AN UPPER PLEISTOCENE MARINE FAUNA FROM MISSION BAY, SAN DIEGO, CALIFORNIA

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ABSTRACT.—Sixty-nine invertebrate species and one chordate have been collected from the upper Pleistocene Bay Point Formation on the northeast shore of Mission Bay in San Diego, California. This protected-bay assemblage lived in water depths of 1 to 2 m. Rocky-shore species at the base of the section were replaced by mudflat species as the initially deposited gravel and boulders were covered by sand and mud. The fauna includes three or four southern extralimital species; their paleoclimatic implications are not clear.

INTRODUCTION

The upper Pleistocene Bay Point Formation crops out in a number of small, isolated exposures on the lowest well-developed, emergent marine terrace (Nestor terrace of Ellis, 1919: pl. 6; La Jolla terrace of Hanna, 1926: 194-195) and at corresponding elevations in coastal embayments from Oceanside, California to northern Baja California. Marine fossil assemblages are preserved in several outcrops of this formation in the area of Mission Bay in northern San Diego (Fig. 1). Exposed-coast faunas occur at Pacific Beach (Valentine, 1961: 359-361, tables 19, 20) and Sunset Cliffs (Valentine and Meade, 1961: 11-13, table 2). Fossils at Crown Point, the type locality of the Bay Point Formation, lived on or near a barrier beach that protected the Pleistocene Mission Bay to the east from strong wave action (Valentine, 1959: 687); the present-day barrier is a mile farther west. Two small, sheltered-water faunas were reported by Stephens (1929: 253, 255), one from the northeast shore of Mission Bay (the railroad cut locality) and one from the south shore. Another sheltered-water fauna was described by Emerson and Chace (1959) from Tecolote Creek on the east shore. All the above localities are shown in Figure 1.

The sheltered-water fauna reported by Stephens (1929: 253) from the northeast shore of Mission Bay (railroad cut locality) has been referred to subsequently by Valentine (1959: 687; 1961: 359) and by Emerson and Chace (1959: 340), but this fauna has never been adequately studied. The locality is near the base of the steep northeastern slope of the present embayment, and the sediments here clearly were deposited close to the eastern shore of the Pleistocene Mission Bay. The purpose of this paper is to describe this fauna and discuss its paleoenvironmental implications.

San Diego State College locality 2276 (Figs. 1-3) is 230,600 ft. north and 1,704,800 ft. east in zone 6 of the California coordinate system (U.S. Geol. Surv. 7.5 minute La Jolla, California quad., 1967 ed.). It is in a low cut on the east side of the tracks of the Santa Fe Railroad between Morena Boulevard and Interstate 5. Fossils should not be collected from this locality without the permission of officials of the Santa Fe Railroad.

STRATIGRAPHY

At this locality the Bay Point Formation lies unconformably on Pliocene rocks of the San Diego Formation. From the lower part of the exposed Bay Point Formation we collected reworked Pliocene fossils including *Astrangia* sp., *Opalia varicostata* Stearns, and two unidentified species of the gastropod families Turridae and Thaididae.

The exposed Pleistocene section is approximately 2 m thick and is fossiliferous for a lateral distance of about 30 m (Figs. 2 and 3). At the base of the section are 60 to 70 cm of poorly sorted conglomerate containing sub-rounded boulders up to 60 cm in diameter. The matrix of the conglomerate is poorly consolidated, poorly sorted, predominantly coarse-grained, brown sand. The fossiliferous upper part of this bed is finer-grained, and

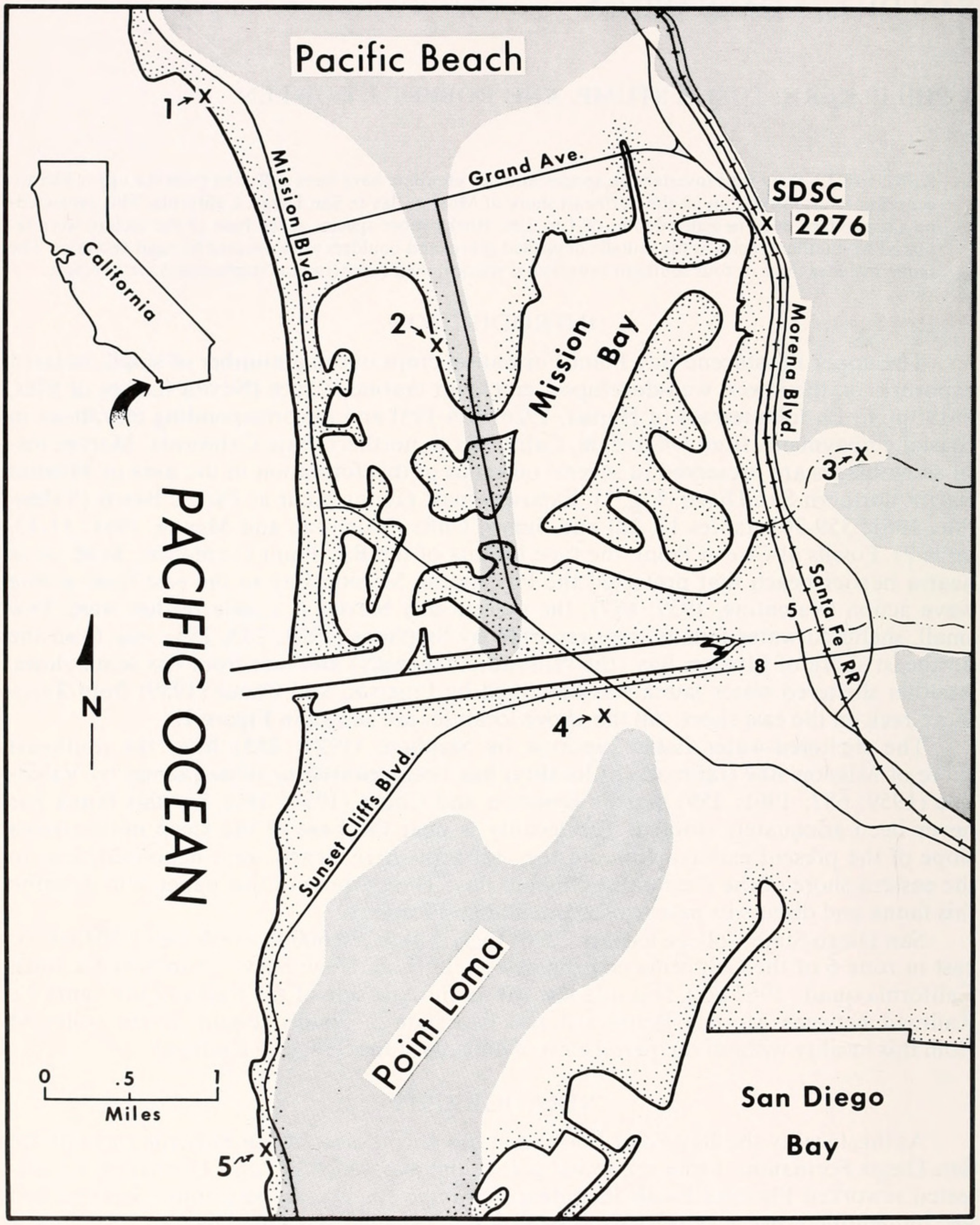

Figure 1. Map of the Mission Bay area showing the location of San Diego State College locality 2276 (Stephens' railroad cut locality) and other Bay Point Formation fossil localities at Pacific Beach (1), Crown Point (2), Tecolote Creek (3), south Mission Bay (4), and Sunset Cliffs (5). Inferred late Pleistocene land areas are shaded. The extension of the barrier beach south of Crown Point is based on the presence of sheltered-bay fossil faunas behind the barrier and the typical development of such barriers today. Probably the barrier was alternately open and closed.

the conglomerate grades rather abruptly upward into somewhat better sorted, poorly consolidated, fine-grained, brown sand. There is a slight upward decrease in grain size through the upper part of the section. Grain-size analyses for the beds described below are shown in Table 1.

Table 1. Sediment grain-size analyses made by the dry sieve method described by Folk (1968: 34-36). Ranges are given because two or more samples from each bed were analyzed.

	coarser than sand $< -1\phi$	*coarse sand* -1ϕ to 1ϕ	*medium sand* 1ϕ to 2ϕ	*fine sand* 2ϕ to 4ϕ	*silt and clay* $> 4\phi$
bed 3	1-4%	5-12%	12-22%	53-70%	9-12%
bed 2	2-6	4-7	22-31	54-60	4-12
bed 1	30-32	14-16	21-22	24-31	4-6
conglomerate	70	8	9	10	3

Fossils are distributed irregularly throughout the section above the lower part of the conglomerate. Collections were made from three rather arbitrarily defined stratigraphic intervals in order to evaluate temporal changes in the fauna. Bed 1 is a highly fossiliferous stratum in the upper 15 to 30 cm of the conglomerate (Fig. 3). Bed 2 is a poorly defined fossiliferous interval from 30 to 45 cm thick directly overlying bed 1. Bed 3 is an irregular stratum 30 cm thick and 15 cm above the top of bed 2.

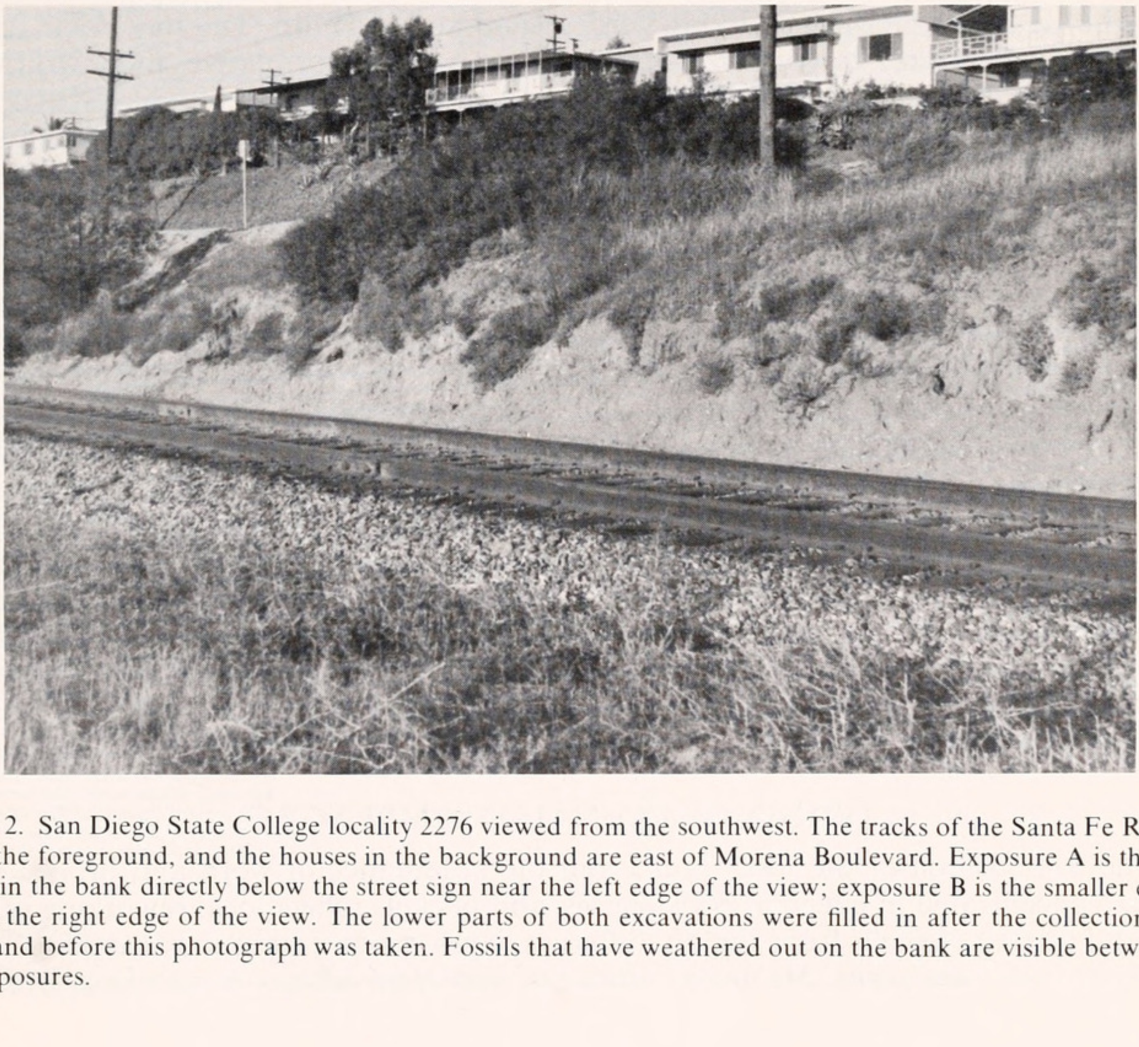

Figure 2. San Diego State College locality 2276 viewed from the southwest. The tracks of the Santa Fe Railroad are in the foreground, and the houses in the background are east of Morena Boulevard. Exposure A is the excavation in the bank directly below the street sign near the left edge of the view; exposure B is the smaller excavation at the right edge of the view. The lower parts of both excavations were filled in after the collections were made and before this photograph was taken. Fossils that have weathered out on the bank are visible between the two exposures.

METHODS AND FAUNAL LIST

Each bed was sampled at two exposures, designated A (at the northern end of the outcrop) and B (10 m to the south of A; Fig. 2). We collected 18 to 22 kg of sediment and fossils in each sample except the one from 2A, which was twice that size. Each sample was washed through a 10-mesh (2 mm) screen, and all identifiable fossil specimens were picked from the material retained in the screen. Sediment passing through the screen was examined for microfossils but none were found.

Sixty-seven species of mollusks, one chordate species, and borings of unidentified species of *Polydora*, an annelid, and *Cliona*, a sponge, have been identified. The distribution and abundance in the three beds of those species collected during this study are shown in Table 2. Also indicated in Table 2 are species present in earlier San Diego State College collections from this locality and in the collections of the San Diego Natural History Museum. The latter include at least part of Stephens' (1929: 253) collection from this locality, though we have not been able to find two of the species he listed, *Macoma calcarea* and *Phacoides californica*. His *Macoma* probably is *Psammotreta viridotincta*, which is common in his collection, but that collection now contains no specimens likely to be confused with *Phacoides* [= *Lucina*] *californica*.

AGE OF THE FAUNA

Odostomia diegensis is the only species in this fauna not known to be living. Addicott and Emerson (1959: 24) suggested that all essentially modern fossil faunas preserved at the lowest emergent terrace level in southern California probably are correlative with the regional type upper Pleistocene Palos Verdes Sand at San Pedro. The Bay Point Formation, which is deposited in part on this terrace, probably is correlative, then, with upper Pleistocene deposits at San Pedro, Cayucos, and San Nicolas Island that have been dated radiometrically at between 95,000 ± 15,000 and 140,000 ± 30,000 years (see discussion in Kern, 1971: 812). These faunas may have lived during Sangamon interglacial time or during an earlier interglacial episode.

ENVIRONMENT OF DEPOSITION

Environmental interpretations are based on distribution data for living species from Berry (1922), Oldroyd (1927), Grant and Gale (1931), Burch (1944-1946), Hertlein and Strong (1955), Morris (1966), Ricketts and Calvin (1968), McLean (1969), and Keen (1971). The fossil fauna is characteristic of the protected-bay environment, consistent with the probable paleogeographic setting of the locality (Fig. 1). However, the inferred coastline suggests that this shore was exposed to over a mile of open water behind the barrier beach, and several molluscan species also suggest that the fauna lived in a somewhat exposed part of the bay. *Littorina scutulata*, a common species at this locality, is most abundant today in the less protected parts of bays (Ricketts and Calvin, 1968: 237). *Lottia gigantea* and *Mopalia ciliata*, rare species in this fauna, are characteristic of a protected outer coast (Ricketts and Calvin, 1968: 26, 138), but they may occur rarely in the relatively exposed parts of bays.

ORIGIN OF FAUNAL ASSEMBLAGE

The composition of the fossil fauna and the abundance of worn and broken shells that are concentrated in irregular beds, lenses, and pockets reflect local reworking of sediment and mixing of shells from slightly different depth zones. *Littorina planaxis*, *L. scutulata*, *Assiminea translucens*, *Melampus olivaceus*, and *Heterodonax bimaculatus* live at or

Table 2. Distribution and abundance of fossil species in beds 1, 2, and 3 in two exposures at San Diego State College locality 2276. Numbers are pairs of bivalves and individual specimens of other fossils. The first two columns indicate species present in other collections at San Diego State College (SDSC) and at the San Diego Natural History Museum (SDNHM). Data on abundance and on distribution within the outcrop are not available for these collections.

Species	Collections							
	SDNHM	SDSC	1A	1B	2A	2B	3A	3B
Porifera								
Cliona sp.	X							
Annelida								
Polydora sp.	X							
Polyplacophora								
Mopalia ciliata (Sowerby, 1840)								1
Gastropoda								
Acmaea insessa (Hinds, 1843)		X						
Acmaea instabilis (Gould, 1846)					1			
Acmaea scabra (Gould, 1846)					1			
Lottia gigantea (Sowerby, 1833)		X			1			
Lucapinella callomarginata (Dall, 1871)	X	X				2		
Tegula gallina (Forbes, 1850)	X	X	10	13	3			1
Liotia fenestrata (Carpenter, 1864)		X						
Epitonium indianorum (Carpenter, 1864)		X						
Littorina planaxis (Philippi, 1847)		X						
Littorina scutulata (Gould, 1849)	X	X	31	26	25	25	3	3
Lacuna sp.		X						
Assiminea translucens (Carpenter, 1864)		X						
?Solariorbis sp.		X						
Alabina tenuisculpta (Carpenter, 1864)		X						
Cerithiopsis carpenteri (Bartsch, 1911)		X				1		
Cerithidea californica (Haldeman, 1840)	X	X		1	6	5	70	66
Hipponix tumens (Carpenter, 1864)			1					
Crepidula perforans (Valenciennes, 1846)		X						
Crepidula sp.			1					
Crepipatella lingulata (Gould, 1846)		X						
Eupleura muriciformis (Broderip, 1833)		X			2			
Morula lugubris (C. B. Adams, 1852)		X						
Anachis coronata (Sowerby, 1832)					3			
Mitrella carinata (Hinds, 1844)		X						
Nassarius tegula (Reeve, 1853)	X	X	48	24	428	112	25	28
Olivella biplicata (Sowerby, 1825)				1				
Conus californicus (Hinds, 1844)		X						
Odostomia diegensis (Dall & Bartsch, 1903)		X				13		
Peristichia pedroana (Dall & Bartsch, 1909)					1			
Pyramidella adamsi (Carpenter, 1864)		X	4		4	5		1
Turbonilla sp.		X						
Acteocina culcitella (Gould, 1853)		X	1		3	2		
Acteon punctocoelata (Carpenter, 1864)		X						
Melampus olivaceus (Carpenter, 1856)	X	X	1		10	10	5	9
Pedipes liratus (Binney, 1860)		X	5		2	10		2
Bivalvia								
Nucula aff. *N. exigua* (Sowerby, 1833)		X				2		1
Anadara multicostata (Sowerby, 1833)	X				1			
Septifer bifurcatus (Conrad, 1837)		X	12	17	5	6	1	1
Ostrea lurida (Carpenter, 1864)	X	X	35	15	3	10	1	10
Argopecten circularis (Sowerby, 1835)	X	X	1	2	4	2		1
Leptopecten latiauratus (Conrad, 1837)		X						
Lima sp.		X						
Anomia peruviana (Orbigny, 1846)			1	1	1			
Crassinella branneri (Arnold, 1903)		X			6	7	2	3
Lucina nuttallii (Conrad, 1837)	X	X	27	26	133	7		
Here excavata (Carpenter, 1857)	X							
Diplodonta sericata (Reeve, 1850)	X	X	12	5	190	415	75	42
Laevicardium substriatum (Conrad, 1837)		X						
Pitar newcombianus (Gabb, 1865)		X			2			
Chione californiensis (Broderip, 1835)	X	X	61	38	89	70		2
Chione fluctifraga (Sowerby, 1853)	X	X			9	2	3	13
Chione gnidia (Broderip & Sowerby, 1829)	X	X				3		
Callithaca staminea (Conrad, 1837)	X	X	9	35	15	43	9	15
Mactra californica (Conrad, 1837)		X			1			
Spisula cf. *S. hemphilli* (Dall, 1894)		X						
Tellina bodegensis (Hinds, 1844)	X	X	2	2	1			
Tellina meropsis (Dall, 1900)	X	X	5	8	42	110	22	18
Macoma nasuta (Conrad, 1837)		X						
Psammotreta viridotincta (Carpenter, 1856)	X	X	2		25	28		1
Cumingia californica (Conrad, 1837)	X							
Donax californicus (Conrad, 1837)		X						1
Heterodonax bimaculatus (Linnaeus, 1758)		X						
Tagelus californianus (Conrad, 1837)	X	X	2	1	110	45	65	18
Cryptomya californica (Conrad, 1837)		X				2	1	1
Corbula luteola (Carpenter, 1864)		X	1			2		
Corbula sp.								1
Chordata								
Myliobatis sp.					1			1

near high tide level where few other marine species live, and *Cerithidea californica* is most common on middle intertidal mud and sand flats where few other species are abundant. Yet at this locality these species are part of a rather diverse assemblage of invertebrates, most of which extend from the lower part of the intertidal zone into deeper water. Because of the relative turbulence of the intertidal zone, even in sheltered environments, such mixing of species from different intertidal levels is not unexpected.

Figure 3. Exposure A at San Diego State College locality 2276. The lower part of the excavation has been covered since the collections were made, and the basal conglomerate and bed 1 are no longer exposed. The abundant fossils in the lower part of the exposure are in bed 2, and the small lens of fossils higher in the exposure is in bed 3. The irregularity and discontinuity of these beds is evident. The pencil is 13 cm long.

However, in spite of this evidence for turbulent conditions and local reworking of sediment, there apparently was no large-scale sediment transport. With the few exceptions described below all the species in this fauna live in the intertidal zone of sheltered bays; thus there was no mixing of shells from widely different environments. *In situ* preservation of the majority of species is suggested by the presence of approximately equal numbers of right and left valves of several bivalve species and by high percentages of articulated specimens of *Lucina nuttallii, Diplodonta sericata, Chione californiensis, Psammotreta viridotincta,* and *Tagelus californianus.* The deeply burrowing *T. californianus* commonly is preserved in life orientation in these beds.

WATER DEPTH

This fauna clearly lived in sediments deposited in or very near the intertidal zone. The shoreline angle of the Nestor terrace in this area is not more than 2 or 3 m higher than the fossil-bearing beds. *Littorina scutulata, Cerithidea californica, Melampus olivaceus, Pedipes liratus,* and *Septifer bifurcatus* are relatively abundant and they are restricted today to the intertidal zone, as are the less abundant *Lottia gigantea, Lucapinella callomarginata, Littorina planaxis, Assiminea translucens,* and *Heterodonax bimaculatus.* All but four of the other species range from the intertidal zone into deeper water.

One of the four exceptions, *Crassinella branneri* is common in this fauna, and the genus has a reported depth range of 2 to 40 m (Keen, 1963: 105). *Psammotreta viridotincta,* also common, occurs today "mostly offshore in depths to 14 fathoms" (Keen, 1971: 231). However, the depth significance of this species is not clear because its present-day minimum depth is not known, and the change in its geographic range since late Pleistocene time (Table 3) suggests that its environmental tolerance limits may have changed. The collections also include four specimens each of *Nucula* aff. *N. exigua* and *Pitar newcombianus.* The former is known to live today in depths of 11 to about 2000 m (Keen, 1971: 26) and the latter in depths of 9 m or more (McLean, 1969: 78). Though these depth ranges are inconsistent with those described above, the few specimens of these two species do not warrant substantial modification of the suggested depth interpretation, especially in light of the questionable identity of the *Nucula.* However, the presence of these four apparently subtidal species in the fauna suggests that deposition may have occurred, at least in part, slightly below the intertidal zone.

Bed 3 contains fewer species than beds 1 and 2, and most of the abundant species in bed 3, including *Littorina scutulata, Cerithidea californica, Nassarius tegula, Melampus olivaceus, Chione fluctifraga,* and *Tagelus californianus,* today are restricted to or are most abundant in the intertidal zone. The other common species in bed 3, *Diplodonta sericata, Protothaca staminea,* and *Tellina meropsis,* are more abundant in bed 2, and these species are not restricted to or most abundant in the intertidal zone today. The four possibly subtidal species are uncommon in bed 3. Thus bed 3 apparently was deposited in the lower part of the intertidal zone, perhaps 1 m below mean sea level, and bed 1 was deposited in water perhaps 1 m deeper. Probably sea level was stable throughout the period of deposition, and the change in water depth reflects the thickness of sediments, about 1 m, deposited from bed 1 through bed 3. The base of the outcrop is approximately 14 m above present mean sea level, so sea level when these sediments were deposited probably was about 16 m higher than it is today. The shoreline angle of the Nestor terrace in this area is within 30 m to the east and no more than 2 or 3 m higher than locality 2276, suggesting that at this level the sea was close to its maximum extent on the terrace. The approximate position of the coastline at that sea level is shown in Figure 1.

The terrace deposits at Tecolote Creek (Fig. 1) are at a present elevation of 6 to 8 m at the base of the section and 14 to 16 m at the top. The fauna (Emerson and Chace, 1959: table 1) includes nearly all the intertidal species present at locality 2276, though their distribution within the section is now known. Possibly the lowest beds were deposited somewhat offshore in depths of 8 to 10 m and the highest beds, at about the same elevation as the beds at locality 2276, were deposited in or near the intertidal zone after this part of the basin had filled with sediments. Alternatively, sea level may have been rising during deposition of these sediments.

Valentine (1959: 685, 687) suggested that maximum sea level during cutting of the Nestor terrace at Crown Point, Pacific Beach, and Sunset Cliffs (Fig. 1) was between 60 and 70 feet (18 and 20 m) above present sea level and that the shallow-water assemblage at Crown Point, at a present elevation of 5 m at the bottom of the section and 9 m at the top, probably lived when the sea was well below its maximum extent on the terrace. This apparent difference in the sea levels under which these two faunas lived suggests that they may not have been contemporaneous.

SUBSTRATE

Stratigraphic faunal changes also reflect a temporal change in the substrate. *Tegula gallina, Littorina scutulata, Septifer bifurcatus, Ostrea lurida,* and *Anomia peruviana* live only or chiefly on hard substrates, and all are very abundant in bed 1 and are either rare or absent in beds 2 and 3. On the other hand, the characteristic mudflat species *Tagelus californianus, Cerithidea californica,* and *Melampus olivaceus* are rare in bed 1 and increasingly abundant in beds 2 and 3. Thus the stratigraphic change in faunal composition reflects both the decrease in water depth and the change from a coarse gravel and boulder substrate to mud.

CLIMATE

Species whose present-day geographic ranges end near or do not include San Diego are listed in Table 3 with their ranges. Six species do not live today south of the San Diego-Ensenada region, and a seventh lives only as far south as Bahía San Quintín. The questionably identified *Spisula hemphilli* also lives only as far south as Ensenada. Seven species live only as far north as the San Diego-Los Angeles region. The overlapping present-day ranges of these 14 species suggest that the late Pleistocene shallow-water marine climate in which they lived was similar to that at the same latitude today.

However, the assemblage also contains several southern extralimital species, species that do not live today as far north as San Diego (Table 3). *Anachis coronata, Psammotreta viridotincta,* and *Chione gnidia* live only as far north as Laguna Scammon or Isla de Cedros (28° north latitude). *Eupleura muriciformis* also is reported to live today only as far north as Isla de Cedros, though Hertlein and Strong (1955: 258) included in its synonymy *Ranella triquetra* Reeve, 1844 from San Diego. Both *Eupleura muriciformis* and

Table 3. Species with geographic ranges that end near or do not include the San Diego area.

Species	Geographic Range
Acmaea instabilis	Alaska to San Diego (Morris, 1959: 57)
Hipponix tumens	Crescent City to San Diego (Oldroyd, 1927, 2 (3): 113-114)
Mopalia ciliata	Alaska to Bahia Todos Santos (Berry, 1922: 449-451)
Epitonium indianorum	Alaska to Bahia Todos Santos (Oldroyd, 1927, 2 (2): 58)
Assiminea translucens	Vancouver to Punta Banda (McLean, 1969: 28)
Callithaca staminea	Alaska to Bahia San Quintin (Grant and Gale, 1931: 329)
Spisula cf. *S. hemphilli*	Santa Barbara to Ensenada (McLean, 1969: 82)
Cerithiopsis carpenteri	San Pedro to South Coronado Island (Oldroyd, 1927, 2 (2): 253)
Alabina tenuisculpta	San Pedro to Magdalena Bay (Oldroyd, 1927, 2 (3): 14)
Nucula aff. *N. exigua*	Los Angeles to Ecuador (Burch, 1944-1946, no. 33: 7)
Anadara cf. *A. multicostata*	Newport Bay to Galapagos Islands (Keen, 1971: 48)
Morula lugubris	San Diego to Panama (Keen, 1971: 554)
Pedipes liratus	San Diego to Golfo de California (Oldroyd, 1927, 2 (1): 54)
Crassinella branneri	San Diego to Panama (Oldroyd, 1927, 1: 110)
Eupleura muriciformis	(San Diego ?) Isla de Cedros to Lobitos, Peru (Hertlein and Strong, 1955: 258)
Anachis coronata	Laguna Scammon to Ecuador (San Diego Natural History Museum Coll.)
Chione gnidia	Isla de Cedros to Peru (Keen, 1971: 188)
Psammotreta viridotincta	Laguna Scammon to Costa Rica (San Diego Natural History Museum Coll.)

Chione gnidia are rare in this assemblage, but the other two species are rather abundant. Two additional uncommon species, *Crassinella branneri* and *Nucula* cf. *N. exigua,* have been regarded in some studies as southern extralimital species, though there are conflicting records on their geographic ranges; both species have been reported in the San Diego area. Thus there apparently are three or four species in this fauna that do not live today in the San Diego region or in the area of overlap of the present-day geographic ranges of all the other species in the assemblage.

The paleoclimatic significance of extralimital species has been discussed by Emerson (1956: 326-327), Valentine (1955: 465-468; 1961: 393-400), Kern (1971: 819-820; in press), and others. Southern extralimital species commonly have been interpreted as indicating that shallow-water marine climates have been substantially warmer in the past than today, at least locally. However, the presence in this fauna of seven or eight molluscan species that do not live today south of the San Diego region suggests that the late Pleistocene marine climate in this area was not as warm as the climate at Laguna Scammon and Isla de Cedros today. The geographic ranges of these and the extralimital species do not overlap today, and paleoclimatic interpretations based on assumed thermal limitations of their ranges must involve more complex changes than simple warming or cooling. It must also be recognized that some of these species may have changed physiologically and ecologically since late Pleistocene time, and some of them may be limited geographically by factors other than water temperature (see discussion in Kern, in press).

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