Arnold (1903) was the first worker to apply the name "San Diego Formation" to these rocks, later selecting the Pacific Beach sea cliff exposures as the type section (Arnold, 1906). Arnold subdivided the formation into an upper and lower horizon and offered a correlation between the type section at Pacific Beach and the "old well" section in Balboa Park.

This early work with the San Diego Formation

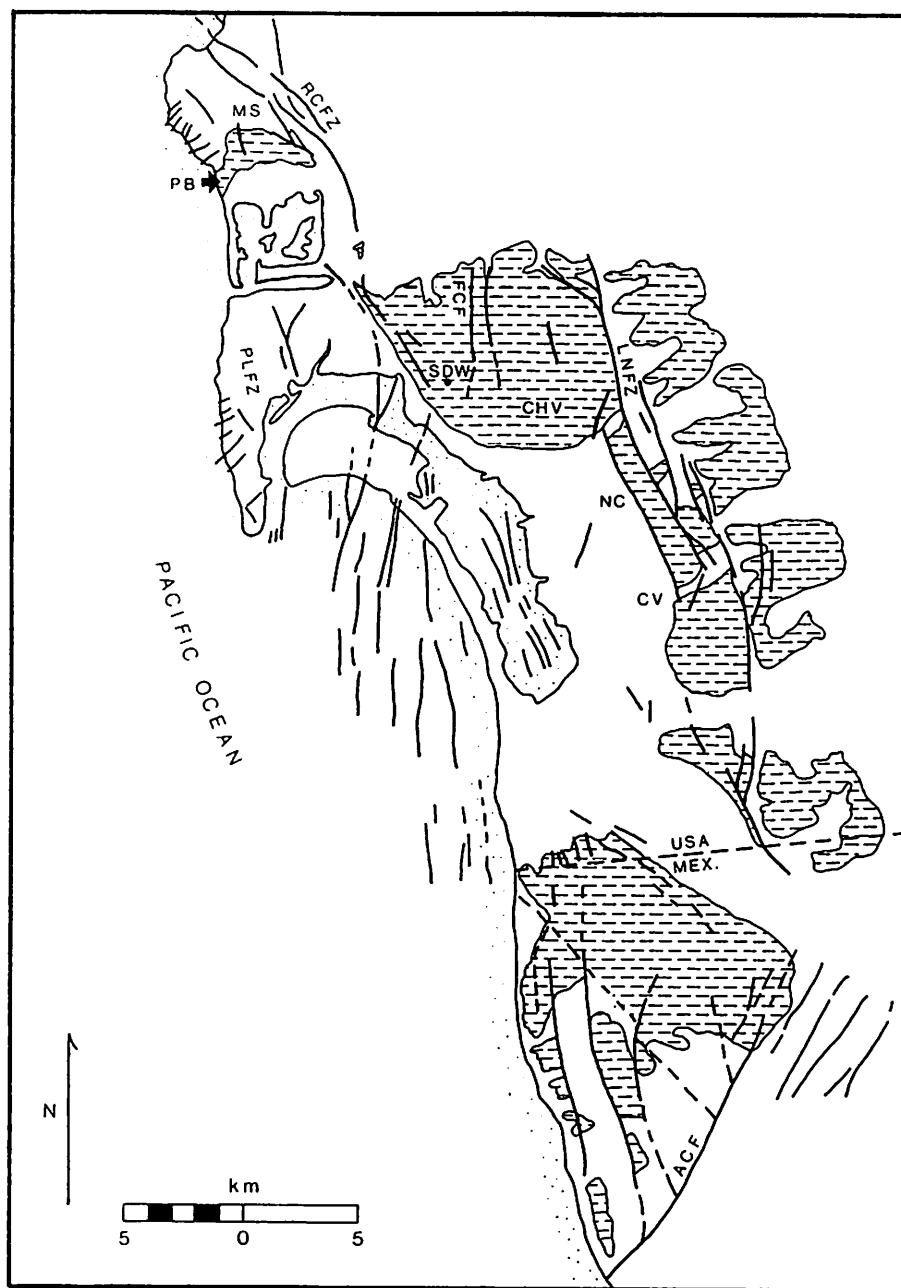


Figure 1. Index map of the San Diego Basin showing the outcrop distribution of the San Diego Formation and the general fault pattern as presently understood. Fault placements from Minch (1967), Kennedy et al. (1975), Kennedy et al. (1980), and Kennedy and Welday (1980). Abbreviations used: ACF = Agua Caliente Fault; CHV = Chollas Valley; CV = Chula Vista; FCF = Florida Canyon Fault; LNFZ = La Nacion Fault Zone; MS = Mount Soledad; NC = National City; PB = Pacific Beach (type section); PLFZ = Point Loma Fault Zone; RCFZ = Rose Canyon Fault Zone; SDW = the old San Diego well.

(see Hertlein and Grant, 1944, for a more complete review) made little mention of the rocks themselves, concentrating primarily on molluscan paleontology and age and dealing only with exposures at Pacific Beach and the northwestern portion of the San Diego Mesa. Hertlein and Grant (1944, 1960, 1972), in their monographic treatment of the geology and paleontology of the San Diego Formation, gave a more thorough description of the geology of this unit although still concentrating on exposures in the northern portion of the basin. They included a limited discussion of lithology and noted some of the variability of this unit (i.e., very fine-grained sandstones to pebble conglomerates). Surprisingly, they did not utilize the biostratigraphic framework earlier established by Arnold (1903) in their largely taxonomic treatment of the macroinvertebrate fauna of the formation.

Deméré (1982) has recently applied Arnold's biostratigraphy to exposures of the San Diego Formation in both the northern and central portions of the basin confirming its utility. With this basic biostratigraphic control it is now possible to recognize broad stratigraphic intervals within the formation which in the future should lead to a more complete understanding of the depositional and structural history of the Neogene San Diego Basin.

GEOLOGIC SETTING

The Neogene San Diego Basin (fig. 1) occupies a graben bounded on the east by the multi-stepped Sweetwater-La Nacion fault system (Artim and Pinckney, 1973; Kennedy et al., 1975) and on the west by offshore faults mapped by Kennedy and others (Kennedy and Welday, 1980; Kennedy et al., 1980). The La Nacion Fault Zone and adjacent high-angle faults fade out to the north, with diminishing dip-slip separation, near the south rim of Mission Valley. They form the northern end of the basin and control the outcrop distribution of the San Diego Formation on the San Diego Mesa. A northwestern extension of the basin occurs in the Mission Bay-Pacific Beach area where it is bounded on the east and west by the Rose Canyon Fault Zone and the Point Loma Fault Zone respectively (Kennedy et al., 1975). The extreme southern portion of the basin, which extends into Baja California, Mexico, was mapped by Minch (1967) who recognized numerous high-angle normal faults in the region. Minch noted the close structural affinity between this area of northwestern Baja California and the continental borderland. The Pliocene geology of this portion of the Neogene San Diego Basin was not investigated for this report but has been briefly discussed by Rowland (1972).

Gastil and Higley (1977) have suggested that the high-angle normal faults of the Sweetwater-La Nacion fault system were active during the initial Pliocene marine transgression and that these faults formed a hingeline producing "...a marine basin to the southwest but maintaining a stable terrace to the northeast and east" (p. 37). These authors further propose that thicker marine deposits accumulated west of the hingeline than east of it and that these thinner eastern deposits were formed only during the later portion of San Diego time when the marine transgression had reached the level of this stable terrace. While it is true that the Sweetwater-La Nacion fault system was probably active during the initial transgression and that the San Diego Formation is indeed thicker west of

this system than east of it, it seems unlikely that the eastern deposits are younger than the western. On the contrary, based on fossils and lithology these eastern deposits appear to have been deposited during the initial transgression and may represent a condensed section which west of the hingeline was expanded through growth-faulting. This hypothesis as well as several alternative ones are still in the process of being tested.

LITHOSTRATIGRAPHY

As briefly mentioned above, the San Diego Formation exhibits considerable lithologic variation over its area of outcrop. Some workers have attempted to describe this variability, and several informal lithologic members have been proposed.

Minch (1967), in mapping Neogene deposits in northwestern Baja California, divided the San Diego Formation into a "lower member", up to 200 feet (60 m) thick, composed of bluish gray to yellowish brown, fine- to medium-grained sandstone with occasional discontinuous layers or lenses of locally indurated conglomerate; and an "upper member", up to 100 feet (30 m) thick, composed of interbedded yellowish brown, medium- to coarse-grained sandstone and sandy cobble conglomerate.

Kennedy and Tan (1977) divided the San Diego Formation in the National City, Chula Vista, and San Ysidro areas into a "lower sandstone part" composed of marine, fine- to medium-grained, yellowish brown, poorly indurated, but locally calcareously cemented sandstone, and an "upper conglomeratic part" composed of pebble, cobble, and boulder conglomerate in a coarse-sandstone matrix. They noted that the conglomeratic part rests generally above and west of the sandstone part, and that in some areas the two interfinger.

Gunther (1964) divided the San Diego Formation on the south slopes of Mount Soledad into a "lower siltstone member" composed of massive, tan to yellow, fine-grained, micaceous sandstone and siltstone with occasional discontinuous beds of pebble conglomerate and medium-grained sandstone; and an "upper coarse-clastic member" composed of sandy, pebble conglomerate, massive, brown, coarse-grained sandstone and well-indurated, shelly sandstone (also in Wicander, 1970).

In general, these workers have recognized a "lower" fine-grained sandstone unit and an "upper" coarser-grained sandstone, conglomerate unit. The "upper" coarse units of Minch (1967) and Kennedy and Tan (1977) appear to be nonmarine in part, whereas the "upper" coarse unit of Gunther (1964) contains marine fossils.

The type section of Arnold (1906), which crops out along the sea cliffs at Pacific Beach (fig. 2), represents the thickest continuous sequence of San Diego Formation sediments exposed anywhere in the basin. This section measures 74 m in thickness and rests unconformably on marine sandstones and shales of the Middle Eocene Mount Soledad Formation. Both "lower" and "upper" San Diego Formation marine sediments occur here. The base of the section is in a 1 m thick, basal pebble to cobble conglomerate overlain by a 4 m thick sequence of gray to yellow, pebbly sandstone, silty sandstone, and conglomerate (fig. 3). The next 10 m of section consists of gray to yellow, fossiliferous, very fine- to coarse-

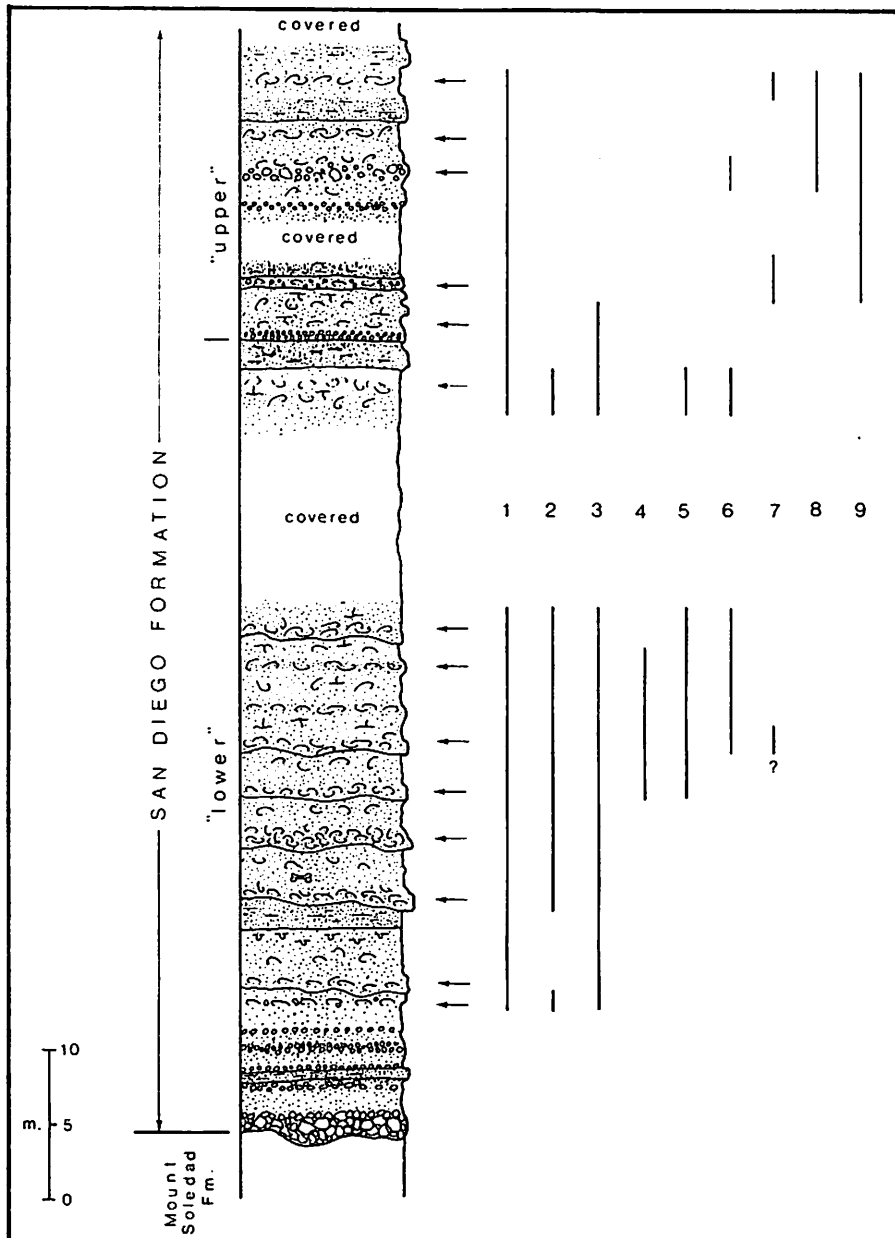


Figure 2. Generalized columnar section for the San Diego Formation as exposed in the type section at Pacific Beach. Also shown are the observed stratigraphic ranges for selected macroinvertebrate taxa: 1 = *Patinopecten healeyi*; 2 = *Lucinoma annulata*; 3 = *Opalia varicostata*; 4 = *Argopecten invalidus*; 5 = *Pecten stearnsii*; 6 = *Glottidia albida*; 7 = *Dendraster ashleyi*; 8 = *Pecten bellus*; 9 = *Ostrea vespertina*.

grained sandstone, silty sandstone, and bioturbated sandstone containing rare to abundant molluscan fossils. *Patinopecten healeyi* along with *Lucinoma annulata* and *Opalia varicostata* are the dominant faunal elements. Above this interval, for at least the next 20 m, is a sequence of gray to orange, locally cemented, fossiliferous, fine- to coarse-grained sandstones containing locally abundant *Patinopecten healeyi* and *Argopecten invalidus*, along with rarer *Lucinoma annulata*, *Pecten stearnsii*, *Opalia varicostata* and *Glottidia albida*. Individual sandstones within this sequence exhibit basal pecten hash concentrations up to 1 m thick and contain abundant bioclastic detritus. The next 16 m of section, although largely covered by slope wash, is probably similar to the underlying locally cemented sequence as it appears to contain a similar molluscan fauna. This largely covered interval is capped by a 2 m thick, massive, very fine-grained, silty sandstone. The remaining 20 m of section is herein referred to the "upper" San Diego Formation and begins in a "basal" fossiliferous, pebble conglomerate which is overlain by a sequence of gray to brown, fossiliferous, medium- to coarse-grained sandstone; orange, fossiliferous, well-cemented pebbly sandstone; gray to brown, fossiliferous, pebble to cobble conglomerate; and light brown, very fine-grained silty sandstone. Within this upper interval the pecten species of the lower part of the section give way to abundant *Pecten bellus*, which is also joined by *Nucella lamellosa*, *Dendraster ashleyi*, and *Balanus* sp. The relatively low faunal diversity at Pacific Beach is in part a product of differential preservation, with calcitic shelled taxa (e.g., pectens, echinoids, and barnacles) predominating.

On the San Diego Mesa, outcrops of the "lower" member are characterized by a basal conglomerate or several conglomeratic layers interbedded with fine- to coarse-grained micaceous sandstone. Overlying this basal conglomerate sequence (where it is exposed) is a yellow to tan, massive, very fine-grained, micaceous sandstone sequence (fig. 4). Individual sedimentary units within this primarily friable sandstone sequence include: well-cemented shell beds or shell lenses; finely laminated sandstones; cross-bedded sandstones; medium- to coarse-grained sandstones; bioturbated sandstones; fining-upward sandstones with basal pebble and gravel stringers; and pebble to cobble conglomerates. This sandstone sequence (which is up to 25 m thick) is locally fossiliferous containing both a rich molluscan fauna (Hertlein and Grant, 1944) as well as a diverse marine vertebrate fauna. This latter fauna includes whales, dolphins, sea lions, sea cows, birds, bony fishes, and sharks (Miller, 1956; Barnes, 1973, 1976; Deméré and Cerutti, 1982).

In the Chula Vista-National City area (west of the La Nacion Fault) outcrops of the "lower" member are similar in overall character to those on the San Diego Mesa. However, here the sandstone sequence (fig. 5) is characterized by thicker and more numerous shell beds (both friable and well cemented), some interbedded green claystones, and fewer conglomerates. The entire sandstone sequence is also thicker (up to 60 m).

The "upper" member of the San Diego Formation crops out over a broad area of the San Diego Mesa between the Florida Canyon Fault in Balboa Park and the La Nacion Fault Zone (fig. 1). It is perhaps best exposed in the Chollas Valley area where, with

an average dip of 05°SW, it attains a total thickness of around 15 m. Typical exposures have a basal sequence of well-cemented, ledgey sandstones interbedded with friable sandstones and well-cemented pebble and cobble conglomerates (fig. 6). The sandstones vary from very fine-grained to coarse-grained and from cross-bedded to massive. These sandstones and the pebble conglomerates are locally fossiliferous (some are shell hash deposits) and contain an invertebrate fauna characterized by *Pecten bellus*, *Nucella lamellosa*, *Dendraster ashleyi*, and numerous barnacle taxa including the large *Balanus gregarius*. This species is often found in clusters still attached, as in life, to pebbles and cobbles. The ledgey sandstone-pebble conglomerate sequence is overlain in many localities by a distinctly bedded unit of massive, laminated, and cross-bedded friable sandstones. Individual beds contain basal pebble or gravel stringers and vary from fine-grained to coarse-grained sandstones. Fossils are very rare in this bedded sandstone unit and have only been collected from a fine-grained sandstone near the top of the unit. These fossils are the same as those from the ledgey sandstone-pebble conglomerate sequence.

Above the bedded sandstone unit is a nonmarine sequence of gray to orange to red, very fine- to very coarse-grained, friable sandstones with interbedded thin pebble stringers and thicker pebble to cobble conglomerates. Sandstone beds vary from micaceous laminated and cross-bedded layers to massively bedded layers and are characteristically barren of fossil material.

Within the small graben (Goldstein, 1956) bounded by the Florida Canyon fault (west) and the Texas Street fault (east), the nonmarine sediments of the "upper" San Diego Formation appear to grade imperceptibly upsection into the overlying Lindavista Formation (= Sweitzer Formation of Hertlein, 1929). West of the Florida Canyon fault, however, the Lindavista Formation rests with marked unconformity on the marine sandstones of the "lower" San Diego Formation. The apparent gradational relationship between the Lindavista Formation and the nonmarine "upper" San Diego Formation within the graben may represent the degradational (erosional) vacuity that elsewhere is represented by an unconformity. The suggestion by Peterson (1977) that the Lindavista Formation may represent the regressive phase of the transgressive San Diego Formation would seem to support this idea of a local gradational contact between the two formations.

In terms of overall stratigraphic thickness, the San Diego Formation has been reported by Hertlein and Grant (1944) to attain a total thickness of 1250 feet (375 m) with the greatest thickness occurring in the Chula Vista and San Ysidro areas. However, recent fieldwork has been unable to account for more than 75 m of marine section, with an additional 9 to 10 m of nonmarine San Diego Formation. Minch (1967) documented only 60 m of section in his "lower member" of the San Diego Formation with an additional 30 m of sandstone and conglomerate in his "upper member". These overall thicknesses of 85 to 90 m are considerably less than the 375 m of Hertlein and Grant. Although it is true that these authors relied on subsurface well data for their total stratigraphic thickness (Hertlein and Grant, 1939), it is now apparent that much of the "missing" thickness is made up for by the recently recognized Sweetwater and Rosarito Beach Formations of Miocene age (Minch,



Figure 3. Unconformity between the San Diego Formation and the Middle Eocene Mount Soledad Formation as exposed in the type section at Pacific Beach. Note the basal pebble to boulder conglomerate.

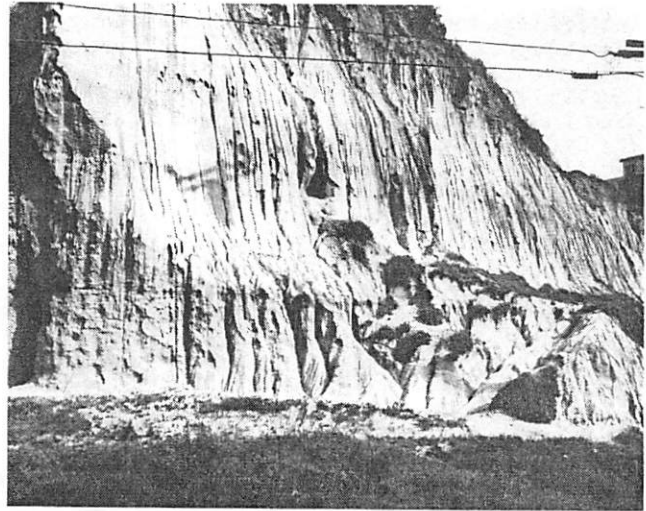


Figure 4. Outcrop of the fine-grained sandstone sequence in the "lower" San Diego Formation as exposed in the northwestern corner of the San Diego Mesa.



Figure 5. Outcrop of "lower" San Diego Formation sandstones as exposed in the National City area. Note the numerous resistant shell beds.

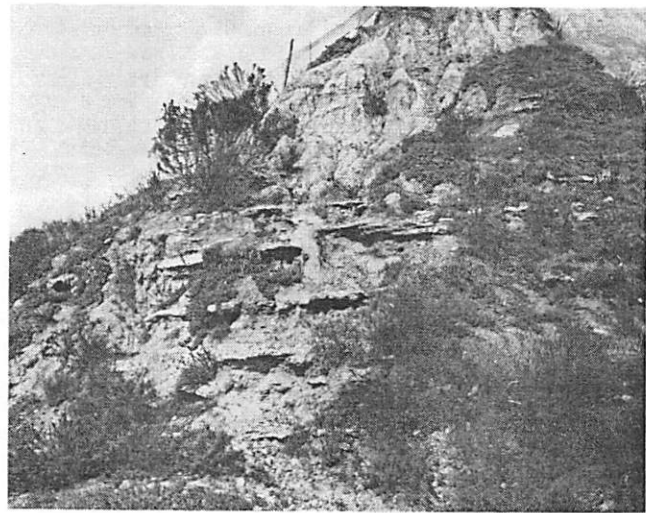


Figure 6. Outcrop of the ledge sandstone sequence of the "upper" San Diego Formation as exposed in Chollas Valley.

1967; Artim and Pinckney, 1973; Scheidmann and Kuper, 1979). These Miocene formations were mapped as Pliocene San Diego Formation by Hertlein and Grant (1939, 1944).

Concerning the lower contact of the San Diego Formation, the base is almost everywhere marked by a basal conglomerate or several conglomeratic layers, although in places the lower contact is beneath coarse-grained sandstone. Gastil and Higley (1977) have suggested that the base of the San Diego Formation is locally characterized by conglomerate-filled channels incised into the underlying formations. Good exposures of these basal channel-filling conglomerates can be seen along the east and west sides of Highway 163 near the 6th Avenue on-ramp (Threet, 1977).

BIOSTRATIGRAPHY

In addition to lithostratigraphic divisions of the San Diego Formation, there have also been attempts in the past to formulate biostratigraphic divisions of this unit. As already mentioned, Arnold (1903) proposed two faunal horizons for the San Diego Formation based on exposures at Pacific Beach. He recognized a "lower horizon" characterized by *Patinopecten healeyi*, *Pecten stearmsii*, *Opalia anomala*, and *Opalia varicostata* (*P. healeyi* being quite common); and an "upper horizon" characterized by *Pecten bellus* (replacing *P. stearmsii*), *Crepidula princeps*, *Dendraster ashleyi*, and rare *P. healeyi*. Arnold extended this two-fold division to strata on the San Diego Mesa, placing the "old well" section into his "lower horizon" and a section

near the old Russ School (now San Diego High School) in his "upper horizon".

Woodring et al. (1940) correlated the beds at San Diego with Pliocene rocks in the southern San Joaquin Valley and attempted to establish three faunal zones for the San Diego Formation. A lower zone from the area around the city of San Diego was characterized by a species of *Trophosycon*, a large form of "*Nassa*" *morani* (= *Nassarius grammatus*), and *Dosinia* (probably *Dosinia ponderosa diegoana*). They correlated this zone with the Lower Pliocene Jacalitos Formation. A middle zone was proposed which included the "old well" section and was characterized by *Siphonalia diegoensis* (probably *Kellettia kelletii*). This zone was tentatively correlated with the middle Pliocene Etchegoin Formation. An upper zone, which they felt was best exposed at Pacific Beach, contained *Dendraster diegoensis* (= *D. ashleyi*), *Merriamaster pacificus*, *Anadara trilineata* var., *Argopecten* sp., *Lyropecten cerrosensis*, and *Ostrea vespertina*. This zone was correlated with the Upper Pliocene San Joaquin Formation.

Woodring and Bramlette (1951) somewhat modified this earlier view and, although still recognizing a three-fold faunal division for the San Diego Formation, they placed the majority of the section including the "old well" in their upper zone. The primary reason for retaining the lower zones was the occurrence of *Trophosycon*. In the San Joaquin Valley this genus has its last reported occurrence within the Lower Pliocene Jacalitos Formation. Woodring and Bramlette suggested the possibility that *Trophosycon* may have lived longer at San Diego, possibly not becoming extinct there until the Late Pliocene. If this model was evoked then the San Diego Formation would fall entirely within the upper zone of Woodring and Bramlette (1951) and in their usage would correlate directly with the Upper Pliocene San Joaquin Formation.

The crux of the problem discussed above revolves around the fact that no detailed biostratigraphic study has yet been done of the San Diego Formation.

Gunther (1964) examined benthonic foraminiferal assemblages from two measured sections along the southern slopes of Mount Soledad and recognized two distinct faunas that corresponded to his lithologic subdivision of the San Diego Formation. Basically, Gunther detected environmental differences with his "lower siltstone member" containing an outer shelf to shelf edge, cold water fauna, and his "upper coarse-clastic member" containing an inner shelf, cold water assemblage.

Ingle (1967, 1970) examined both planktonic and benthonic foraminifers from the Pacific Beach section and recognized a warm water (20°C), outer shelf to shelf edge assemblage in the lower part of the section and a cold water (15°C), shallower assemblage in the upper part.

These foraminiferal data offer some means of biostratigraphically dividing the San Diego Formation. As an example, Mandel (1973) examined planktonic foraminifers from exposures of this rock unit near the U.S.-Mexico border, recognizing a decidedly warm water (22-26°C), outer shelf assemblage. Mandel was not aware of the work of Ingle (1970) and had only considered the planktonic data of Wicander (1970) when he suggested that the border section was younger than that at Pacific Beach. However, it

appears more likely that the border section is correlative with the warm water facies at Pacific Beach as recognized by Ingle (1970) and that the coarse-clastic member of Gunther (1964) is younger than both.

Recent examination of the macroinvertebrate fossils at Pacific Beach essentially seconds Arnold's original biostratigraphic division of this section. The mollusks agree with the scenario based on the foraminifers, i.e., that the section reflects successively shoaling and cooling conditions from the base to the top. This relationship is found in many outcrops of the San Diego Formation and together with the faunal indices represents a useful tool for recognizing a lower and upper portion of this rock unit.

Except for the enigmatic *Trophosycon*, all of the faunal zones of Woodring et al. (1940) and Woodring and Bramlette (1951) can be correlated to the "lower" San Diego Formation as first recognized by Arnold (1903) and re-established by Deméré (1982). The faunal zones of the Woodring group then become various facies within this part of the section. The true biostratigraphic significance of these facies has yet to be worked out.

Barnes (1976) has correlated the vertebrate bearing portion of the San Diego Formation ("lower" member) with the Blancan land mammal stage.

In terms of provincial correlation based on molluscan biostratigraphy, the "lower" San Diego Formation is equivalent to the Niguel Formation and the "upper" Fernando Formation in the southeastern Los Angeles Basin (Vedder, 1972), the Careaga Sandstone in the Santa Maria Basin (Woodring and Bramlette, 1951), and the San Joaquin Formation in the San Joaquin Basin (Woodring et al., 1940). Characteristic index species in the "lower" member include *Anadara trilineata*, *Pecten stearnsii*, *Patinopecten healeyi*, *Opalia varicostata*, and *Ophiodermella graciosa*.

The "upper" San Diego Formation is correlative with the lower portion (Member A) of the Santa Barbara Formation in the Ventura Basin. The subdivision of this rock unit into two faunal zones (an upper *Patinopecten caurinus* zone and a lower *Pecten bellus* zone) by Keen and Bentson (1944) allows for a refined correlation between their lower *Pecten bellus* zone and the "upper" member of the San Diego Formation. Characteristic index species in the "upper" San Diego Formation include *Pecten bellus*, *Argopecten hakei*, *Nucella lamellosa*, *Dendraster ashleyi*, and *Balanus gregarius*. Additional species found in the "upper" member but also occurring in the "lower" member include *Nuculana zaphria*, *Pododesmus macrochisma*, *Luciniscia nuttalli*, *Macoma inquinata*, *Tegula hemphilli*, *Tegula gallina*, *Crepidula princeps*, *Neverita reclusiana*, *Acanthina emersoni*, and *Thais transcosana*.

AGE

The age of the San Diego Formation has been variously fixed at Miocene, Pliocene, or Pleistocene; however, most workers assign it a Pliocene age. The exact position of this unit within the Pliocene has been a source of debate over the years. Arnold (1903, table on p. 13) placed his "lower" San Diego Formation, as recognized by contained molluscan fossils, in the Upper Pliocene. In turn, he placed his

"upper" San Diego Formation within the Lower Pleistocene. Unfortunately, Arnold did not discuss the details of these correlations. Grant and Gale (1931), using a three-fold subdivision of the Pliocene, placed the entire formation within the middle Pliocene based on the stratigraphic ranges of molluscan species. Woodring et al. (1940), as already discussed, correlated the San Diego Formation with Lower, middle, and Upper Pliocene rocks in the San Joaquin Valley using molluscan species. Again much of the fauna of the formation was placed in the Upper Pliocene while the presence of the enigmatic *Trophosyacon* suggested an Early Pliocene age. Grant and Hertlein (1943) and Hertlein and Grant (1944) referred the formation to the middle Pliocene. Woodring and Bramlette (1951) again placed much of the San Diego Formation in the Upper Pliocene except for the beds containing *Trophosyacon*. They noted that the middle Pliocene correlation of other workers was based primarily on the erroneous assignment of the Santa Barbara Formation and Timms Point Silt to the Upper Pliocene. Since both of these formations are younger than the San Diego Formation, their placement into the Upper Pliocene by some workers resulted in a middle Pliocene correlation for the San Diego Formation. Woodring (1952) placed his "upper part" of the San Diego Formation in the Upper Pliocene but did not discuss any further the enigmatic faunal aspect of his "lower part" of the formation. Vedder (1972) in discussing correlations between Pliocene rocks in the southeastern Los Angeles Basin (Niguel and Fernando Formations) and those in the San Diego Basin assigned an age of Late Pliocene to the San Diego Formation as exposed at Pacific Beach. These earlier correlations were based on fossil material collected primarily from what has herein been referred to as "lower" San Diego Formation rocks, which in terms of present West Coast usage are Late Pliocene in age. In addition, the correlation of the marine "upper" San Diego Formation with the lower Santa Barbara Formation suggests an age assignment of Late Pliocene or Early Pleistocene.

The Santa Barbara Formation is considered by most workers to be Early Pleistocene in age (Woodring, 1952), although Keen and Bentson (1944) have proposed that their *Pecten bellus* zone (basal Santa Barbara Formation) is probably latest Pliocene in age.

It is important to note that all of these correlations have been based on the stratigraphic ranges of molluscan and echinoid species and represent provincial age assignments. Recent work with planktonic foraminifers allows a tentative correlation of the local section to the more standard stratigraphy established by the Deep Sea Drilling Project (DSDP). This refined biostratigraphy has revealed some discrepancies in the provincial stratigraphy. Although it is almost certain that the San Diego Formation correlates directly with the San Joaquin Formation, it appears that both are, at least in part, Early Pleistocene in age. A. D. Warren (personal communication) believes, based on foraminifers, that the San Diego Formation is correlative with the Wheelerian Stage traditionally assigned to the provincial Upper Pliocene but Lower Pleistocene in terms of DSDP usage. Dean Milow (personal communication) assigns (based on calcareous nannoplankton) part of the formation to the Early Pleistocene *Emiliana annula* Subzone. Both of these opinions are based on samples from the Mount Soledad area which may correlate with the middle part of the Pacific Beach

section. As discussed above, the border exposures of the San Diego Formation are probably correlative with the lower part of the Pacific Beach section. Mandel (1973) assigned these border strata an age no older than planktonic foraminifer zone N-21 and suggested that they may be as young as Early Pleistocene. For the present, and until a more detailed biostratigraphic study can be carried out, it appears that the San Diego Formation can be considered, in DSDP usage, to be no older than Late Pliocene (N-21, approximately 3.0 million years B.P.) and at least as young as Early Pleistocene (*Emiliana annula* Subzone, approximately 1.5 million years B.P.).

It is interesting to note after all the study and debate of subsequent workers that Ralph Arnold back in 1903 had concluded a similar Late Pliocene/Early Pleistocene age assignment for the San Diego Formation, albeit based on a very different concept of these epoch divisions.

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