

# Zoogeography of Holocene Ostracoda off Western North America and Paleoclimatic Implications

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 916





# Zoogeography of Holocene Ostracoda off Western North America and Paleoclimatic Implications

By PAGE C. VALENTINE

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*Holocene ostracode distribution related  
to marine climatic conditions off the  
coasts of the United States and Baja  
California, Mexico; paleoclimatic  
interpretation, Pliocene and Pleistocene  
marine deposits, southern California*



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# ZOOGEOGRAPHY OF HOLOCENE OSTRACODA OFF WESTERN NORTH AMERICA AND PALEOCLIMATIC IMPLICATIONS

By PAGE C. VALENTINE

## ABSTRACT

Holocene shelf samples (255) from off the west coasts of the United States and Baja California, Mexico, yielded 341 species of ostracodes. The distributions of biogeographically diagnostic species are established. Species present within each 15-minute segment of latitude constitute samples which are compared on the basis of their faunal composition. Cluster analysis of 110 samples containing 192 ostracode species from the continental shelf between 21°43' N. and 48°24' N. permits recognition of four faunal provinces which are similar to modern molluscan provinces of the eastern Pacific. The existence of subprovinces is also evident from this analysis. Faunal distributions and faunal provinces are principally controlled by marine climate, especially water temperature. Seasonal climatic changes and the influence of the California Current, in conjunction with intense seasonal upwelling, are responsible for the configuration of marine isotherms off these coasts. The faunal discontinuity at the Oregonian-Californian provincial boundary (35°30' N.) is characterized by range terminations of many northward ranging thermophiles, and nine important southern genera do not occur north of this boundary; many southward ranging cryophiles terminate their ranges at the Californian-Surian boundary (28°15' N.).

Large, well-preserved fossil ostracode assemblages were studied from six Pliocene or Pleistocene formations from southern California. These are the San Diego Formation, San Pedro Formation (Lomita Marl and Timms Point Silt Members), Palos Verdes Sand, Santa Barbara Formation, Foxen Mudstone, and the Careaga Sandstone. Of 123 diagnostic species found in these units, only 19 are not known to be living today. Although most fossil species, therefore, have living representatives, a cluster analysis reveals no marked similarity between living and fossil assemblages, and this disagreement is probably the result of an alteration in the marine climate. Comparison of the temperature tolerances of species common to the Holocene and to fossil assemblages yields yearly temperature maxima and minima that could have occurred during deposition of the fossil units. These paleotemperature determinations indicate that all fossil assemblages are representative of a warm temperate marine climate which was broadly similar but not necessarily identical to that present today in the Californian faunal province offshore of the fossil localities.

## INTRODUCTION

The first part of this study is an investigation of the zoogeography of the modern podocypid Ostra-

coda found on the shelf off the west coasts of the United States and Baja California, Mexico. The ostracodes of the west coast of North America are not well known, and this report is an attempt to establish the geographic distribution of important ostracode species, to identify distributional patterns, and to determine factors influencing these patterns. The results of this study are intended to aid in establishing a basis for future studies involving ostracode zoogeography, paleocology, biostratigraphy, and taxonomy.

The second part of this report seeks to apply the results of the zoogeographic study to an interpretation of the paleoclimates of selected Pliocene and Pleistocene marine deposits of southern California which contain large, well-preserved ostracode assemblages. The large size of the total fauna (373 species), only a fraction of which have been described, precludes a taxonomic study at this time. Many important species are illustrated, however, and illustrated specimens have been deposited in the collections of the U.S. National Museum, Washington, D.C.

## ACKNOWLEDGMENTS

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Many people have assisted me in obtaining samples, and sample sources are listed in table 1. I would like to thank in particular G. A. Fowler, formerly of Oregon State University; R. L. Kolpack, University of Southern California; F. B. Phleger, Scripps Institution of Oceanography; E. E. Welday, California Division of Mines and Geology; and the Department of Oceanography, University of Washington, for generously providing me with samples from their collections and for allowing me to use

their laboratories during my visits. I also wish to thank R. J. Enrico and G. S. Zumwalt of the Department of Geology, University of California at Davis for furnishing me with many valuable samples. I am grateful to both J. C. Ingle, Stanford University, for permitting me to examine L. W. LeRoy's type specimens, and to Dustin Chivers of the California Academy of Sciences for allowing me to examine T. Skogsberg's types.

The scanning electron micrographs were taken by R. W. Wittkopp and R. L. Gertman of the Department of Geology at Davis and printed by Kenji Sakamoto of the U.S. Geological Survey, and their assistance is greatly appreciated. I am indebted to Lanci Valentine who assisted in processing many of the samples and drafted the original illustrations.

#### OSTRACODE ZOOGEOGRAPHY OFF THE WEST COAST OF THE UNITED STATES AND BAJA CALIFORNIA, MEXICO

##### PREVIOUS STUDIES

In contrast to other groups, notably the Mollusca and the Foraminifera which have been intensively studied on the west coast, few investigations of the ostracode assemblages of this region have been undertaken. Most studies of Holocene forms are of a local nature, restricted to assemblages of bays and estuaries, chiefly in Baja California and Central America.

The following papers have listed or described ostracode species from off the west coasts of Mexico and Central America. Benson (1959) reported on the fauna (46 species) of Todos Santos Bay, Baja California, and Benson and Kaesler (1963) on that (16 species) of an estuary and a lagoon in the north-eastern Gulf of California. Swain (1967) treated the ostracodes (91 species) of the Gulf of California; McKenzie and Swain (1967) described the fauna (52 species) of Scammon Lagoon, Baja California, and Swain and Gilby (1967) the fauna (37 species) of Corinto Bay, Nicaragua. Hartmann (1953, 1956, 1957, 1959) studied ostracodes (55 species) from estuaries and coastal regions of El Salvador, and Ishizaki and Gunther (1974) reported on 31 species from the Gulf of Panama.

As a result of these studies, the fauna of the southern regions is better known than that to the north off the United States and Canada. Juday (1907) described two species from the San Diego area. LeRoy (1943a, b; 1945) reported on 27 species found in Pliocene and Pleistocene deposits of south-

ern California and also living along that coast. Skogsberg (1928, 1950) studied seven species of the Monterey Peninsula, and Watling (1970) two species from Tomales Bay. Lucas (1931) and Smith (1952) recorded 32 species from the Vancouver Island region of British Columbia.

With the exception of Swain's (1967) Gulf of California paper, the studies cited above all deal with local assemblages, and while they are a valuable contribution to an understanding of elements of the west coast fauna, no zoogeographic study of broad areal extent had been conducted until Swain (1969) analyzed samples from off the west coasts of the United States and Baja California. Swain's report, however, is based on only 40 samples (94 species) and is of a preliminary nature. In a recent paper, Swain and Gilby (1974), using essentially the same samples studied by Swain in 1969, have described 80 species (16 of them new) and indicated their distribution off the west coasts of the United States, Baja California, and Nicaragua.

Fossil ostracode species have been listed or described only from California and Alaska. In addition to LeRoy's papers, mentioned above, Crouch (1949) reported on 29 species from the Pliocene (and Pleistocene) of southern California; Triebel (1957) described five new species and Hazel (1962) two new species from the Pleistocene of that region. Hazel (in Addicott, 1966) listed 15 species from the late Pleistocene of central California. Swain (1963) treated 43 species from the Pleistocene of the Arctic Coastal Plain of Alaska, and Schmidt (1963, 1967) and Schmidt and Sellmann (1966) also reported on several forms from the Pleistocene of Alaska.

In the area presently under study, which includes the shelf off the west coasts of the United States and Baja California and a coastline of about 2,000 miles, only 141 species have been described from the Holocene, Pleistocene, and Pliocene, the total fauna of which is approximately 400 species.

The following investigations of Holocene and fossil ostracode assemblages from the eastern Pacific and coasts of North, Central, and South America, the Caribbean Sea, and the coasts of Japan were used in identifying the species found during this study: Benson (1959); Benson and Kaesler (1963); Bold (1963); Coryell and Fields (1937); Crouch (1949); Hanai (1957a, b, c, 1959a, b, 1961, 1970); Hartmann (1953, 1956, 1957, 1959, 1962, 1965); Hazel (1962); Ishizaki (1966, 1968, 1969, 1971); Ishizaki and Gunther, 1974; Juday (1907); Leroy (1943 a, b; 1945); Lucas (1931); McKenzie and Swain (1967); Morkhoven (1963); Ohmert (1968,

1971); Pokorný (1968, 1969, 1970); Schmidt (1963, 1967); Schmidt and Sellmann (1966); Skogsberg (1928, 1950); Smith (1952); Swain (1963, 1967, 1969); Swain and Gilby (1967, 1974); Triebel (1957); and Watling (1970).

#### HOLOCENE COLLECTIONS

Holocene samples for this study were collected from the continental shelf off the west coasts of the United States and Baja California from about 21°43' N. to 48°24' N. (figs. 1-4). The size of the area under study made it impossible to procure uniform, original samples for this report. Consequently, the samples were assembled from many sources and were collected and processed in various ways. It is felt that the large number of samples (255) from which ostracodes were identified provides adequate coverage for the purpose of this study. The collections are chiefly from the inner sublittoral, although several samples were collected from greater depths, and some are from tide pools, intertidal areas, and beach swash zones. The source, geographic location, and depth of the samples used in this study are presented in table 1.

The number of Holocene species distinguished is 341. Many of these species are rare, however, and their distributions are not well known. As this study is concerned with and based on species distributions, the inclusion of poorly known species would distort any distributional patterns which exist. Therefore, 192 well-known species, all of which are living off the coast today, are utilized in the zoogeographic study. Living or recently dead specimens were found in most samples examined. Groups not treated in the study include xestoleberids, paradoxostomatids, Cypridacean ostracodes, and the genus *Cytherura*.

#### DISTRIBUTION OF MARINE ORGANISMS

Studies of the distribution patterns of shallow-water organisms (chiefly Mollusca, but also other marine invertebrates) indicate that distinctive assemblages are characteristic of particular regions of the shelf. These regions, or faunal provinces, have been identified on continental shelves throughout the world. Those of the northeastern Pacific have recently been reviewed and analyzed by J. W. Valentine (1966, 1973). Hazel (1970) traces the historical development of the faunal province concept and treats the provinces of the North Atlantic in detail. Provincial boundaries are recognized where shelf assemblages, diagnostic over a broad geographic area, alter their composition because of the termina-

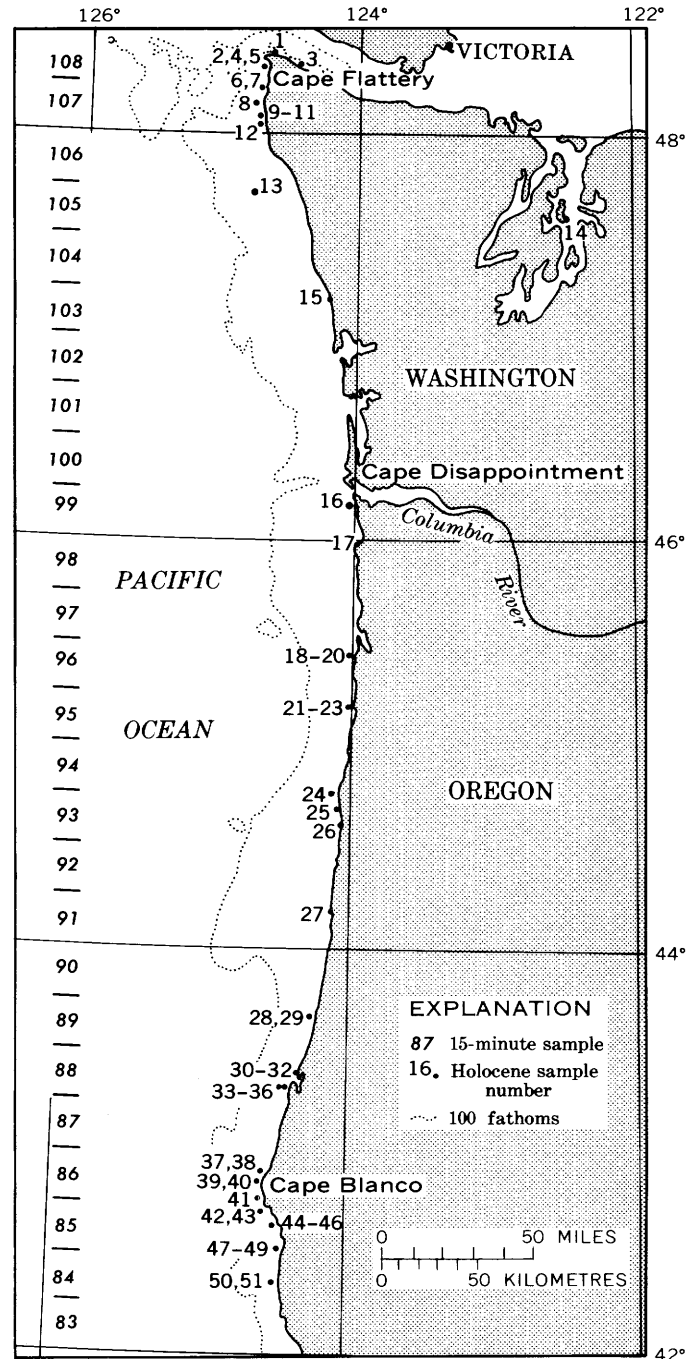


FIGURE 1.—Locations of Holocene sample stations, Cape Flattery, Wash., to the California-Oregon border. For exact location see table 1.

tion of species ranges and the appearance of forms ranging in from neighboring provinces. These boundaries mark distributional discontinuities which are controlled by environmental factors.

Marine invertebrates cannot control their body temperature, and the rates of their physiological processes are directly influenced by the ambient

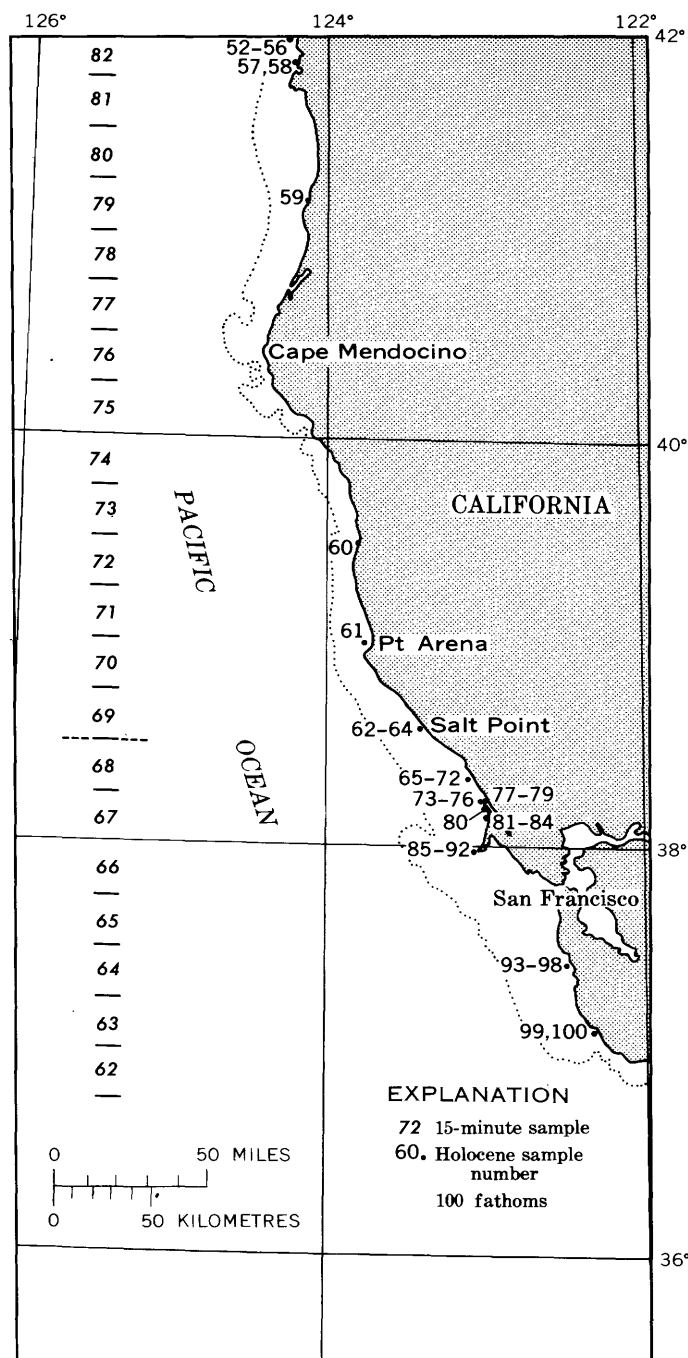


FIGURE 2.—Locations of Holocene sample stations, California-Oregon border to Point Año Nuevo, Calif. For exact location, see table 1. Dashed lines between 15-minute samples indicate ostracode faunal (sub)province boundaries.

water temperature. An increase in temperature of  $10^{\circ}\text{C}$  can cause a twofold to threefold increase in the rates of these processes in marine poikilotherms. And as the rates of different metabolic processes may not increase or decrease in concert, a marked change in water temperature can disrupt the har-

mony in which the processes operate. Water temperature is considered the fundamental factor limiting species distribution (Gunter, 1957; Kinne, 1963; J. W. Valentine, 1973); its importance is demonstrated by the fact that marine sublittoral province boundaries are often located where isotherm convergence causes a steep temperature gradient to occur seasonally or annually within a short geographic distance. Such a temperature gradient may act as a survival barrier if it incorporates the lethal temperature of a species. Water temperature may also act as a repopulation barrier to organisms whose reproduction and larval development must occur in a temperature range which lies within the range of their maximum temperature tolerances (Hutchins, 1947).

Other environmental factors also influence the distribution of marine organisms and especially the composition, structure, and function of marine communities (Margalef, 1968; J. W. Valentine, 1971, 1973). These factors include salinity, turbulence, turbidity, substrates, light intensity, and nutrient supply. Since these determinants are developed to differing degrees along the shelves, it follows that community attributes should also vary in this direction; therefore, faunal provinces could be characterized by their community types as well as by their faunal assemblages, which are really collections of communities (J. W. Valentine, 1968, 1973). This ideal has not been achieved, however, perhaps because few quantitative determinations of community composition and response to environmental factors have been made. Indeed, faunal province assemblages are at present not readily characterized by their relation to any of the physical factors mentioned above with the exception of water temperature. Other factors have less direct influence on most species ranges over the broad areas and diverse habitats of the continental shelves.

The role of the marine climate in influencing the establishment of faunal provinces is evident in that each geographic faunal province is associated with a climatic term expressing in a qualitative way the nature of the marine climate in that province. From south to north the northern hemisphere climatic zones are: tropical, subtropical, warm-temperate, mild-temperate, cold-temperate, subfrigid, and frigid. Depending on the interactions of factors controlling the marine environment, one or more of these zones (and provinces) may not be developed. Seemingly as a result of the influence of marine temperature, then, distributional patterns of marine

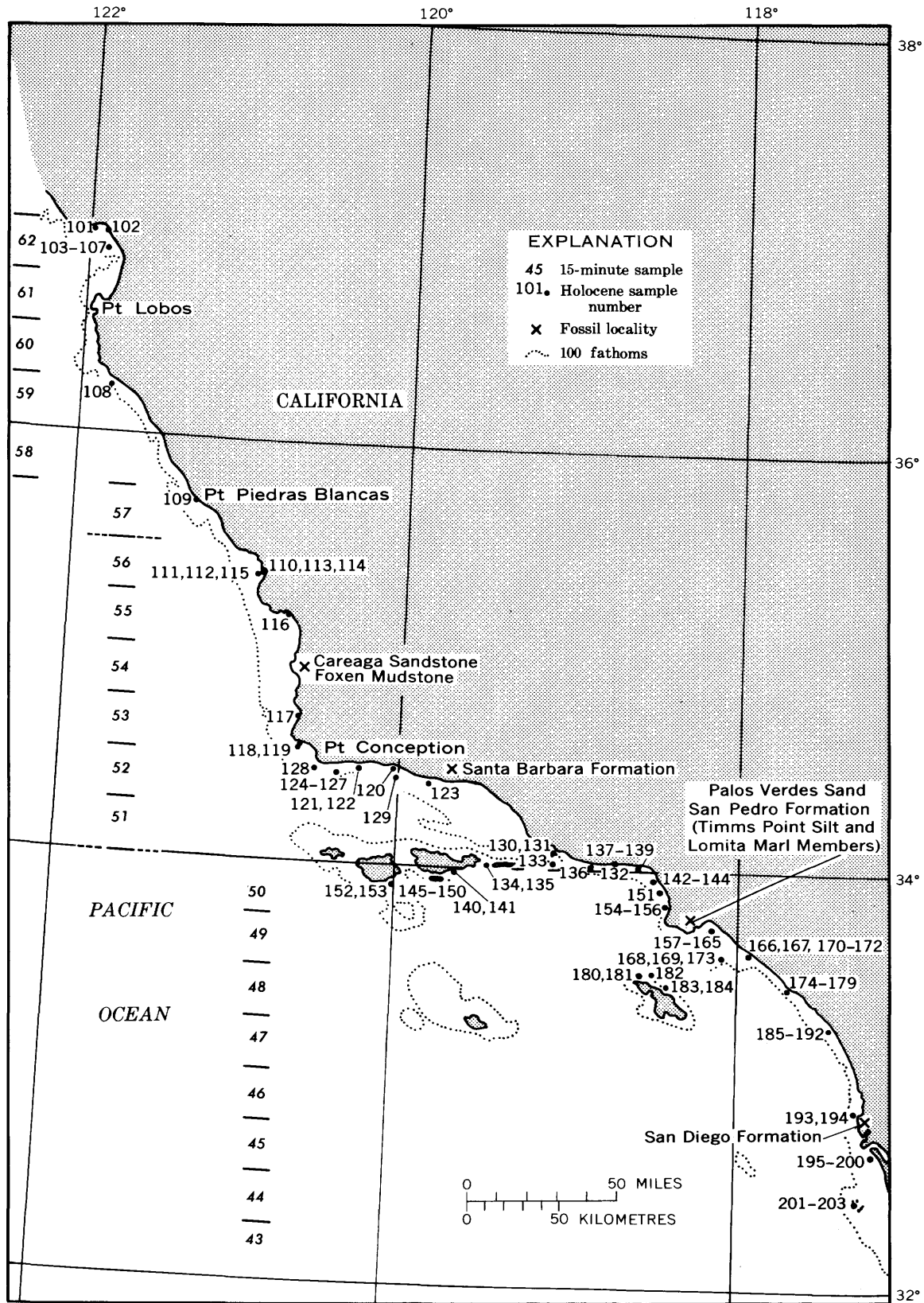


FIGURE 3.—Locations of Holocene sample stations, Point Año Nuevo, Calif., to San Diego, Calif. For exact location, see table 1. Dashed lines between 15-minute samples indicate ostracode faunal (sub) province boundaries.



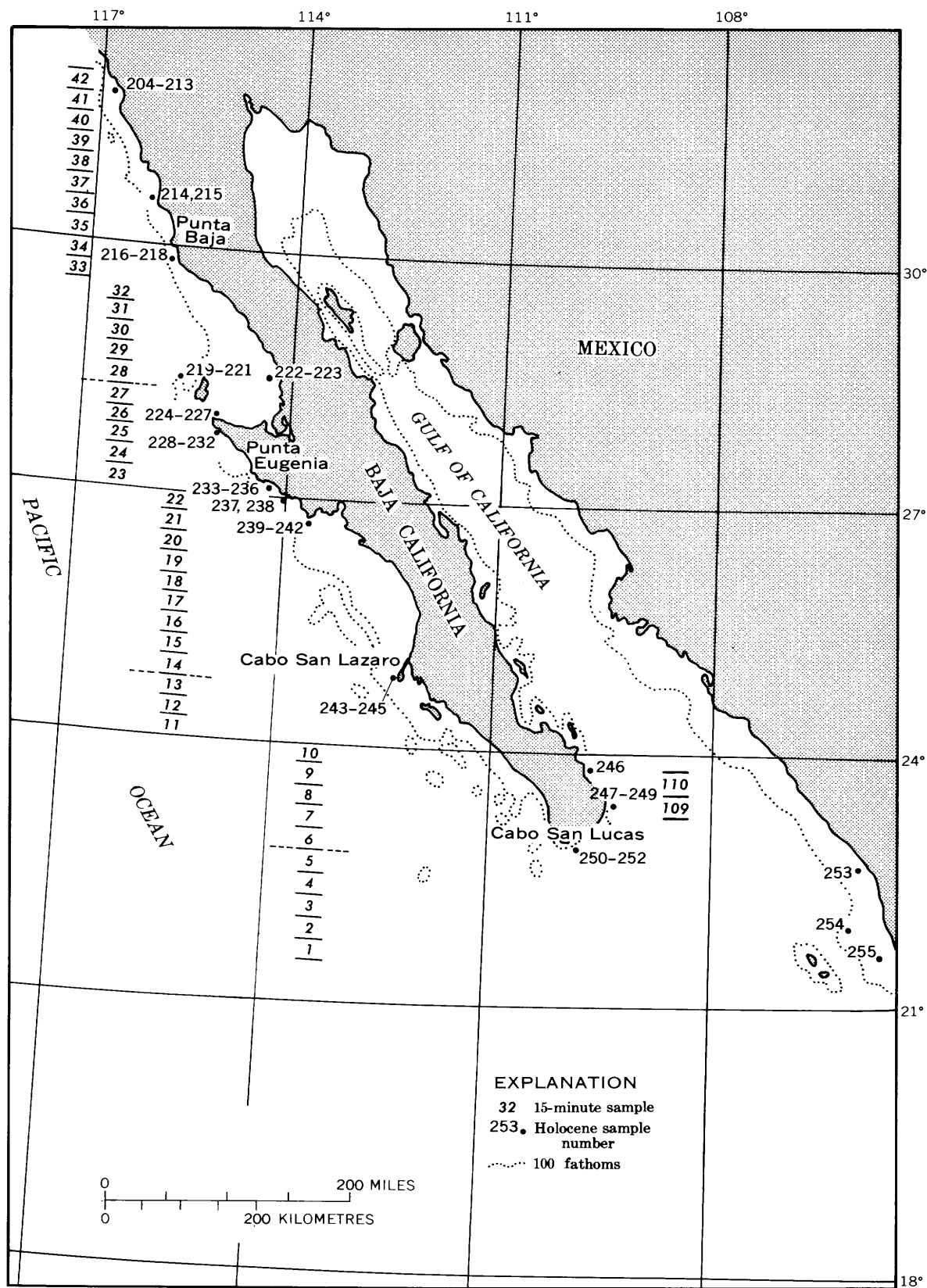


FIGURE 4.—Locations of Holocene sample stations, San Diego, Calif., to south of Cabo San Lucas, Baja California, Mexico. For exact location, see table 1. Dashed lines between 15-minute samples indicate ostracode faunal (sub) province boundaries.

TABLE 1.—Location and source of Holocene samples from the shelf off the west coast of the United States and Baja California, Mexico, and 16 Pliocene or Pleistocene samples from southern California.

<b>Source.—</b>			
UW:	Samples obtained from the collections of the Univ. Washington through the courtesy of the Dept. Oceanography. Collections made in 1967 on <i>Oceaner</i> Cruise No. 14 by T. L. Burrett (1967).	M, V, Z:	made in 1970-71 on cruises of the <i>Velero IV</i> supported by National Science Foundation Grant GB-8206, the National Sea Grant Program, U.S. Dept. Commerce Grant GH-89, and the Western Oil and Gas Association.
SB:	Sample obtained from Sarah Barnes, Dept. Oceanography, Univ. Washington.	TZ, C:	Samples collected in 1972-73 by Page Valentine and Lanci Valentine.
F:	Samples obtained from the collections of G. A. Fowler, Dept. Oceanography, Oregon State Univ.	JH:	Samples obtained from the collections of the Scripps Institution of Oceanography through the courtesy of F. B. Phleger, Geological Research Division. TZ samples were collected in 1962 by R. R. Lankford (1962), and C samples were collected by J. R. Curry, Scripps Institution of Oceanography.
CQR:	Samples obtained from W. N. Orr, Dept. Geology, Univ. Oregon.		Samples collected by John Holden, N.O.A.A. Research Laboratory and obtained from J. E. Hazel, U.S. Geological Survey.
FP:	Sample obtained from F. B. Phleger, Scripps Institution of Oceanography.		USGS Cenozoic sample localities Mf2165-2180—Pliocene and Pleistocene of southern California collected in 1971 by Page Valentine and J. W. Valentine, Department of Geology, University of California, Davis; J. H. Lipps of the same department provided sample Mf2170.
EZ, RE, ZUM:	Samples collected in 1972-73 by R. J. Enrico and G. S. Zumwalt, Dept. Geology, Univ. California, Davis.		
BHL:	Samples obtained through the courtesy of Pat Wilde and Ken Leslie from the collections of the Hydraulic Engineering Lab, Univ. California, Berkeley.		
CDM:	Samples obtained through the courtesy of E. E. Welday from the collections of the California Division of Mines and Geology.		
USC:	Samples obtained from the collections of the Univ. Southern California through the courtesy of R. L. Kolpack, Dept. Geological Sciences. Collections were		

Depth.—

B=beach swash zone.

IT=intertidal.

TP=tide pool.

Sample		Location			
No.	Source	Geographic	Lat north	Long west	Depth (metres)
1----	UW 146	Cape Flattery, Wash	48°24'	124°40'	80
2----	UW 136	do	48°21'	124°45'	47
3----	UW 150	do	48°21'	124°32'	17
4----	UW 153	Waatch Point	48°20'	124°42'	20
5----	UW 154	Mukkaw Bay	48°19'	124°41'	17
6----	UW 125	Point of the Arches	48°15'	124°42'	17
7----	UW 162	do	48°14'	124°43'	28
8----	UW 163	Cape Alava	48°10'	124°45'	16
9----	UW 112	do	48°06'	124°42'	23
10----	UW 165	do	48°06'	124°42'	11
11----	UW 111	do	48°05'	124°43'	13
12----	UW 109	do	48°04'	124°44'	30
13----	UW 197	Destruction Island	47°41'	124°47'	11
14----	SB 1	Blakely Rock	47°35'	122°28'	15
15----	V 22	South of Pacific Beach	47°12'	124°12'	B
16----	F 6508-58	Columbia River	46°10'	124°01'	18
17----	V 20	Tillamook Head, Ore	45°58'	123°56'	B
18----	F 6508-14	Netarts Bay	45°25'	124°00'	37
19----	F 6508-15	do	45°25'	124°02'	55
20----	F 6508-16	do	45°25'	124°04'	73
21----	F 6405-37	Nestucca Bay	45°10'	124°04'	64
22----	F 6405-38	do	45°10'	124°01'	29
23----	F 6405-39	do	45°10'	123°59'	15
24----	TZ 86	Depoe Bay	44°48'	124°04'	21
25----	V 18	Newport	44°40'	124°04'	B
26----	V 16	do	44°35'	124°04'	B
27----	V 17	Heceta Head	44°09'	124°06'	B
28----	F 6410-21	Umpqua River	43°40'	124°14'	27
29----	F 6410-22	do	43°40'	124°14'	52
30----	V 19	Coos Head	43°20'	124°22'	B
31----	CQR 382	Sunset Bay	43°20'	124°22'	TP
32----	CQR 462	do	43°20'	124°22'	TP
33----	F 6505-49	Cape Arago	43°16'	124°24'	22
34----	F 6505-50	do	43°16'	124°25'	40
35----	F 6505-51	do	43°16'	124°27'	52
36----	F 6505-53	do	43°16'	124°29'	74
37----	F 6505-83	Cape Blanco	42°53'	124°35'	47
38----	F 6505-84	do	42°53'	124°34'	18
39----	F 6505-91	do	42°50'	124°37'	43
40----	V 21	do	42°50'	124°33'	B
41----	F 6505-92	do	42°47'	124°37'	65
42----	F 6505-103	South of Cape Blanco	42°44'	124°31'	30
43----	F 6505-104	do	42°41'	124°27'	21
44----	F 6505-117	do	42°38'	124°27'	55
45----	F 6505-118	do	42°38'	124°25'	28
46----	F 6505-119	do	42°35'	124°24'	23
47----	F 6505-134	do	42°32'	124°31'	50
48----	F 6505-135	do	42°32'	124°28'	39
49----	F 6505-137	do	42°29'	124°29'	35
50----	F 6505-152	do	42°23'	124°26'	22
51----	F 6505-153	do	42°23'	124°28'	39
52----	F 6511-39	California-Oregon border	41°59'	124°14'	18

TABLE 1.—Location and source of Holocene samples from the shelf off the west coast of the United States and Baja California, Mexico, and 16 Pliocene or Pleistocene samples from southern California—Continued

Sample		Location			
No.	Source	Geographic	Lat north	Long west	Depth (metres)
53----	F 6511-40	California-Oregon Border	41°59'	124°16'	24
54----	F 6511-41	----do	41°59'	124°17'	27
55----	F 6511-42	----do	41°59'	124°18'	37
56----	F 6511-43	----do	41°59'	124°20'	43
57----	V 15	Crescent City, Calif	41°44'	124°10'	B
58----	FP 1	----do	41°44'	124°10'	B
59----	V 5	Patrick's Point	41°08'	124°10'	IT
60----	V 4	Laguna Point	39°30'	123°48'	TP
61----	F 7002-26	Point Arena	39°01'	123°43'	37
62----	ZUM 1	Salt Point	38°34'	123°20'	12
63----	ZUM 2	----do	38°34'	123°20'	9
64----	ZUM 3	----do	38°34'	123°20'	9
65----	V 2	Bodega Head	38°19'	123°04'	TP
66----	V 3	----do	38°19'	123°04'	TP
67----	RE 3	Horseshoe Cove	38°19'	123°04'	6
68----	RE 2	Bodega Harbor	38°18'	123°03'	IT
69----	BHL 1165	Bodega Bay	38°18'	123°03'	5
70----	BHL 1166	----do	38°18'	123°02'	5
71----	BHL 1168	----do	38°18'	123°02'	5
72----	BHL 1164	----do	38°17'	123°03'	10
73----	BHL 802	Tomales Point	38°15'	123°00'	20
74----	BHL 804	----do	38°15'	122°59'	18
75----	BHL 805	----do	38°15'	122°59'	13
76----	BHL 806	----do	38°15'	122°58'	11
77----	BHL 782	Bodega Bay	38°15'	122°57'	IT
78----	BHL 785	----do	38°14'	122°58'	IT
79----	BHL 786	----do	38°14'	122°58'	IT
80----	BHL 800	South of Tomales Point	38°13'	123°01'	49
81----	BHL 1182	----do	38°11'	122°59'	38
82----	F 7002-29	----do	38°10'	122°59'	35
83----	BHL 1191	----do	38°10'	123°00'	61
84----	BHL 1190	Point Reyes Beach	38°09'	122°59'	51
85----	BHL 640	Drakes Bay	38°01'	122°56'	13
86----	BHL 642	----do	38°00'	122°56'	18
87----	BHL 643	----do	38°00'	122°56'	20
88----	BHL 644	----do	38°00'	122°56'	22
89----	BHL 645	----do	38°00'	122°55'	29
90----	BHL 648	----do	37°59'	122°57'	9
91----	BHL 651	----do	37°59'	122°56'	13
92----	BHL 658	Point Reyes	37°59'	122°59'	14
93----	BHL 1420	Halfmoon Bay	37°34'	122°35'	39
94----	BHL 1454	----do	37°28'	122°27'	9
95----	BHL 1469	----do	37°30'	122°29'	11
96----	BHL 1473	----do	37°36'	122°30'	IT
97----	BHL 1476	----do	37°36'	122°30'	IT
98----	BHL 1478	----do	37°36'	122°31'	IT
99----	F 7002-55	Point Año Nuevo	37°07'	122°21'	36
100----	V 6	Greyrock	37°06'	122°17'	B
101----	V 9	Soquel Cove	36°58'	121°56'	B
102----	V 8	Seacliff Beach	36°57'	121°53'	B
103----	M 4	Monterey Bay	36°54'	121°51'	12
104----	M 3	----do	36°53'	121°50'	10
105----	M 5	----do	36°51'	121°50'	18
106----	M 2	----do	36°50'	121°49'	11
107----	M 1	----do	36°48'	121°48'	18
108----	ZUM 4	Partington Point	36°12'	121°44'	11
109----	V 1	Point Piedras Blancas	35°40'	121°15'	TP
110----	Z 52	Morro Bay	35°22'	120°51'	5
111----	Z 50	Estero Bay	35°21'	120°52'	12
112----	Z 51	----do	35°21'	120°52'	14
113----	Z 53	Morro Bay	35°21'	120°51'	5
114----	Z 54	----do	35°21'	120°50'	IT
115----	TZ 54	Estero Bay	35°21'	120°53'	31
116----	V 10	Avila State Beach	35°10'	120°43'	B
117----	V 11	Surf	34°41'	120°36'	B
118----	USC 16175	Point Conception	34°31'	120°33'	37
119----	USC 13833	----do	34°30'	120°31'	67
120----	V 12	El Capitan State Park	34°29'	120°01'	B
121----	USC 13824	Gaviota	34°26'	120°15'	117
122----	USC 13826	Gato	34°26'	120°21'	84
123----	V 13	Goleta State Beach	34°25'	119°50'	B
124----	USC 13825	Gato	34°25'	120°21'	100

TABLE 1.—Location and source of Holocene samples from the shelf off the west coast of the United States and Baja California, Mexico, and 16 Pliocene or Pleistocene samples from southern California—Continued

Sample		Location			
No.	Source	Geographic	Lat north	Long west	Depth (metres)
125----	USC 13827	Gato -----	34°25'	120°23'	114
126----	USC 13828	----do -----	34°25'	120°23'	88
127----	USC 13830	Government Point -----	34°25'	120°25'	117
128----	USC 13832	Point Conception -----	34°25'	120°29'	148
129----	USC 13821	Capitan -----	34°24'	120°01'	108
130----	CDM 16322	Point Mugu -----	34°04'	119°03'	33
131----	CDM 16323	----do -----	34°03'	119°00'	40
132----	V 14	Malibu Beach -----	34°02'	118°40'	B
133----	USC 15709	Point Mugu -----	34°02'	119°01'	119
134----	CDM 16318	Anacapa Island -----	34°01'	119°26'	64
135----	CDM 16319	----do -----	34°01'	119°27'	64
136----	CDM 16325	Point Dume -----	34°01'	118°51'	37
137----	USC 15462	Santa Monica Bay -----	34°01'	118°36'	37
138----	USC 15464	----do -----	34°01'	118°34'	27
139----	USC 15466	----do -----	34°01'	118°33'	20
140----	CDM 16308	Santa Cruz Island -----	33°59'	119°32'	22
141----	CDM 16309	----do -----	33°59'	119°33'	31
142----	USC 15476	Santa Monica Bay -----	33°59'	118°29'	15
143----	USC 15478	----do -----	33°59'	118°31'	37
144----	USC 15482	----do -----	33°59'	118°35'	57
145----	CDM 16311	Santa Cruz Island -----	33°58'	119°36'	46
146----	CDM 16311B	----do -----	33°58'	119°36'	46
147----	CDM 16292	Santa Cruz Island -----	33°58'	119°35'	83
148----	CDM 16293	----do -----	33°58'	119°39'	55
149----	CDM 16295	----do -----	33°57'	119°40'	55
150----	CDM 16297	----do -----	33°57'	119°43'	51
151----	USC 15456	Santa Monica Bay -----	33°56'	118°28'	34
152----	CDM 16300	Santa Rosa Island -----	33°55'	120°00'	26
153----	CDM 16298	----do -----	33°54'	119°59'	37
154----	USC 15440	Santa Monica Bay -----	33°53'	118°32'	70
155----	USC 15443	----do -----	33°53'	118°28'	46
156----	USC 15424	----do -----	33°50'	118°31'	97
157----	USC 15552	San Pedro Bay -----	33°42'	118°12'	22
158----	USC 15068	----do -----	33°41'	118°16'	31
159----	USC 15131	----do -----	33°41'	118°12'	24
160----	CDM 16338	----do -----	33°41'	118°11'	22
161----	CDM 16346	----do -----	33°40'	118°08'	24
162----	USC 15064	----do -----	33°39'	118°15'	46
163----	CDM 16330	----do -----	33°38'	118°10'	33
164----	USC 15142	----do -----	33°38'	118°11'	33
165----	CDM 16329	----do -----	33°36'	118°11'	35
166----	Z 41	Balboa -----	33°35'	117°52'	30
167----	Z 43	----do -----	33°35'	117°52'	8
168----	USC 15155	San Pedro Bay -----	33°35'	118°12'	60
169----	USC 15158	----do -----	33°35'	118°07'	62
170----	Z 48	Balboa -----	33°34'	117°50'	14
171----	Z 45	----do -----	33°33'	117°49'	8
172----	Z 47	----do -----	33°33'	117°49'	18
173----	USC 15166	San Pedro Bay -----	33°33'	118°13'	247
174----	Z 34	Dana Point -----	33°28'	117°43'	12
175----	Z 35	----do -----	33°28'	117°44'	20
176----	Z 31	----do -----	33°27'	117°41'	12
177----	Z 33	----do -----	33°27'	117°43'	14
178----	Z 37	----do -----	33°27'	117°43'	12
179----	Z 40	----do -----	33°27'	117°41'	6
180----	CQR 318	Santa Catalina Island -----	33°27'	118°30'	61
181----	TZ 100	----do -----	33°26'	118°29'	6
182----	USC 15272	----do -----	33°26'	118°23'	247
183----	USC 15260	----do -----	33°23'	118°20'	64
184----	USC 15255	----do -----	33°21'	118°18'	91
185----	Z 30	Oceanside -----	33°12'	117°23'	7
186----	Z 29	----do -----	33°12'	117°23'	8
187----	Z 20	----do -----	33°11'	117°24'	14
188----	Z 21	----do -----	33°11'	117°24'	16
189----	Z 27	----do -----	33°11'	117°23'	6
190----	Z 22	----do -----	33°10'	117°24'	18
191----	Z 24	----do -----	33°10'	117°23'	14
192----	CDM 15800	----do -----	33°09'	117°17'	64
193----	V 7	Pacific Beach -----	32°48'	117°16'	B
194----	Z 10	----do -----	32°45'	117°16'	14
195----	Z 7	San Diego -----	32°41'	117°13'	12
196----	Z 6	----do -----	32°40'	117°13'	5

TABLE 1.—Location and source of Holocene samples from the shelf off the west coast of the United States and Baja California, Mexico, and 16 Pliocene or Pleistocene samples from southern California—Continued

Sample		Location			Depth (metres)
No.	Source	Geographic	Lat north	Long west	
197----	Z 2	San Diego -----	32°39'	117°11'	12
198----	Z 3	----do -----	32°39'	117°10'	12
199----	Z 4	----do -----	32°39'	117°09'	8
200----	Z 1	----do -----	32°38'	117°13'	12
201----	TZ 97	Coronados Island, B.C -----	32°25'	117°15'	11
202----	TZ 98	----do -----	32°25'	117°15'	18
203----	TZ 99A, B	----do -----	32°24'	117°14'	18
204----	TZ 117	Bahia de Todos Santos -----	31°45'	116°41'	31
205----	TZ 118	----do -----	31°44'	116°40'	24
206----	TZ 119	----do -----	31°44'	116°41'	18
207----	TZ 120	----do -----	31°44'	116°40'	13
208----	TZ 121	----do -----	31°43'	116°40'	9
209----	TZ 122	----do -----	31°43'	116°40'	5
210----	TZ 113	Punta Banda -----	31°42'	116°41'	32
211----	TZ 114	----do -----	31°42'	116°41'	24
212----	TZ 115	----do -----	31°42'	116°41'	15
213----	TZ 116	----do -----	31°42'	116°41'	6
214----	TZ 18	Isla San Martin -----	30°29'	116°06'	9
215----	TZ 19	----do -----	30°28'	116°06'	1
216----	TZ 20	Isla San Geronimo -----	29°47'	115°47'	11
217----	TZ 21	----do -----	29°47'	115°47'	8
218----	TZ 22	----do -----	29°47'	115°47'	8
219----	CQR 12	Islas San Benitos -----	28°18'	115°34'	165
220----	TZ 23	----do -----	28°18'	115°34'	17
221----	TZ 24	----do -----	28°18'	115°34'	6
222----	TZ 2	Bahia Vizcaino -----	28°08'	114°17'	248
223----	TZ 4	----do -----	28°06'	114°15'	248
224----	TZ 26	Punta Eugenia -----	27°52'	115°02'	9
225----	TZ 48-Z	----do -----	27°52'	115°02'	8
226----	TZ 48-7	----do -----	27°52'	115°02'	8
227----	TZ 25	----do -----	27°51'	114°51'	35
228----	TZ 45	Puerto S. Bartolome -----	27°41'	114°52'	6
229----	TZ 46	----do -----	27°41'	114°53'	1
230----	TZ 43	----do -----	27°40'	114°53'	9
231----	TZ 44	----do -----	27°40'	114°53'	9
232----	TZ 47	----do -----	27°39'	114°52'	11
233----	TZ 41	Bahia Asuncion -----	27°08'	114°17'	9
234----	TZ 42	----do -----	27°08'	114°17'	6
235----	TZ 40A	----do -----	27°07'	114°17'	9
236----	TZ 40B	----do -----	27°07'	114°17'	9
237----	TZ 27	Bahia San Hipolito -----	26°58'	113°58'	9
238----	TZ 28	----do -----	26°58'	114°00'	6
239----	TZ 38A	Punta Abrejos -----	26°42'	113°39'	6
240----	TZ 38B	----do -----	26°42'	113°39'	6
241----	TZ 39	----do -----	26°42'	113°38'	10
242----	TZ 37	----do -----	26°41'	113°39'	16
243----	TZ 30	Punta Huches -----	24°46'	112°16'	17
244----	TZ 29	----do -----	24°45'	112°16'	6
245----	TZ 31	----do -----	24°45'	112°15'	20
246----	EZ 4	Punta Pescadores -----	23°45'	109°44'	3
247----	EZ 3	Cabo Pulmo -----	23°27'	109°25'	2
248----	JH 3	Los Frailes -----	23°24'	109°25'	29
249----	JH 2	----do -----	23°24'	109°25'	23
250----	TZ 35	Cabo San Lucas -----	22°53'	109°53'	10
251----	TZ 32	----do -----	22°52'	109°53'	24
252----	TZ 33	----do -----	22°52'	109°53'	7
253----	C 376	West Coast Mexico -----	22°45'	105°59'	15
254----	C 327	----do -----	22°10'	106°07'	58
255----	C 300	----do -----	21°43'	105°40'	31
Santa Maria district					
Mf2180	-----	Careaga Sandstone -----	34°54'	120°19'	--
Mf2179	-----	----do -----	34°52'	120°31'	--
Mf2178	-----	Foxen Mudstone -----	34°52'	120°31'	--
Mf2177	-----	----do -----	34°52'	120°31'	--
Santa Barbara					
Mf2176	-----	Santa Barbara Formation -----	34°25'	119°41'	--
Mf2175	-----	----do -----	34°25'	119°41'	--
Mf2174	-----	----do -----	34°25'	119°41'	--

TABLE 1.—*Location and source of Holocene samples from the shelf off the west coast of the United States and Baja California, Mexico, and 16 Pliocene or Pleistocene samples from southern California—Continued*

Sample		Location			
No.	Source	Geographic	Lat north	Long west	Depth (metres)
San Pedro					
Mf2173	-----	Palos Verdes Sand -----	33°44'	118°17'	--
Mf2172	-----	Timms Point Silt Member of San Pedro Formation.	33°44'	118°17'	--
Mf2171	-----	do -----	33°44'	118°17'	--
Mf2170	-----	Lomita Marl Member of San Pedro Formation.	33°44'	118°17'	--
Mf2169	-----	do -----	33°44'	118°17'	--
Mf2168	-----	do -----	33°44'	118°17'	--
Pacific Beach					
Mf2167	-----	San Diego Formation -----	32°48'	117°16'	--
Mf2166	-----	do -----	32°48'	117°16'	--
Mf2165	-----	do -----	32°48'	117°16'	--

organisms are developed on the continental shelves, and these patterns are recognized as faunal provinces.

Provinces are unique. Climatic changes, faunal migrations, and evolutionary events militate against duplication of successive provinces through time. Even if only the climate is altered, species will be found in new associations and thus constitute different provinces. Hazel (1970) showed that modern amphiatlantic ostracode species exhibit different latitudinal ranges and form different species associations because the marine climates differ on opposite sides of the same ocean basin.

Six provinces based on molluscan distributions (J. W. Valentine, 1966, 1973) can be identified on the west coast of North America. These are: the Bering province extending from Point Barrow to the Aleutian Island arc area; the Aleutian province south to Dixon Entrance; the Oregonian extending to Point Conception; the Californian south to Punta Eugenia-Cedros Island; the Surian which reaches Cabo San Lucas; and finally the tropical Panamanian province which extends southward. Prior to the present study, no ostracode provinces have been delineated along this coast, although they have been established off the east coast of North America (Hazel, 1970; P. C. Valentine, 1971).

#### MARINE CLIMATE OFF THE WEST COAST OF THE UNITED STATES AND BAJA CALIFORNIA, MEXICO

A marine climate is expressed primarily in temperature, and, to a far lesser degree, salinity configurations which result from the interactions of many factors. Latitudinal position (especially along north-south coastlines), worldwide seasonal climatic patterns, and major oceanic current patterns impart a

fundamental character to the marine climate. Other factors such as seasonal wind-driven currents, upwelling, and current interactions produce local temperature anomalies and steep temperature gradients which form thermal barriers that restrict the distributions of many species.

The pattern of the earth's atmospheric winds is responsible for the configuration of major oceanic current systems. The North Pacific Ocean exhibits an anticyclonic current pattern, which results in the transport of water from north to south along the coasts of the eastern Pacific, westward in equatorial latitudes toward the Asian mainland, and then northward along the coast of Japan, and finally eastward to North America. The waters of this North Pacific gyre are affected by mixing of waters from neighboring regions which, along with the effects of solar radiation, determine the overall temperature and salinity of the system.

The west coast of North America, from British Columbia to the southern tip of Baja California, is bathed by cold northern waters of the California Current, the south-southeast-flowing arm of the North Pacific gyre, which is the major influence on the marine climate along the coasts of the United States and Baja California. Reid and others (1958) have discussed the characteristics of this current system, and the following summary is based mainly on their report.

The California Current is a permanent stream of cold water about 560 km wide and 300 m deep which moves southeastward at about 0.5 knot. It transports approximately one-tenth the volume of water carried by the Gulf Stream of the western Atlantic Ocean. Near Cabo San Lucas, Baja California, the current turns west to become part of the westward-

flowing North Equatorial Current. The waters of the current system are a mixture of four water masses. Subarctic water enters from the north (relatively low temperature and salinity and high phosphate and dissolved-oxygen content) and maintains its character throughout the length of the current. Central North Pacific water (relatively higher temperature and salinity and lower nutrient content) lies to the west of the Subarctic Water Mass and mixes with it at the surface. Equatorial Pacific water (still higher temperature, salinity, and phosphate content but low dissolved-oxygen content) flows northward in a countercurrent below 200 m along the Baja California and California coasts to about Cape Mendocino. Finally, upwelled water, which is colder, more saline, and higher in nutrients than the surrounding water masses, originates from Subarctic and Equatorial Pacific water at depth. Although the California Current is the dominant oceanic flow off these coasts, a complex system of transient seasonal currents and eddies occurs between the main current and the coast. They are the result of the interaction of seasonal winds, the main current, the deep countercurrent, and upwelled waters.

Winds influencing the system are principally from the north and northwest, and they are strongest from spring to fall. During the winter months these winds weaken or reverse direction, which results in the surfacing of the northwest-flowing countercurrent (often called the Davidson Current) along Baja California to north of Point Conception. The Southern California Countercurrent is a permanent but weak cyclonic eddy located south of Point Conception in the Channel Island region. The eastern arm of this eddy flows slowly north adjacent to the coastline and becomes warmer than the western arm which is exposed to the California Current. In the late fall and early winter, when the deep countercurrent surfaces, warm southern water augments this gyre and northward surface flow takes place around Point Conception where at other times of the year the flow is southward.

Interaction of northerly winds, the Coriolis effect, and the configuration of the coasts and the sea bottom causes movement of the surface waters away from the shore and establishes areas of upwelling along the coast from Cape Mendocino south to Cabo San Lazaro. Upwelling occurs chiefly in the spring and summer when the northerly winds are strongest. These winds increase in strength along the coasts from south to north as the year progresses. Consequently, upwelling is most pronounced off Baja

California in April and May, off southern and central California in May and June, off northern California in June and July, and off Oregon in August and September. Upwelling is common to some extent all along these coasts. It is, however, intensified in some regions (fig. 5), especially south of coastal promontories. These regions include: Cape Mendocino and Cape Blanco; off the central California coast south of Monterey Bay; and off the southern California coast north of Santa Monica Bay. To the south the area from north of San Diego to south of Punta Baja is characterized by upwelling, as is the coast south of Punta Eugenia and south of Cabo San Lazaro.

The upwelling of cold, nutrient-rich water is, in particular, a phenomenon which has profound effects on the marine environment along these coasts. It is an important mechanism for the recycling of nutrients from deep oceanic waters into the shallow marine ecosystem, and its effect on the marine climate influences the distribution of organisms along the shelf. The minimum and maximum water temperatures off the west coasts of the United States and Baja California are illustrated in figures 6 and 7. From Cabo San Lucas north to San Francisco the maps are based on temperature determinations at -10 m (Lynn, 1967); from San Francisco north to Cape Flattery they are based on surface temperatures (Robinson, 1957). Areas of intense upwelling are easily discernible on these maps.

In the region from Punta Baja to Cape Blanco, upwelling has the effect of reducing the annual temperature range to 3° to 5° C and retarding the seasonal warming produced by solar radiation. South of Punta Baja, the contrast between pronounced spring upwelling and summer warming caused by both intense radiation and warm, northward-flowing surface waters produces annual temperature ranges greater than 10° C. Upwelling, rather than current interactions (such as those in existence off the east coast of North America), causes the most pronounced temperature gradients along this coast.

#### HOLOCENE OSTRACODE DISTRIBUTION PATTERNS

Although Swain (1966) and Swain and Gilby (1974) noted an ostracode faunal discontinuity at Point Conception, the present study is the first attempt to define faunal provinces in the eastern Pacific on the basis of ostracode distributions. From biogeographic studies on this and other coasts, it is apparent that provincial schemes based on different invertebrate and plant groups (Mollusca, Crustacea,



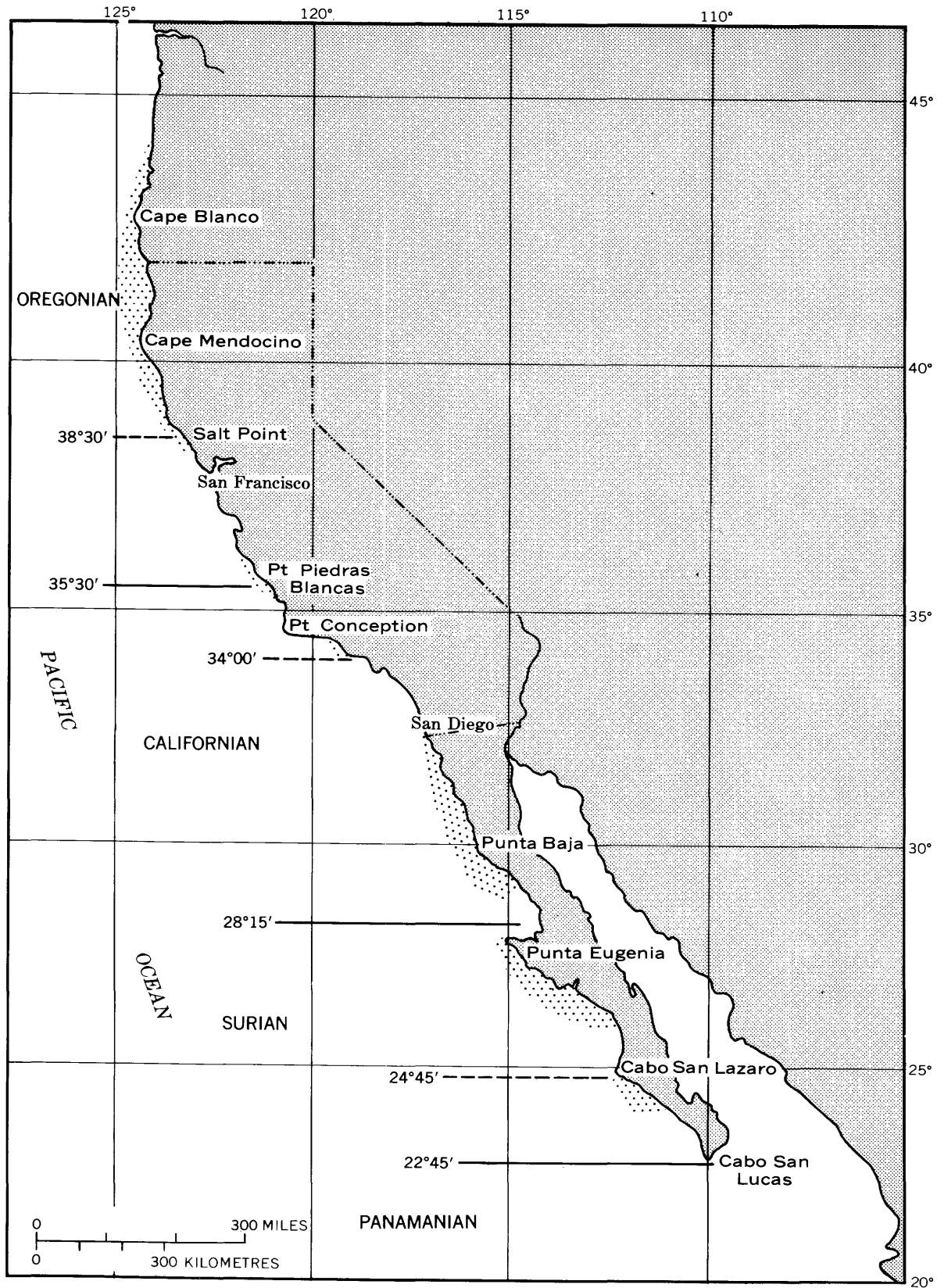


FIGURE 5.—Ostracode faunal provinces and the distribution of areas of intense upwelling (stippled pattern) along the Pacific coasts of the United States and Baja California (after Manar, 1953, and Lynn, 1967).

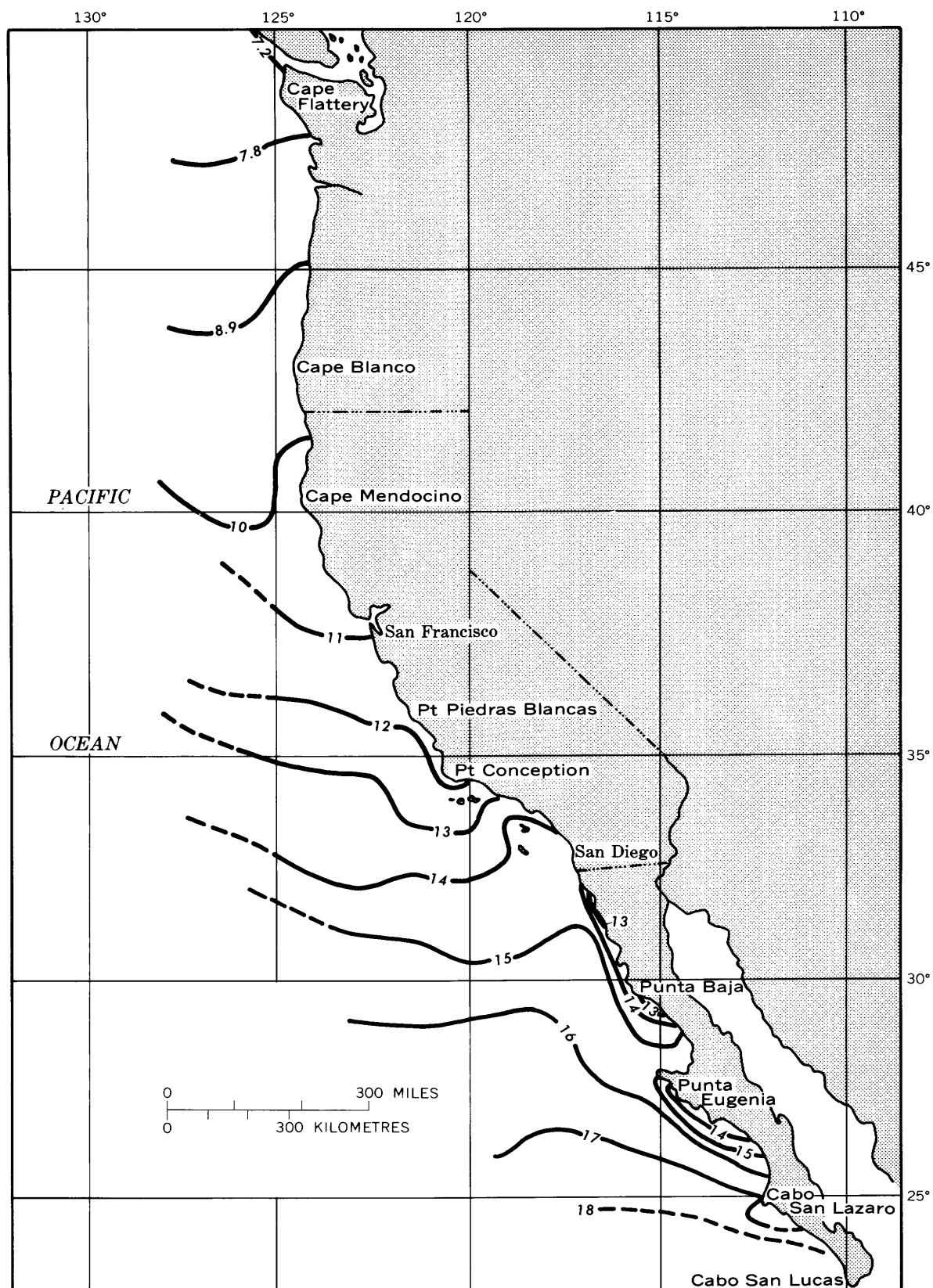


FIGURE 6.—Sea-temperature map (in degrees Celsius) for the shelf off the Pacific coasts of the United States and Baja California. Yearly minimum temperatures at  $-10$  m from San Francisco south are after Lynn, 1967, and yearly minimum surface temperatures from San Francisco north are after Robinson, 1957.

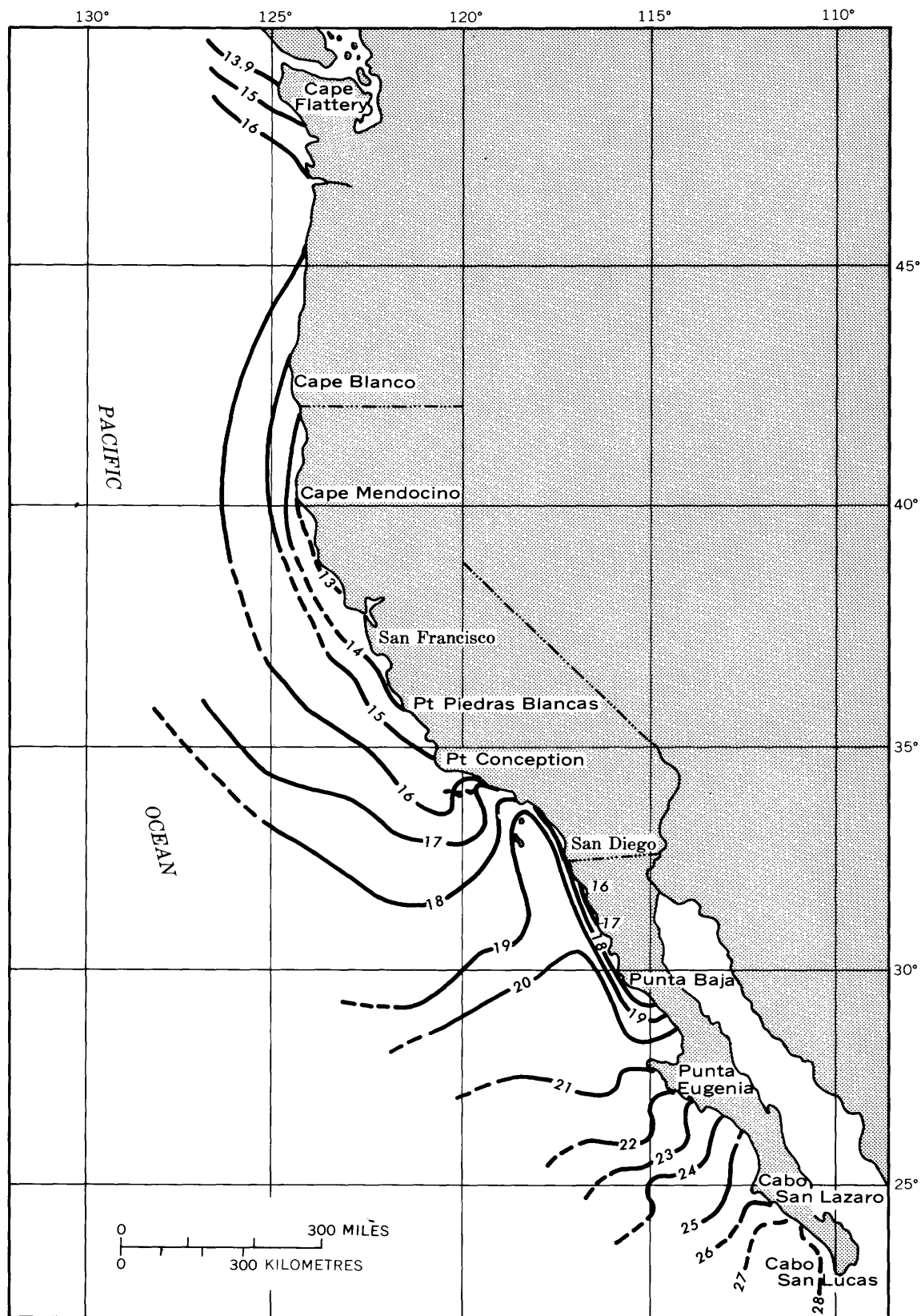


FIGURE 7.—Sea-temperature map (in degrees Celsius) for the shelf off the Pacific coasts of the United States and Baja California. Yearly maximum temperatures at -10 m from San Francisco, south are after Lynn, 1967, and yearly maximum surface temperatures from San Francisco north are after Robinson, 1957.

Ostracoda, Foraminifera, and intertidal flora and fauna) are fairly coincident. (See references in J. W. Valentine, 1966; in Hazel, 1970; and in Lankford and Phleger, 1973.) This result lends weight to the hypothesis (J. W. Valentine, 1968, 1973) that provinces are composed of communities, the aspects (structure, composition, function) of which are characteristic of the provinces in which they occur. As expected, the ostracode provinces in the area under investigation mimic those based on the Mollusca. Subprovinces exist, however, which are new or which deviate from those of the Mollusca.

In order to delineate the provinces, a cluster analysis of similarity coefficients was made. I consider this method to be the most expeditious and efficient means of comparing the faunal compositions of shelf areas. This tool has been utilized in previous studies (J. W. Valentine, 1966; J. W. Valentine and Peddicord, 1967; P. C. Valentine, 1971). The samples for this investigation were assembled from various sources and are not evenly distributed over the shelf area. The study, however, is based on the latitudinal ranges of ostracode species, and these ranges are adequately delineated by the samples analyzed. It is considered that samples composed of assemblages from consecutive latitudinal segments of shelf along the coast form a better basis for comparison than samples distributed nonuniformly over the shelf. If it is reasonable to conclude that species occurring at points along the shelf also occur on the shelf between those points, then all species occurring in or ranging into or through each 15-minute (latitude) shelf segment (sample) can be considered to be a member of that sample (figs. 1-4; see table 2 for latitudinal ranges of 15-minute samples). Choice of 15-minute samples was made to achieve a balance between sample size and sampling detail; the sample matrix was limited to manageable proportions, and samples remained small enough so that sample groups that might segregate over short geographic distances on the shelf would be detected.

A Q-mode cluster analysis (defining groups of samples based on the similarity of their species composition) was therefore based on a comparison of the faunal content of 110 15-minute samples. Degree of similarity between samples was calculated using the Otsuka similarity coefficient ( $C/\sqrt{N_1N_2}$ ) and presence-absence data, where  $C$  = number of species in common between two samples containing  $N_1$  and  $N_2$  species. The Otsuka coefficient was chosen because it gives results which neither emphasize difference (as does the Jaccard coefficient) nor similarity (as

TABLE 2.—*Latitudinal ranges of 15-minute samples along the west coast of the United States and Baja California, Mexico*

Sample	Latitudinal range (north)
<b>Panamanian faunal province</b>	
001	21°30'–21°45'
002	45'–22°00'
003	22°00'– 15'
004	15'– 30'
005	30'– 45'
<b>southern Surian faunal province</b>	
006	22°45'–23°00'
007	23°00'– 15'
008, 109	15'– 30'
009, 110	30'– 45'
010	45'–24°00'
011	24°00'– 15'
012	15'– 30'
013	30'– 45'
<b>northern Surian faunal province</b>	
014	24°45'–25°00'
015	25°00'– 15'
016	15'– 30'
017	30'– 45'
018	45'–26°00'
019	26°00'– 15'
020	15'– 30'
021	30'– 45'
022	45'–27°00'
023	27°00'– 15'
024	15'– 30'
025	30'– 45'
026	45'–28°00'
027	28°00'– 15'
<b>southern Californian faunal province</b>	
028	28°15'–28°30'
029	30'– 45'
030	45'–29°00'
031	29°00'– 15'
032	15'– 30'
033	30'– 45'
034	45'–30°00'
035	30°00'– 15'
036	15'– 30'
037	30'– 45'
038	45'–31°00'
039	31°00'– 15'
040	15'– 30'
041	30'– 45'
042	45'–32°00'
043	32°00'– 15'
044	15'– 30'
045	30'– 45'
046	45'–33°00'
047	33°00'– 15'
048	15'– 30'
049	30'– 45'
050	45'–34°00'
<b>northern Californian faunal province</b>	
051	34°00'–34°15'
052	15'– 30'
053	30'– 45'
054	45'–35°00'
055	35°00'– 15'
056	15'– 30'
<b>southern Oregonian faunal province</b>	
057	35°30'–35°45'
058	45'–36°00'

TABLE 2.—*Latitudinal ranges of 15-minute samples along the west coast of the United States and Baja California, Mexico—Continued*

Sample	Latitudinal range (north)	
southern Oregonian faunal province		
059	36°00'–	15
060	15'–	30'
061	30'–	45'
062	45'–37°00'	
063	37°00'–	15'
064	15'–	30'
065	30'–	45'
066	45'–38°00'	
067	38°00'–	15'
068	15'–	30'
northern Oregonian faunal province		
069	38°30'–38°45'	
070	45'–39°00'	
071	39°00'–	15'
072	15'–	30'
073	30'–	45'
074	45'–40°00'	
075	40°00'–	15'
076	15'–	30'
077	30'–	45'
078	45'–41°00'	
079	41°00'–	15'
080	15'–	30'
081	30'–	45'
082	45'–42°00'	
083	42°00'–	15'
084	15'–	30'
085	30'–	45'
086	45'–43°00'	
087	43°00'–	15'
088	15'–	30'
089	30'–	45'
090	45'–44°00'	
091	44°00'–	15'
092	15'–	30'
093	30'–	45'
094	45'–45°00'	
095	45°00'–	15'
096	15'–	30'
097	30'–	45'
098	45'–46°00'	
099	46°00'–	15'
100	15'–	30'
101	30'–	45'
102	45'–47°00'	
103	47°00'–	15'
104	15'–	30'
105	30'–	45'
106	45'–48°00'	
107	48°00'–	15'
108	15'–	30'

does the Simpson coefficient) between the samples being compared. (See Cheetham and Hazel, 1969, for a résumé of binary similarity coefficients.) The samples were associated and ordered in a dendrogram using the unweighted pair-group method of clustering (Sokal and Michener, 1958). This procedure allows all samples to have equal weight when being compared to another sample or samples (in an already formed cluster). Since all samples in this study represent an equal geographic range (except where the coastline deviates from its approximate

north-south trend), each sample should be considered to be of equal importance in determining sample clusters (ultimately faunal provinces). The matrix used was 192 species by 110 15-minute samples. (See table 3 for alphabetical list of ostracode species included in cluster analyses.)

TABLE 3.—*Alphabetical list of Holocene and fossil ostracode species included in cluster analyses*  
[F=species occurs only in fossil deposits]

No.	Species	Occurrence		Cluster analyses	
		Holo-	Fos-	Holo-	Holo-
		cene	sil	cene	fos-
					sil
150	<i>Ambostracum californicum</i> (Hazel, 1962)	×	×	×	×
151	<i>A. costatum</i> Hazel, 1962	×	×	×	×
094	<i>A. diegoensis</i> (LeRoy, 1943a)	×	×	×	×
093	<i>A. glaucum</i> (Skogsberg, 1928)	×	×	×	×
126	<i>A. microreticulatum</i> (LeRoy, 1943a)	×	×	×	×
001	<i>A. sp. A</i>	×	×	×	×
091	<i>A. sp. B</i>	×	×	×	×
015F	<i>A. sp. C</i>	×	×	×	×
152	<i>A. sp. D</i>	×	×	×	×
101	<i>A. sp. E</i>	×	×	×	×
120	<i>A. sp. F</i>	×	×	×	×
103	<i>A. sp. G</i>	×	×	×	×
118	<i>A. sp. I</i>	×	×	×	×
095	<i>A. sp. J</i>	×	×	×	×
097	<i>A. sp. K</i>	×	×	×	×
099	<i>A. sp. L</i>	×	×	×	×
154	<i>A. sp. M</i>	×	×	×	×
098	<i>A. sp. N</i>	×	×	×	×
116	<i>A. sp. O</i>	×	×	×	×
114	<i>A. sp. P</i>	×	×	×	×
053	<i>A. sp. Q</i>	×	×	×	×
002	<i>Aurila lincolniensis</i> (LeRoy, 1943a)	×	×	×	×
007	<i>A. montereyensis</i> (Skogsberg, 1928)	×	×	×	×
004	<i>A. sp. A</i>	×	×	×	×
006	<i>A. sp. B</i>	×	×	×	×
009	<i>A. sp. C</i>	×	×	×	×
010	<i>A. sp. D</i>	×	×	×	×
056	" <i>Aurila</i> " <i>californica</i> Benson and Kaesler, 1963	×	×	×	×
113	" <i>A.</i> " <i>driveri</i> (LeRoy, 1943a)	×	×	×	×
108	" <i>A.</i> " <i>schumannensis</i> (LeRoy, 1943a)	×	×	×	×
008	" <i>A.</i> " <i>sp. C</i>	×	×	×	×
110	" <i>A.</i> " <i>sp. D</i>	×	×	×	×
112	" <i>A.</i> " <i>sp. E</i>	×	×	×	×
016F	" <i>A.</i> " <i>sp. G</i>	×	×	×	×
024F	" <i>A.</i> " <i>sp. H</i>	×	×	×	×
104	<i>Basslerites delreyensis</i> LeRoy, 1943a	×	×	×	×
155	<i>B. thlipsuroidea</i> Swain, 1967	×	×	×	×
102	<i>B. sp. B</i>	×	×	×	×
174	<i>B. sp. C</i>	×	×	×	×
171	" <i>Bradleya</i> " <i>pennata</i> (LeRoy, 1943a)	×	×	×	×
078	" <i>B.</i> " <i>simiensis</i> (LeRoy 1943a, b)	×	×	×	×
100F	<i>Buntonia sp. A</i>	×	×	×	×
096	<i>B. sp. B</i>	×	×	×	×
092F	<i>B. sp. C</i>	×	×	×	×
178	<i>Bythoceratina sp. A</i>	×	×	×	×
040F	<i>Bythocythere sp. A</i>	×	×	×	×
069	<i>Catwellia semitranslucens</i> (Crouch, 1949)	×	×	×	×
100	<i>C. unitaria</i> Swain, 1967	×	×	×	×
017	<i>C. sp. A</i>	×	×	×	×
015	<i>C. sp. B</i>	×	×	×	×
020	<i>Caudites fragilis</i> LeRoy, 1943a	×	×	×	×
023	<i>C. puri</i> (McKenzie and Swain, 1967)	×	×	×	×
121	<i>C. sp. A</i>	×	×	×	×
022	<i>C. sp. B</i>	×	×	×	×
156	<i>C. sp. C</i>	×	×	×	×
025	<i>C. sp. D</i>	×	×	×	×
027	<i>C. sp. E</i>	×	×	×	×
181	<i>C. sp. F</i>	×	×	×	×
190	<i>C. sp. G</i>	×	×	×	×
177	<i>C. sp. H</i>	×	×	×	×
191	<i>C. sp. I</i>	×	×	×	×
021	<i>C. sp. J</i>	×	×	×	×
157	<i>C. sp. K</i>	×	×	×	×
041	<i>C. sp. L</i>	×	×	×	×
075	<i>C. sp. M</i>	×	×	×	×
087	<i>Coquimba pichelingensis</i> (Swain, 1967)	×	×	×	×
158	<i>C. schencki</i> (LeRoy, 1943a)	×	×	×	×
029	<i>C. sp. A</i>	×	×	×	×
042F	<i>C. sp. B</i>	×	×	×	×
092	<i>Costa? sanfelipensis</i> Swain, 1967	×	×	×	×
035	<i>Cythere maia</i> (Benson, 1959)	×	×	×	×
037	<i>C. sp. A</i>	×	×	×	×
039	<i>C. sp. B</i>	×	×	×	×
138	<i>Cytherella banda</i> Benson, 1959	×	×	×	×

TABLE 3.—Alphabetical list of Holocene and fossil ostracode species included in cluster analyses—Continued

No.	Species	Occurrence		Cluster analyses	
		Holo- cene	Fos- sil	Holo- cene and fos- sil	Holo- cene and fos- sil
140	<i>C. sp. A</i> -----	X	--	X	--
136	<i>Cytherelloidea californica</i> LeRoy, 1943a	X	X	X	X
043	<i>C. sp. A</i> -----	X	X	X	X
105	<i>C. sp. B</i> -----	X	--	X	--
044	<i>C. sp. C</i> -----	X	--	X	--
187	<i>"Cytheretta" corrugata</i> (LeRoy, 1943a)	X	X	X	X
046	<i>"C." sp. A</i> -----	X	--	X	--
133	<i>"C." sp. B</i> -----	X	X	X	X
129	<i>"C." sp. C</i> -----	X	X	X	X
048	<i>Cytheromorpha sp. A</i> -----	X	X	X	X
127	<i>C. sp. B</i> -----	X	X	X	X
106	<i>Cytheropteron dobladoensis</i> Swain, 1967	X	--	X	--
115	<i>C. johnsonoides</i> (Swain, 1967)	X	--	X	--
161	<i>C. newportense</i> Crouch, 1949	X	--	X	--
050	<i>C. sp. A</i> -----	X	--	X	--
105F	<i>C. sp. B</i> -----	X	--	X	--
164	<i>Eucytherura sp. A</i> -----	X	--	X	--
011	<i>Hemicythere sp. A</i> -----	X	--	X	--
013	<i>H. sp. B</i> -----	X	--	X	--
012	<i>H.? sp. C</i> -----	X	--	X	--
122	<i>"Hemicythere" californiensis</i> LeRoy, 1943a	X	X	X	X
162	<i>"H." hispida</i> LeRoy, 1943a	X	X	X	X
123	<i>"H." sp. A</i> -----	X	X	X	X
186	<i>"H." sp. B</i> -----	X	X	X	X
131	<i>"H." sp. C</i> -----	X	X	X	X
163	<i>"H." sp. D</i> -----	X	X	X	X
125	<i>"H." sp. E</i> -----	X	X	X	X
124	<i>"H." sp. F</i> -----	X	X	X	X
165	<i>"H." sp. G</i> -----	X	X	X	X
106F	<i>"H." sp. H</i> -----	X	X	X	X
054	<i>Hemicytherura sp. A</i> -----	X	--	X	--
055	<i>H. sp. B</i> -----	X	--	X	--
057	<i>H. sp. C</i> -----	X	X	X	X
059	<i>H. sp. D</i> -----	X	X	X	X
065	<i>H. sp. E</i> -----	X	--	X	--
060	<i>H. sp. F</i> -----	X	--	X	--
063	<i>H. sp. G</i> -----	X	--	X	--
062	<i>H. sp. H</i> -----	X	X	X	X
064	<i>H. sp. I</i> -----	X	X	X	X
066	<i>H. sp. J</i> -----	X	X	X	X
067	<i>H. sp. K</i> -----	X	X	X	X
068	<i>H. sp. L</i> -----	X	X	X	X
070	<i>Hermantes kewi</i> (LeRoy, 1943a)	X	X	X	X
132	<i>H. sp. A</i> -----	X	--	X	--
071	<i>H. sp. B</i> -----	X	--	X	--
073	<i>H. sp. C</i> -----	X	X	X	X
074	<i>H. sp. D</i> -----	X	X	X	X
166	<i>H. sp. E</i> -----	X	X	X	X
072	<i>H. sp. F</i> -----	X	X	X	X
005	<i>H. sp. G</i> -----	X	X	X	X
140F	<i>H. sp. H</i> -----	X	X	X	X
045	<i>Kangarina aff. K. quellata</i> Coryell and Fields, 1937	X	--	X	--
003	<i>K. sp. A</i> -----	X	--	X	--
036	<i>K. sp. B</i> -----	X	--	X	--
038	<i>K. sp. C</i> -----	X	--	X	--
184	<i>K. sp. D</i> -----	X	X	X	X
185	<i>K. sp. E</i> -----	X	X	X	X
188	<i>K. sp. F</i> -----	X	--	X	--
155F	<i>K. sp. G</i> -----	X	X	X	X
149	<i>K. sp. H</i> -----	X	X	X	X
077	<i>"Kangarina" sp. A</i> -----	X	X	X	X
164F	<i>Krithe sp. A</i> -----	X	--	X	--
081	<i>Loxoconcha helenae</i> Crouch, 1949	X	X	X	X
082	<i>L. lenticulata</i> LeRoy, 1943a	X	X	X	X
079	<i>L. sp. A</i> -----	X	X	X	X
083	<i>L. sp. B</i> -----	X	X	X	X
085	<i>L. sp. C</i> -----	X	X	X	X
084	<i>L. sp. D</i> -----	X	X	X	X
167	<i>L. sp. E</i> -----	X	--	X	--
169	<i>L. sp. F</i> -----	X	--	X	--
170	<i>"Loxoconcha" emaciata</i> Swain, 1967	X	--	X	--
168	<i>Loxocorniculum sculptoides</i> , Swain, 1967	X	--	X	--
086	<i>L. sp. A</i> -----	X	X	X	X
080	<i>L. sp. B</i> -----	X	X	X	X
058	<i>Munseyella pedroensis</i> Triebel, 1957	X	X	X	X
174F	<i>M. similis?</i> Triebel, 1957	X	X	X	X
088	<i>M. sp. A</i> -----	X	--	X	--
090	<i>M. sp. B</i> -----	X	X	X	X
089	<i>M. sp. C</i> -----	X	X	X	X
178F	<i>M. sp. D</i> -----	X	X	X	X
128	<i>Neocaudites? henryhowei</i> (McKenzie and Swain, 1967)	X	--	X	--
172	New genus A sp. A -----	X	--	X	--
188F	New genus B sp. A -----	X	--	X	--
193F	New genus C sp. A -----	X	--	X	--
160	New genus D sp. A -----	X	X	X	X
194F	New genus E sp. A -----	X	X	X	X
130	New genus F sp. A -----	X	X	X	X
134	<i>Orionina pseudovaughni</i> Swain, 1967	X	X	X	X
195F	<i>Paijenborchella sp. A</i> -----	X	X	X	X

TABLE 3.—Alphabetical list of Holocene and fossil ostracode species included in cluster analyses—Continued

No.	Species	Occurrence		Cluster analyses	
		Holo- cene	Fos- sil	Holo- cene and fos- sil	Holo- cene and fos- sil
117	<i>"Paijenborchella" sp. A</i> -----	X	X	X	X
119	<i>"P." sp. B</i> -----	X	X	X	X
135	<i>Palacioa sp. A</i> -----	X	X	X	X
137	<i>P. sp. B</i> -----	X	X	X	X
052	<i>P. sp. C</i> -----	X	--	X	--
139	<i>P. sp. D</i> -----	X	X	X	X
141	<i>Palmenella californica</i> Triebel, 1957	X	X	X	X
146	<i>Paracytheridea granti</i> LeRoy, 1943a	X	X	X	X
143	<i>P. sp. A</i> -----	X	X	X	X
142	<i>P. sp. B</i> -----	X	X	X	X
144	<i>P. sp. C</i> -----	X	--	X	--
145	<i>P. sp. D</i> -----	X	--	X	--
173	<i>P. sp. E</i> -----	X	X	X	X
175	<i>P. sp. F</i> -----	X	--	X	--
176	<i>P. sp. G</i> -----	X	X	X	X
061	<i>Pectocythere clavata</i> (Triebel, 1957)	X	X	X	X
148	<i>P. tomalensis</i> Watling, 1970	X	X	X	X
147	<i>P. sp. A</i> -----	X	X	X	X
189	<i>P. sp. B</i> -----	X	--	X	--
196F	<i>P. sp. D</i> -----	X	X	X	X
049	<i>Pellucistoma bensoni</i> McKenzie and Swain, 1967	X	X	X	X
179	<i>P. scrippsi</i> Benson, 1959	X	--	X	--
051	<i>P. sp. A</i> -----	X	--	X	--
047	<i>P. sp. B</i> -----	X	--	X	--
180	<i>Perissocytheridea pedroensis</i> (LeRoy, 1943a)	X	X	X	X
159	<i>Pontocythere sp. A</i> -----	X	X	X	X
076	<i>P. sp. B</i> -----	X	X	X	X
033	<i>P. sp. C</i> -----	X	--	X	--
192	<i>P. sp. D</i> -----	X	--	X	--
016	<i>Pterygocythereis? sp. A</i> -----	X	--	X	--
018	<i>Pulmilocytheridea pseudoguardensis</i> McKenzie and Swain, 1967	X	X	X	X
019	<i>Puriana pacifica</i> Benson, 1959	X	--	X	--
024	<i>P. sp. A</i> -----	X	--	X	--
153	<i>P. sp. B</i> -----	X	--	X	--
183	<i>Radimella convergens</i> (Swain, 1967)	X	X	X	X
026	<i>R. palosensis</i> (LeRoy, 1943a)	X	X	X	X
030	<i>R. sp. A</i> -----	X	--	X	--
031	<i>R. sp. B</i> -----	X	--	X	--
028	<i>"Radimella" aurita</i> (Skogsberg, 1928)	X	X	X	X
107	<i>"R." jollaensis</i> (LeRoy, 1943a)	X	X	X	X
109	<i>"R." pacifica</i> (Skogsberg, 1928)	X	X	X	X
111	<i>"R." sp. A</i> -----	X	X	X	X
182	<i>"R." sp. B</i> -----	X	X	X	X
032	<i>Sahnia sp. A</i> -----	X	X	X	X
040	<i>"Trachyleberis" sp. A</i> -----	X	--	X	--
042	<i>"T." sp. B</i> -----	X	--	X	--
014	<i>Triebelina reticulopunctata</i> Benson, 1959	X	X	X	X
034	<i>T. sp. A</i> -----	X	X	X	X

New information has made it necessary to change the names of several of the species treated in this study. The new species designations are indicated below, and the reader may make these changes in tables 3 and 4 and in the plate explanations.

037 *Cythere* sp. A = *C. alveolivalva* Smith, 1952

046 *"Cytheretta" sp. A* = *"C." minutipunctata* Swain and Gilby, 1974

105 *Cytherelloidea* sp. B = *C. paratewarii* Swain and Gilby, 1974

062 *Hemicytherura* sp. H = *H. santosensis* Swain and Gilby, 1974

090 *Munseyella* sp. B = *M. parkerae* (Swain and Gilby, 1974)

105 *Cytherelloidea* sp. B = *C. paratewarii* Swain and Gilby, 1974

117 *"Paijenborchella" sp. A* = *Acuminocythere crescentensis* Swain and Gilby, 1974

- 119 "*Paijenborchella*" sp. B = *Acuminocythere* sp. B  
 132 *Hermanites* sp. A = "*Lucasocythere*" *sanmartinensis* Swain and Gilby, 1974  
 133 "*Cytheretta*" sp. B = "*C.*" *rothwelli* Swain and Gilby, 1974  
 167 *Loxoconcha* sp. E = *Palmoconcha laevimarginata* Swain and Gilby, 1974.

## SHELF ASSEMBLAGES DEFINED BY CLUSTER ANALYSIS

The cluster analysis of Holocene samples (fig. 8, 9) indicates that the samples segregate into four major clusters on the basis of species content. These major sample clusters (actually provincial assemblages) define ostracode faunal provinces. In general, they are areally equivalent to molluscan provinces (J. W. Valentine, 1966, figs. 1, 4), and rather than propose new names for the ostracode provinces, molluscan provincial terminology will be retained. Latitudinal discrepancies between ostracode and molluscan (sub) provincial boundaries are summarized below.

Molluscan provinces	Latitude North	Ostracode provinces	Cluster
	49		
	-----48°24' (limit of study area)		
	48		
47°30' -----	*		
	*	northern	
	*		
Mendocinan	39		
	-----38°30'		
OREGON- 37°30' -----	38	OREGONIAN	A
IAN	37	southern	
Montereyan	36		
	-----35°30'-----		
	35		
-----34°30'-----		northern	
	34-----		
	33		
CALIFORNIAN	32	CALIFORNIAN	B
		southern	
	31		
	30		
	29		
-----28°15'-----			
	28		
	27		
	26	northern	
SURIAN			SURIAN C
	25-----24°45'		
	24		
		southern	
	23		
-----22°45'-----			
PANAMANIAN	22	PANAMANIAN	D

Cluster A (Oregonian ostracode province) contains samples occurring from the northern limit of the study area at Cape Flattery, Wash. (48°24' N.), south to latitude 35°30' N. near Point Piedras Blancas, Calif. (35°40' N.). Further, this cluster contains two subprovinces, a southern and northern, which segregate at latitude 38°30' N., south of Salt Point, Calif. (38°34' N.). Cluster A corresponds to the Oregonian molluscan faunal province, although the subprovincial boundary within the ostracode province as well as the Californian-Oregonian ostracode provincial boundary are shifted to the north 1° of latitude.

Cluster B (Californian ostracode province) includes samples extending from Point Piedras Blancas south to the Bahia Sebastian Vizcaino area (28°15' N.). This province, the approximate equivalent of the Californian molluscan province, also contains two subprovinces which segregate south of Point Conception in the region of the northern Channel Islands. The ostracode faunal nature of the Californian-Oregonian provincial boundary is discussed in the following section.

Cluster C, the Surian ostracode province, is equivalent to the molluscan province of the same name which extends from Punta Eugenia south to latitude 22°45' N. south of Cabo San Lucas (22°52' N.); two subprovinces segregate at latitude 24°45' N., south of Cabo San Lazaro (24°48' N.). The two subprovinces are not discernible in molluscan studies.

Cluster D is a small but distinctive group of samples occurring at the southern end of the study area off the west coast of Mexico. They, together with samples 4 and 5 (which cluster at a low level with samples of the Surian province), demonstrate a faunal discontinuity at latitude 22°45' N., south of Cabo San Lucas (22°52' N.). Cluster D lies in the northernmost part of the Panamanian molluscan faunal province.

The problem of deciding which clusters represent groupings of faunal-province magnitude is difficult and must be resolved subjectively. Delineation of known major provinces by cluster analysis provides a somewhat quantitative basis for the comparison of sample clusters and the detection of new provinces and subprovinces. Major provincial boundaries delineated by cluster analysis coincide in most cases with those previously determined by other means.

Discussion of faunal provinces in the following sections refers to those based on ostracode distributions (table 5 and figs. 5, 9, and 13) unless otherwise indicated.



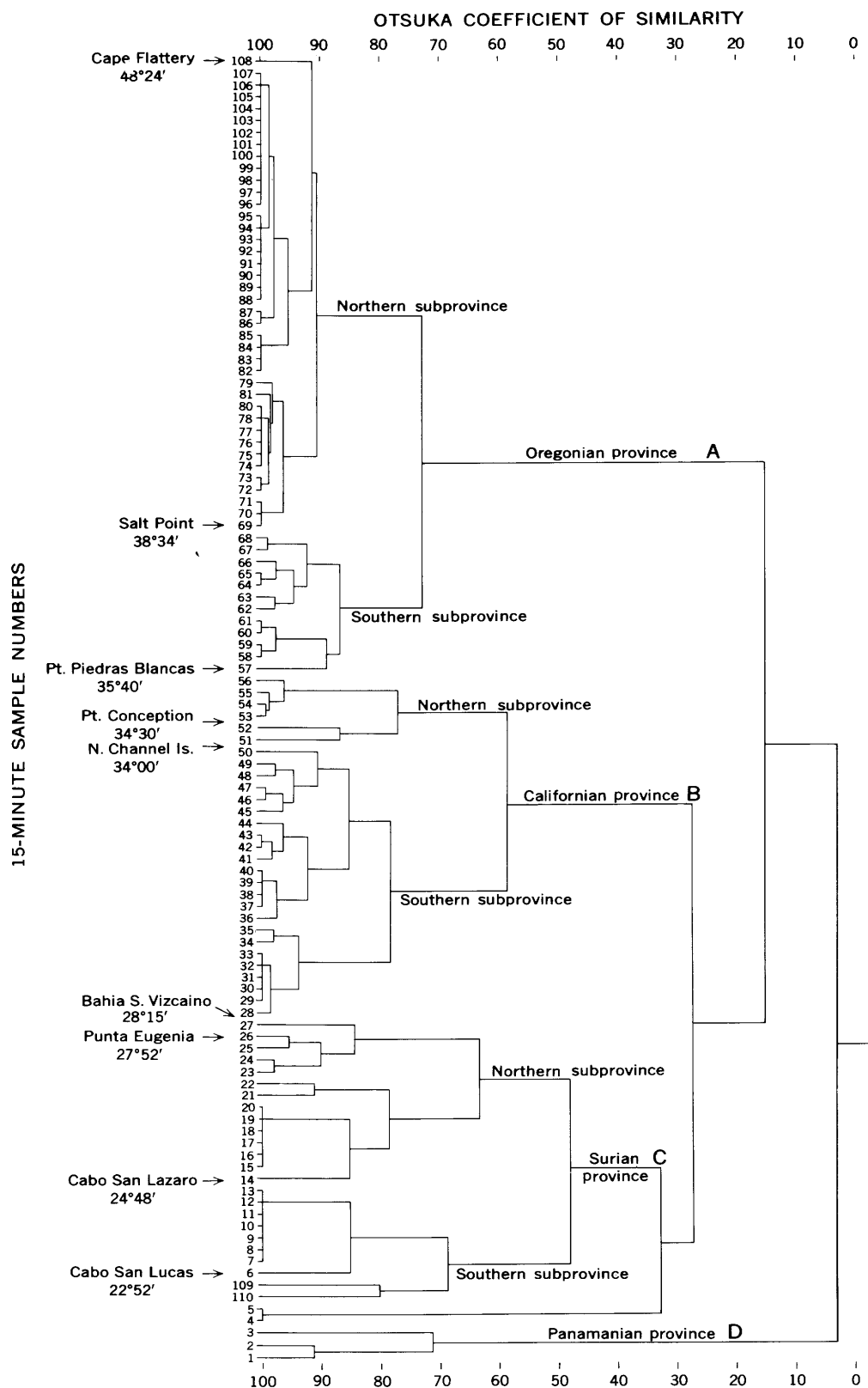


FIGURE 8.—Dendrogram of Holocene sample clusters. Samples are compared on the basis of their ostracode species composition using the Otsuka similarity coefficient  $(C/\sqrt{N_1N_2}) \times 100$ ; clustering was by the unweighted pair-group method.

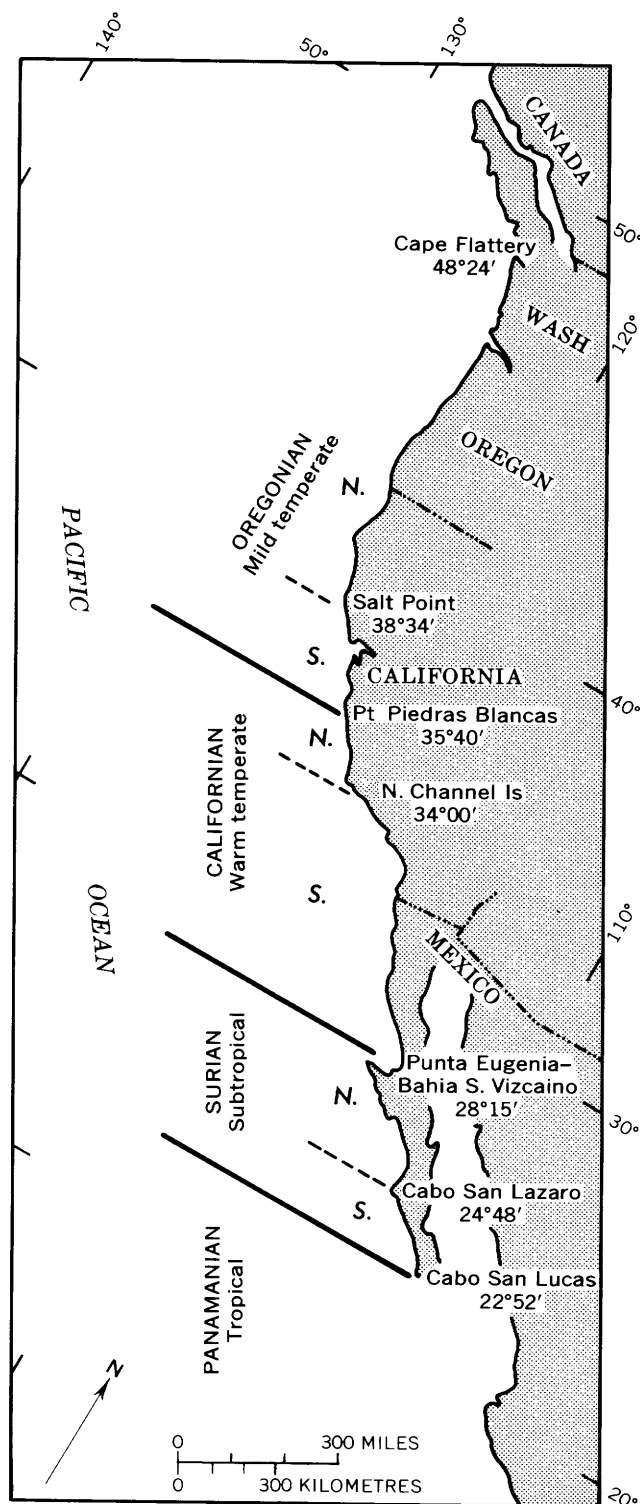


FIGURE 9.—The geographic extent of faunal provinces and climatic zones of the eastern Pacific shelf based on distributions of ostracode species.

#### FAUNAL CHARACTER OF PROVINCES AND PROVINCIAL BOUNDARIES

As noted, 192 diagnostic species out of a total of 341 Holocene species have been used in this zoogeo-

graphic study. The geographic ranges of Holocene species and the occurrence of species in Pliocene and Pleistocene units are shown in table 4, and some of the important members of the fauna are illustrated in the plates. Of the 56 genera treated in the total fauna (Holocene and fossil), 50 occur in the Holocene, and 9 are particularly diverse. Others, though less diverse, are important members of the fauna. The generic ranges which will now be discussed are based on the results of this study and, for occurrences in the Panamanian province, the literature was a determining factor. The Gulf of California is considered to be part of the Panamanian province.

The genus *Ambostracon* contains 21 species, 20 of which occur in the Holocene. *Ambostracon* is found in all provinces, but reaches its highest diversity in the Californian province. *Loxoconcha*, comprising 8 Holocene species, ranges throughout all four provinces. Another diverse genus, *Caudites*, is represented by 15 species in the Holocene, all but one of which occur in the Surian province. Eleven species of *Caudites* are endemic to the Surian, and the genus is restricted to the south of Point Piedras Blancas. *Caudites* is also recorded in the Panamanian province.

*Kangarina* contains 9 species (8 occur in the Holocene) and is mainly an element of the Californian and Surian provinces; it is also known to occur in the Panamanian. Likewise, *Paracytheridea* (8 Holocene species) is found only in the Panamanian, Surian, and Californian provinces. *Hemicytherura* is represented by 12 species which are rather evenly distributed throughout the study area, although it is not yet known from the Panamanian province.

"*Hemicythere*" is an undescribed genus based on LeRoy's (1934a) *Hemicythere? californiensis* (two forms recognized by LeRoy) and *H.? hispida* forms. This taxon includes 10 species, 9 of which occur in the Holocene, and it is found chiefly in the Californian province and the northern Surian subprovince, although it is reported from the Panamanian province (Gulf of California; Swain, 1967). *Hermanites* includes 9 species, 8 occurring in the Holocene; the genus occurs in the Californian and Surian provinces, and it too has been reported from the Gulf of California.

"*Aurila*" is an undescribed genus (or genera) and comprises 8 species, 6 of which occur in the Holocene. This group has representatives throughout the four provinces. *Radimella* (4 species occurring in the Holocene) occurs chiefly in the Californian and more southern provinces, but 1 species ranges into the southern Oregonian subprovince. "*Radimella*,"

TABLE 4.—Holocene geographic ranges and fossil occurrences of ostracode species in the study area  
[F=species occurs only in fossil deposits]

No.	Species	Holocene geographic range		Fossil occurrence						
		15-minute sample range	Maximum latitudinal range (north)	San Diego Formation	San Pedro Formation Lomita Marl Member	Timms Point Silt Member	Palos Verdes Sand	Santa Barbara Formation	Foxen Mudstone	Careaga Sandstone
001	<i>Ambostracon</i> sp. A	053-108	34°30'-48°30'							
002	<i>Aurila lincolniensis</i>	028-108	28°15'-48°30'	×	×			×	×	
003	<i>Kangarina</i> sp. A	034-044	29°45'-32°30'							
004	<i>Aurila</i> sp. A	028-108	28°15'-48°30'	×	×			×	×	×
005	<i>Hermanites</i> sp. G	044	32°15'-32°30'	×	×			×	×	×
006	<i>Aurila</i> sp. B	026-057	27°45'-35°45'	×	×				×	×
007	<i>Aurila montereyensis</i>	053-107	34°30'-48°15'					×		
008	" <i>Aurila</i> " sp. C	028-063	28°15'-37°15'	×	×		×			
009	<i>Aurila</i> sp. C	036-085	30°15'-42°45'		×		×	×		
010	A. sp. D	014-057	24°45'-35°45'		×		×			
011	<i>Hemicythera</i> sp. A	064-108	37°15'-48°30'							
012	H.? sp. C	109, 110	22°45'-25°00'							
		006-014								
013	H. sp. B	081-108	41°30'-48°30'							
014	<i>Triebelina reticulopunctata</i>	021-051	26°30'-34°15'	×						
015	<i>Cativella</i> sp. B	001-003	21°30'-22°15'							
015F	<i>Ambostracon</i> sp. C								×	×
016	<i>Pterygocythereis?</i> sp. A	001-003	21°30'-22°15'							
016F	" <i>Aurila</i> " sp. G			×						
017	<i>Cativella</i> sp. A	023-056	27°00'-35°30'							
018	<i>Pulmilocytheridea pseudoguardensis</i>	014-036	24°45'-30°30'	×						
019	<i>Puriana pacifica</i>	109,	22°00'-35°30'							
		003-056								
020	<i>Caudites fragilis</i>	023-057	27°00'-35°45'	×	×		×			
021	<i>Caudites</i> sp. J	109	23°15'-23°30'							
022	<i>Caudites</i> sp. B	014-052	24°45'-34°30'				×			
023	<i>Caudites purii</i>	021-028	26°30'-28°30'							
024	<i>Puriana</i> sp. A	001-003	21°30'-22°15'							
024F	" <i>Aurila</i> " sp. H			×						
025	<i>Caudites</i> sp. D	109,	22°45'-28°00'							
		006-026								
026	<i>Radimella palosensis</i>	014-068	24°45'-38°30'		×		×			
027	<i>Caudites</i> sp. E	109,	22°45'-28°00'							
		006-026								
028	" <i>Radimella</i> " <i>aurita</i>	014-062	24°45'-37°00'		×		×			
029	<i>Coquimba</i> sp. A	022-051	26°45'-34°15'	×	×	×	×	×		
030	<i>Radimella</i> sp. A	109, 110	22°45'-32°45'							
		006-045								
031	R. sp. B	109, 110,	22°45'-27°15'							
		006-023								
032	<i>Sahnia</i> sp. A	023-107	27°00'-48°15'				×			
033	<i>Pontocythere</i> sp. C	053-108	34°30'-48°30'							
034	<i>Triebelina</i> sp. A	025-049	27°30'-33°45'	×						
035	<i>Cythere maia</i>	022-057	26°45'-35°45'	×	×					
036	<i>Kangarina</i> sp. B	034-045	29°45'-32°45'					×		
037	<i>Cythere</i> sp. A	069-108	38°30'-48°30'						×	
038	<i>Kangarina</i> sp. C	021-067	26°30'-38°15'		×					×
039	<i>Cythere</i> sp. B	067-108	38°00'-48°30'					×	×	
040	" <i>Trachyleberis</i> " sp. A	001-003	21°30'-22°15'							
040F	<i>Bythocythere</i> sp. A							×		
041	<i>Caudites</i> sp. L	110	23°30'-23°45'							
042	" <i>Trachyleberis</i> " sp. B	001-003	21°30'-22°15'							
042F	<i>Coquimba</i> sp. B			×	×					
043	<i>Cytherelloidea</i> sp. A	109,	22°45'-34°00'					×		
		006-050								
044	C. sp. C	109, 110	23°15'-23°45'							
045	<i>Kangarina</i> aff. <i>K. quellita</i>	109, 110,	22°45'-28°00'							
		006-026								
046	" <i>Cytheretta</i> " sp. A	052-108	34°15'-48°30'							
047	<i>Pellucistoma</i> sp. B	014-027	24°45'-28°15'							
048	<i>Cytheromorpha</i> sp. A	056-108	35°15'-48°30'						×	
049	<i>Pellucistoma bensoni</i>	023-051	27°00'-34°15'		×					
050	<i>Cytheropteron</i> sp. A	067-108	38°00'-48°30'							
051	<i>Pellucistoma</i> sp. A	025-049	27°30'-33°45'							
052	<i>Palaciosia</i> sp. C	049-059	33°30'-36°15'							
053	<i>Ambostracon</i> sp. Q	021-025	26°30'-27°45'							
054	<i>Hemicytherura</i> sp. A	053-108	34°30'-48°30'							
055	H. sp. B	053-108	34°30'-48°30'							
056	" <i>Aurila</i> " <i>californica</i>	109, 110,	22°00'-32°45'							
		003-045								
057	<i>Hemicytherura</i> sp. C	021-052	26°30'-34°30'	×	×			×	×	×
058	<i>Munseyella pedroensis</i>	027-053	28°00'-34°45'		×	×		×		
059	<i>Hemicytherura</i> sp. D	056-107	35°15'-48°15'					×		
060	H. sp. F	006-041	22°45'-31°45'							
061	<i>Pectocythere clavata</i>	049-052	33°30'-34°30'			×		×		
062	<i>Hemicytherura</i> sp. H	034-059	29°45'-36°15'	×	×			×		
063	H. sp. G	006-014	22°45'-25°00'							
064	H. sp. I	036-107	30°15'-48°15'	×	×			×		
065	H. sp. E	082-108	41°45'-48°30'							
066	H. sp. J	034-107	29°45'-48°15'	×				×		
067	H. sp. K	027-049	28°00'-33°45'							
068	H. sp. L	034-081	29°45'-41°45'		×			×		
069	<i>Cativella semitranslucens</i>	028-052	28°15'-34°30'		×			×		
070	<i>Hermanites kewi</i>	046-057	32°45'-35°45'	×	×	×	×	×	×	×
071	H. sp. B	021-028	26°30'-28°30'	×	×					
072	H. sp. F	025-034	27°30'-30°00'		×					
073	H. sp. C	028-050	28°15'-34°00'	×	×					
074	H. sp. D	026-056	27°45'-35°30'	×	×		×			
075	<i>Caudites</i> sp. M	014-026	24°45'-28°00'							
076	<i>Pontocythere</i> sp. B	028-068	28°15'-38°30'			×	×			
077	" <i>Kangarina</i> " sp. A	036-108	30°15'-48°30'					×		
078	" <i>Bradleya</i> " <i>simiensis</i>	047-050	33°00'-34°00'		×	×	×	×		

TABLE 4.—Holocene geographic ranges and fossil occurrences of ostracode species in the study area—Continued

No.	Species	Holocene geographic range		Fossil occurrence						
		15-minute sample range	Maximum latitudinal range (north)	San Diego Formation	San Pedro Formation Lomita Marl Member	Timms Point Silt Member	Palos Verdes Sand	Santa Barbara Formation	Foxen Mudstone	Careaga Sandstone
079	<i>Loxococoncha</i> sp. A	056-108	35°15'-48°30'						X	
080	<i>Loxocorniculum</i> sp. B	109, 110	22°45'-23°45'							
		006								
081	<i>Loxococoncha helenae</i>	051-085	34°00'-42°45'			X		X		
082	<i>L. lenticulata</i>	041-052	31°30'-34°30'	X	X	X	X	X		
083	<i>L. sp. B</i>	025-063	27°30'-37°15'		X		X			
084	<i>L. sp. D</i>	036-048	30°15'-33°30'							
085	<i>L. sp. C</i>	034-052	29°45'-34°30'	X				X	X	
086	<i>Loxocorniculum</i> sp. A	023-049	27°00'-33°45'	X			X			
087	<i>Coquimba pichelinguensis</i>	109, 110	22°45'-28°00'							
		006-026								
088	<i>Munseyella</i> sp. A	036-045	30°15'-32°45'							
089	<i>M. sp. C</i>	062-108	36°45'-48°30'							
090	<i>M. sp. B</i>	045-095	32°30'-45°15'		X			X		
091	<i>Ambostracon</i> sp. B	045-108	32°30'-48°30'	X					X	X
092	<i>Costa? sanfelipensis</i>	001-003	21°30'-22°15'							
092F	<i>Buntonia</i> sp. C					X				
093	<i>Ambostracon glaucum</i>	028-057	28°15'-35°45'	X			X		X	
094	<i>A. diegoensis</i>	028-050	28°15'-34°00'	X	X					
095	<i>A. sp. J</i>	014-057	24°45'-35°45'	X	X		X	X		
096	<i>Buntonia</i> sp. B	048-051	33°15'-34°15'	X	X			X		
097	<i>Ambostracon</i> sp. K	109,	22°45'-25°00'							
		006-014								
098	<i>A. sp. N</i>	021-050	26°30'-34°00'		X	X		X		
099	<i>A. sp. L</i>	028-051	28°15'-34°15'	X	X					X
100	<i>Catvella unitaria</i>	003	22°00'-22°15'							
100F	<i>Buntonia</i> sp. A									X
101	<i>Ambostracon</i> sp. E	053-108	34°30'-48°30'	X						
102	<i>Basslerites</i> sp. B	028-041	28°15'-31°45'							
103	<i>Ambostracon</i> sp. G	021-108	26°30'-48°30'	X	X		X		X	
104	<i>Basslerites delreyensis</i>	036-065	30°15'-37°45'		X					
105	<i>Cytherelloidea</i> sp. B	003	22°00'-22°15'							
105F	<i>Cytheropteron</i> sp. B				X			X		
106	<i>C. dobladoensis</i>	001-003	21°30'-22°15'							
106F	"Hemicythere" sp. H									X
107	"Radimella" jollaensis	021-108	26°30'-48°30'	X	X	X	X	X	X	
108	"A." schumannensis	062-108	36°45'-48°30'							X
109	"Radimella" pacifica	014-073	28°34'-39°45'	X	X					X
110	"Aurila" sp. D	028-057	28°15'-35°45'	X	X	X	X	X	X	
111	<i>Radimella</i> sp. A	028-108	28°15'-48°30'	X	X	X	X	X		
112	"A." sp. E	063-108	37°00'-48°30'							
113	"A." driveri	028-056	28°15'-35°30'	X	X	X	X	X	X	X
114	<i>Ambostracon</i> sp. P	022-027	26°45'-28°15'							
115	<i>Cytheropteron johnsonoides</i>	003-006	22°00'-23°00'							
116	<i>Ambostracon</i> sp. O	023-050	27°00'-34°00'	X					X	
117	"Paijenborchella" sp. A	053-108	34°30'-48°30'						X	
118	<i>Ambostracon</i> sp. I	023-034	27°00'-30°00'							X
119	"Paijenborchella" sp. B	056-071	35°15'-39°15'							X
120	<i>Ambostracon</i> sp. F	041-051	31°30'-34°15'	X	X		X			
121	<i>Caudites</i> sp. A	045-057	32°30'-35°45'				X			
122	"Hemicythere" californiensis	027-071	28°00'-39°15'	X	X	X	X	X	X	
123	"Hemicythere" sp. A	027-051	28°00'-34°15'	X	X	X	X	X	X	X
124	"H." sp. F	022-027	26°45'-28°15'							
125	"H." sp. E	025-036	27°30'-30°30'							
126	<i>Ambostracon microreticulatum</i>	028-056	28°15'-35°30'	X	X		X		X	
127	<i>Cytheromorpha</i> sp. B	051-108	34°00'-48°30'		X	X		X		X
128	<i>Neocaudites? henryhowei</i>	026-045	27°45'-32°45'							
129	"Cytheretta" sp. C	041-052	31°30'-34°30'	X						
130	New genus F sp. A	067-108	38°00'-48°30'							X
131	"Hemicythere" sp. C	014-036	24°45'-30°30'							
132	<i>Hermanites</i> sp. A	026-036	27°45'-30°30'							
133	"Cytheretta" sp. B	025-052	27°30'-34°30'	X		X			X	X
134	<i>Orionina pseudovaughni</i>	109, 110,	21°30'-27°15'							
		001-023								
135	<i>Palaciosia</i> sp. A	036-068	30°15'-38°30'		X				X	
136	<i>Cytherelloidea californica</i>	006-056	22°45'-35°30'	X	X		X	X	X	
137	<i>Palaciosia</i> sp. B	034-065	29°45'-37°45'	X						
138	<i>Cytherella banda</i>	036-051	30°15'-34°15'							
139	<i>Palaciosia</i> sp. D	022-034	26°45'-30°00'				X			
140	<i>Cytherella</i> sp. A	001-003	21°30'-22°15'							
140F	<i>Hermanites</i> sp. H				X			X		
141	<i>Palmenella californica</i>	025-056	27°30'-35°30'	X		X	X	X	X	X
142	<i>Paracytheridea</i> sp. B	022-051	26°45'-34°15'	X	X				X	
143	<i>P. sp. A</i>	022-057	26°45'-35°45'	X	X			X		
144	<i>P. sp. C</i>	021-050	26°30'-34°00'							
145	<i>P. sp. D</i>	023-041	27°00'-31°45'							
146	<i>P. granti</i>	041-050	31°30'-34°00'	X	X	X		X		
147	<i>Pectocythere</i> sp. A	053-108	34°30'-48°30'						X	X
148	<i>P. tomalensis</i>	062-108	36°45'-48°30'							
149	<i>Kangarina</i> sp. H	048-050	33°15'-34°00'							
150	<i>Ambostracon californicum</i>	050-051	33°45'-34°15'		X	X	X	X		
151	<i>A. costatum</i>	048-051	33°15'-34°15'	X	X	X				
152	<i>A. sp. D</i>	050-056	33°45'-35°30'					X		
153	<i>Puriana</i> sp. B	006	22°45'-23°00'							
154	<i>Ambostracon</i> sp. M	049-108	33°30'-48°30'	X	X			X	X	
155	<i>Basslerites thlipsuroidea</i>	001	21°30'-21°45'							
155F	<i>Kangarina</i> sp. G				X				X	
156	<i>Caudites</i> sp. C	109, 110,	22°45'-25°00'							
		006-014								
157	<i>C. sp. K</i>	109	23°15'-23°30'			X	X	X	X	X
158	<i>Coquimba schencki</i>	028-051	28°15'-34°15'	X			X	X	X	X

TABLE 4.—Holocene geographic ranges and fossil occurrences of ostracode species in the study area—Continued

No.	Species	Holocene geographic range		Fossil occurrence						
		15-minute sample range	Maximum latitudinal range (north)	San Diego Formation	San Pedro Formation	Palos Verdes Sand	Santa Barbara Formation	Foxen Mudstone	Careaga Sandstone	
159	<i>Pontocythere</i> sp. A	044-050	32°15'-34°00'	×	--	×	--	--	--	--
160	New genus D sp. A	052-068	34°15'-38°30'	--	--	--	--	×	×	--
161	<i>Cytheropteron newportense</i>	050-052	33°45'-34°30'	--	--	--	--	--	--	--
162	" <i>Hemicythere</i> " <i>hispida</i>	048-051	33°15'-34°15'	×	×	--	×	--	--	--
163	"H." sp. D	041-050	31°30'-34°00'	--	×	--	×	--	--	--
164	<i>Eucytherura</i> sp. A	001-003	21°30'-22°15'	--	--	--	--	--	--	--
164F	<i>Krithe</i> sp. A	-----	-----	--	×	--	×	--	--	--
165	" <i>Hemicythere</i> " sp. G	048-052	33°15'-34°30'	--	×	×	×	--	--	--
166	<i>Hermanites</i> sp. E	036-049	30°15'-33°45'	×	--	--	--	--	--	--
167	<i>Loxoconcha</i> sp. E	109, 110, 003-050	22°00'-34°00'	--	--	--	--	--	--	--
168	<i>Loxocorniculum sculptoides</i>	109, 110, 006-014	22°45'-25°00'	--	--	--	--	--	--	--
169	<i>Loxoconcha</i> sp. F	109, 110, 006-014	22°45'-25°00'	--	--	--	--	--	--	--
170	" <i>Loxoconcha</i> " <i>emaciata</i>	109, 110, 006	22°45'-23°45'	--	--	--	--	--	--	--
171	" <i>Bradleya</i> " <i>pennata</i>	028-056	28°15'-35°30'	--	×	×	--	×	--	--
172	New genus A sp. A	028-050	28°15'-34°00'	--	×	--	--	--	--	--
173	<i>Paracytheridea</i> sp. E	041-051	31°30'-34°15'	×	×	×	×	--	--	--
174	<i>Basslerites</i> sp. C	001	21°30'-21°45'	--	--	--	--	--	--	×
174F	<i>Munseyella similis?</i>	-----	-----	--	--	--	--	--	--	×
175	<i>Paracytheridea</i> sp. F	109, 110, 006	22°45'-23°45'	--	--	--	--	--	--	--
176	<i>P.</i> sp. G	041-050	31°30'-34°00'	--	×	--	×	--	--	--
177	<i>Caudites</i> sp. H	109, 110, 006	22°45'-23°45'	--	--	--	--	--	--	--
178	<i>Bythoceratina</i> sp. A	003	22°00'-22°15'	--	--	--	--	--	--	--
178F	<i>Munseyella</i> sp. D	-----	-----	--	--	--	×	--	--	--
179	<i>Pellucistoma scrippsi</i>	109, 110, 006-052	22°45'-34°30'	--	--	--	--	--	--	--
180	<i>Periasocytheridea pedroensis</i>	045-050	32°30'-34°00'	--	×	×	×	--	--	--
181	<i>Caudites</i> sp. F	006-014	22°45'-25°00'	--	--	--	--	--	--	--
182	" <i>Radimella</i> " sp. B	028-051	28°15'-34°15'	--	×	--	--	×	--	--
183	<i>R. convergens</i>	109	23°15'-23°30'	--	--	--	--	--	--	--
184	<i>Kangarina</i> sp. D	036-049	30°15'-33°45'	--	×	--	--	--	--	--
185	<i>K.</i> sp. E	006	22°45'-23°00'	--	--	--	--	--	--	--
186	" <i>Hemicythere</i> " sp. B	044-051	32°15'-34°15'	--	×	--	×	×	×	×
187	" <i>Cytheretta</i> " <i>corrugata</i>	041-051	31°30'-34°15'	×	×	--	×	--	--	--
188	<i>Kangarina</i> sp. F	003	22°00'-22°15'	--	--	--	--	--	--	--
188F	New genus B sp. A	-----	-----	--	--	×	--	--	--	--
189	<i>Pectocythere</i> sp. B	088-108	43°15'-48°30'	--	--	--	--	--	--	--
190	<i>Caudites</i> sp. G	014	24°45'-25°00'	--	--	--	--	--	--	--
191	<i>C.</i> sp. I	014	24°45'-25°00'	--	--	--	--	--	--	--
192	<i>Pontocythere</i> sp. D	006	22°45'-23°00'	--	--	--	--	--	--	--
193F	New genus C sp. A	-----	-----	--	--	--	--	--	--	×
194F	New genus E sp. A	-----	-----	×	--	--	--	--	--	×
195F	<i>Paijenborchella</i> sp. A	-----	-----	--	--	--	--	×	×	×
196F	<i>Pectocythere</i> sp. D	-----	-----	--	--	--	--	×	×	--

another undescribed genus (or genera) comprising 5 Holocene species, occurs in the Surian, Californian, and Oregonian provinces.

*Cythere*, a genus usually restricted to northern latitudes in other parts of the world (Hazel, 1970), includes 3 species in the study area, 2 of which occur in the Oregonian province and probably range farther north. One species, however (*Cythere maia*), is confined to the Californian and northern Surian sub-province, and although it is very similar to one of the northern species (*Cythere* sp. B), it is distinctive, and their ranges do not overlap. Its present distribution may be the result of southward migration facilitated by the cooling of coastal waters by upwelling. *Hemicythere*, represented by 2 Holocene species, is another cryophilic genus (Hazel, 1970), and it occurs only in the Oregonian province and most probably farther north.

A summary of the provincial distribution of these and other important genera follows. Numbers in parentheses indicate, first, species occurring in the Holocene and, secondly, species occurring only in the Pliocene or Pleistocene.

#### Panamanian-Oregonian provinces:

<i>Ambostracon</i>	(20; 1)
" <i>Aurila</i> "	(6; 2)
<i>Cytheropteron</i>	(4; 1)
" <i>Hemicythere</i> "	(9; 1), mainly Californian and south.
<i>Kangarina</i>	(8; 1), mainly Californian and south.
<i>Loxoconcha</i>	(8; 0)
<i>Pontocythere</i>	(4; 0)
<i>Radimella</i>	(4; 0), mainly Californian and south.

## Panamanian-Californian provinces:

<i>Cativella</i>	(4; 0)
<i>Caudites</i>	(15; 0)
<i>Coquimba</i>	(3; 1)
<i>Cytherelloidea</i>	(4; 0)
<i>Hermanites</i>	(8; 1)
<i>Loxocorniculum</i>	(3; 0)
<i>Paracytheridea</i>	(8; 0)
<i>Pellucistoma</i>	(4; 0)
<i>Puriana</i>	(3; 0)

These genera do not range north of Point Piedras Blancas.

## Surian-Oregonian provinces:

<i>Aurila</i>	(6; 0), mainly Californian and north.
<i>Cythere</i>	(3; 0)
" <i>Cytheretta</i> "	(4; 0), mainly Californian and north.
<i>Hemicytherura</i>	(12; 0)
<i>Munseyella</i>	(4; 2), mainly Californian and north.
" <i>Radimella</i> "	(5; 0)

## Californian-Oregonian provinces:

" <i>Paijenborchella</i> "	(2; 0), does not range south of Point Conception.
<i>Pectocythere</i>	(4; 1)

## Oregonian province:

<i>Hemicythere</i>	(2; 0), does not range south of Point Piedras Blancas.
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This summary clearly indicates the magnitude of the faunal discontinuity between the Californian and Oregonian provinces. Nine important genera terminate their northern ranges in the Californian province. The nature of other provincial boundaries, namely the Panamanian-Surian and the Surian-Californian, are not as well understood on the basis of generic distributions. From the information at hand, it seems that the Panamanian-Surian discontinuity may be of the magnitude of the Californian-Oregonian break. The Surian-Californian faunal boundary is probably of less magnitude, as indicated by the fact that these two provinces show more similarity to each other than to either the Oregonian or Panamanian provinces (fig. 8).

The distributions of ostracode genera provide a broad outline of provincial configuration. The faunal character of a province can be more precisely evaluated on the basis of the numbers of species it contains and their distribution patterns within and outside of the province (tables 4, 5). The northern limit of the study area apparently does not include the northern boundary of the Oregonian province, and therefore comparative figures on the occurrences of species in this province are incomplete.

TABLE 5.—Distribution of inner sublittoral ostracode species and their occurrence in faunal provinces off the west coast of North America

[Based on 143 species which range through at least 2° of latitude; also included are 28 species which exhibit short ranges or single occurrences in the Panamanian province and adjacent southern Surian subprovince and are considered to represent northern distributional limits of southern species]

Eastern Pacific faunal province	PANAM:	SURIAN				CALIFORNIAN				OREGONIAN																				
Subprovince		S		North		South		N	South	North																				
Latitude north		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Northern range end points of ostracode species	16			12		15				34				29			22	7*												
				27				63				29																		
Southern range end points of ostracode species	4			17		45				49				16			8	4												
				62				65				12																		
Endemic species	-			0		2				13				0			0	?												
				14				27				?																		
Species ranging through	?			4		8				30				37			31	?												
				3				15				?																		
Species in common	-			21						66								39												
Total species	20			33		66				100				82			61	42												
				78				116				64																		

Limit of study area

\*36 species range north to 48°24'N (limit of study area), and it is not known at this time how many range on northward.

Limit of study area

Of the 171 species treated in table 5, the Oregonian, Californian, and Surian provinces contain 64, 116, and 78 species, respectively. A similar diversity trend was noted in molluscan distributional studies (J. W. Valentine, 1966, table 2). The increase in diversity from the Oregonian to the Californian province conforms to the generally recognized latitudinal diversity gradient which increases from polar to equatorial regions. Ostracode as well as molluscan diversity decreases from the Californian to the Surian province, however. This reduction in the number of species may simply be the result of a lack of adequate sampling along the coasts of southern Baja California, or it may be partially due to lower habitat diversity in the Surian province, which is smaller areally than the Californian.

The boundary between the Californian and Oregonian provinces is characterized by many range endpoints. This boundary is essentially the result of northern range terminations of thermophilic species and actually occurs in two steps—a southern break between the southern and northern subprovinces of the Californian province at 34° N. where, within 1° of latitude, 37 southern species end their ranges (contrasted with only 6 endpoints of northern species), and a northern break between the Californian and Oregonian province at about 35°30' N. where 19 thermophiles end their ranges within 1° of latitude (against only 4 southern endpoints for cryophiles). This major faunal discontinuity is related to the marine climatic regime (figs. 6, 7). The southern faunal elements encounter the coolest water in their ranges in the area between 34° N. and 35°45' N. where the temperature minimum is 11° to 12° C. It is difficult to ascertain whether the temperature minima represent a survival limit for the northward-ranging thermophiles, or whether the maximum yearly temperatures are more important. The minimum yearly temperatures of 11° to 12° C in this area also occur to the north, whereas the maximum yearly temperatures of 14° to 17° C do not, an indication that maximum water temperatures may not be high enough to permit repopulation, thus limiting the northward expansion of thermophilic species. Southward ranging cryophiles are little affected because the thermal maxima in this area (14° to 17° C), which they tolerate, extend continuously farther south within the Californian province due to upwelling along the coast (figs. 5, 6, 7).

The boundary between the Californian and Surian provinces is characterized by the occurrence of range endpoints of northern species and is of lesser magnitude (see fig. 8, where clusters B and C indi-

cate closer affinity than do A and B.) At this boundary 26 cryophiles end their ranges within 1° of latitude while only 6 thermophiles drop out. In fact, 49 southward-ranging species terminate their ranges in the southern Californian subprovince, and they drop out in a stepwise manner southward, an indication that these species are reaching their temperature limits in areas where temperature maxima are dampened by upwelling. They may be reacting to increased temperature and survival limits or to the failure of upwelling to produce temperatures low enough to allow repopulation. Temperature minima enhanced by upwelling occur both north and south of the Californian–Surian boundary at Punta Eugenia–Bahia S. Vizcaino. Cryophilic species ranging southward past this boundary must pass through an apparent barrier of shallow, relatively warm waters of the bay to reach the cool, upwelled waters south of Punta Eugenia; they must then be able to tolerate still higher temperatures during thermal maxima in an area where upwelling occurs only seasonally.

The northern and southern Surian subprovinces are similar in that their northern boundaries are marked by promontories where seasonal upwelling lowers the temperature markedly; to the south, however, the coasts are embayed and little or no upwelling occurs. Because these waters are warmed both by solar radiation and by a warm surface countercurrent in the summer and fall, the annual range of temperature is greater (as much as 10° C in the areas where seasonal upwelling occurs) than that (3° to 6° C) to the north in the Californian province. Many cryophilic species (62), chiefly from the Californian province where waters are cooler, end their ranges in the Surian province. They can survive temperature minima in the upwelling areas of the Surian province, but temperature maxima limit their southward movement. Perhaps they survive where they do because minimum temperatures are cool enough for repopulation to occur and maximum temperatures are not high enough to kill. When temperatures remain too high for repopulation or become high enough to be lethal, these species can no longer expand southward. Of the 27 species which end their northern expansion in the Surian province, many are endemic. It is possible that their range records will be extended southward when better collections can be made in this area and in the adjacent Panamanian province. Formidable thermal barriers limit the northward expansion of species through the Surian province, principally the two large areas of upwelling to the south of Cabo San Lazaro and Punta Eugenia (fig. 5). Maximum temperatures in



these regions may well be tolerated by southern species, but minima due to upwelling can be more than 10° C lower than maxima and probably reach the killing temperatures of many species.

The Panamanian province is here represented by only a few samples which contain a total of 20 species, 16 of which do not occur in the Surian province to the north. This suggests that the Surian-Panamanian boundary represents a major faunal discontinuity in ostracode distributions, but more detailed sampling is needed to verify this assumption.

Although there are few species endemic to any province, there are also few that range through an entire province, though many range through each subprovince (tables 4 and 5). The nature of their geographic distribution illustrates the response of species to changes in the marine climate within provinces as well as at provincial boundaries. Although faunal provinces are equated with climatic zones, a practice which lends a somewhat quantitative aspect to the provincial marine climate, such usage should not be construed to indicate that a province exhibits a particular climate throughout. If this were the case, there would be many more endemic species, and range endpoints of species would occur almost exclusively at provincial boundaries, a situation which of course does not occur.

It is noted in table 5 that the southern Surian, northern Californian, and southern Oregonian subprovinces do not contain any endemic species. These subprovinces occupy short segments of coastline and small areas of shelf compared to other subprovinces, and they might be considered to represent areas of overlap of species chiefly confined to neighboring provinces. However, as shown in the cluster analysis (fig. 8), the subprovinces within each major province cluster at approximately the same level and therefore appear to constitute entities of equivalent importance. Although the importance of endemic species in defining faunal provinces has been emphasized by some workers (Ekman, 1953; Holland, 1971), I feel that faunal distinctiveness rather than the presence or absence of a certain number of endemic species should be the criterion for recognition of a faunal province. Indeed, as has just been shown, endemics make up a very small proportion of the faunas of even the larger areas considered by most workers to represent faunal provinces; this situation has also been observed in molluscan studies (J. W. Valentine, 1966, table 2).

#### MARINE PALEOCLIMATES OF SELECTED PLIOCENE AND PLEISTOCENE UNITS OF SOUTHERN CALIFORNIA

A knowledge of the Holocene distributional patterns of the Ostracoda and determination of the marine climatic conditions which govern those distributions provide a basis for the initiation of paleoecologic analyses of fossil ostracode assemblages. Studies of ostracode (paleo)zoogeography will also provide a test for conclusions already drawn from more extensive investigations which have been conducted with the Mollusca and Foraminifera. It is hoped that studies of a heretofore neglected group will contribute to an understanding of the factors controlling provincial biogeography in general.

An effort has been made to utilize the information resulting from study of Holocene ostracode zoogeography to interpret marine climatic conditions during the late Cenozoic at selected locations along the coast of southern California. The paucity of information on ostracode fossil assemblages on the west coast constrains the scope of the investigation. The results will therefore be of a preliminary nature.

#### FOSSIL COLLECTIONS

Collections were made from formations of Pliocene to Pleistocene age which occur in four areas along the California coast (fig. 3). These units and their generally accepted ages include: San Diego Formation (late Pliocene age) at San Diego (32°48' N.); San Pedro Formation (early Pleistocene age) and the Palos Verdes Sand (late Pleistocene age) at San Pedro (33°44' N.); Santa Barbara Formation (early Pleistocene age) at Santa Barbara (34°25' N.); and the Foxen Mudstone (middle to late Pliocene age) and the Careaga Sandstone (late Pliocene age) of the Santa Maria district (34°54' N.).

The stratigraphy of these units has been adequately described by others and will be only summarized herein. The ages of some of the formations treated here are in dispute, especially with respect to the placement of the Pliocene-Pleistocene boundary in the west coast sequence. Delineation of this boundary has been reviewed elsewhere (Woodring, 1952; J. W. Valentine, 1961; Bandy, 1967; Bandy and Wilcoxon, 1970). The west coast fossil ostracode assemblages are at this time too poorly known to contribute to the solution of this problem. Previous paleoecologic interpretations are based mainly on fossil molluscan and foraminiferal assemblages; they are reviewed in a later section. A register of fossil localities is in table 6.

TABLE 6.—Register of fossil localities

- Mf2165-2167: Pacific Beach, San Diego, Calif.; La Jolla 7.5' quad., 1953. Locality of Hertlein and Grant, 1944. San Diego Formation (upper Pliocene); approximately 400 ft (120 m) thick; unconformable on Eocene marine sandstones; unconformable under horizontal Bay Point Formation (upper Pleistocene).
- Mf2165: San Diego Formation (upper Pliocene); in a gully in sea cliffs off Crystal Drive where it turns from east-west to north-south; shell bed in yellow-brown marine sands; about 100 ft (30 m) above Eocene-Pliocene contact.
- Mf2166: San Diego Formation (upper Pliocene); 35 ft (11 m) north of the end of Law Street in sea cliff facing Pacific Ocean; white sandy marl containing *Pecten* and echinoid fragments; about 100 ft (30 m) above Mf2165 and approximately in the middle of the exposure at Pacific Beach; about 20 ft (6 m) above high tide; from the beach to the sample locality the outcrop is covered by slumped material and a thick bed of tide-deposited cobbles.
- Mf2167: San Diego Formation (upper Pliocene); 4 ft (1 m) above Mf2166.
- Mf2168, 2169, 2171, 2172: Second St., between Pacific Ave. and Mesa St., San Pedro, Calif.; San Pedro 7.5' quad., 1964. Lomita Marl Member of San Pedro formation (lower Pleistocene) consists of approximately 50 ft (15 m) of marls and calcareous sands; Lomita overlain unconformably by Timms Point Silt Member of San Pedro Formation (lower Pleistocene) which consists of about 80 ft (24 m) of fossiliferous marine silty sands. Horizontal Palos Verdes Sand (upper Pleistocene) unconformably overlies the Timms Point. Localities 42-44 of Woodring and others, 1946. (See their p. 46 for measured sections.)
- Mf2168: Lomita Marl Member (lower Pleistocene); fine-grained marl; lowest sample in Lomita (base not exposed); in an alley across from a bakery on north side of Second St.
- Mf2169: Lomita Marl Member (lower Pleistocene); coarse marl; north side of Second St. in middle of Lomita exposure and approximately 25 ft (8 m) higher than Mf2168.
- Mf2171: Timms Point Silt Member (lower Pleistocene); shell bed in fine-grained marine silty sands; at Lomita-Timms Point contact on

TABLE 6.—Register of fossil localities—Continued

- south side of Second St.; contact burrowed downward into Lomita.
- Mf2172: Timms Point Silt Member (lower Pleistocene); shell bed 20 ft (6 m) above Mf2171 and 6 ft (2 m) below Palos Verdes Sand.
- Mf2170: Lomita Quarry, Torrance, Calif.; Torrance 7.5' quad., 1964, (not shown on this map; see Woodring and others, 1946, pl. 1; also Galloway and Wissler, 1927).
- Mf2170: Lomita Marl Member (lower Pleistocene); marl; near top of formation; "upper foram bed" of Galloway and Wissler, 1927.
- Mf2173: Vacant lot west of Pacific Ave. between Bonita St. and Miner St., San Pedro, Calif.; San Pedro 7.5' quad., 1964.
- Mf2173: Palos Verdes Sand (upper Pleistocene); collected in 2-3 ft (1 m) of shelly marine sands.
- Mf2174, 2175, 2176: West side of Shoreline Drive, south of Castillo St. and 0.1 mile (163 m) southwest of the municipal pool in Santa Barbara, Calif.; Santa Barbara 7.5' quad., 1952. Santa Barbara Formation (lower Pleistocene) consists of about 70 ft (21 m) of silty bryozoan marls, and unconformably overlies the Sespe Formation (Oligocene?).
- Mf2174: Santa Barbara Formation (lower Pleistocene); silty bryozoan marl; approximately 21 ft (6 m) from base of formation.
- Mf2175: Santa Barbara Formation (lower Pleistocene); silty bryozoan marl; approximately 24 ft (7 m) above Mf2074.
- Mf2176: Santa Barbara Formation (lower Pleistocene); silty bryozoan marl; approximately 12 ft (4 m) above Mf2075 and 12 ft (4 m) below top of formation.
- Mf2177, 2178, 2179: Southern Pacific RR cut, 0.75 mile (1.2 km) northeast of Shuman, Calif. (Casmalia 7.5' quad., 1959) where the road from Shuman to Santa Maria crosses RR, at benchmark 370; Guadalupe 7.5' quad., 1959. Locality 170 of Woodring and Bramlette, 1950. (See their p. 38 and p. 44 for measured sections.) Foxen Mudstone (middle to upper Pliocene) consists of about 285 ft (87 m) of fine-grained sands containing shell beds; Careaga Sandstone (upper Pliocene) consists of about 290 ft (90 m) of medium-to coarse-grained sands containing shell beds.
- Mf2177: Foxen Mudstone (middle to upper Pliocene); fine sandy shell bed, about 95 ft (29 m) above base of exposure.

TABLE 6.—Register of fossil localities—Continued

	Mf2178: Foxen Mudstone (middle to upper Pliocene); fine sandy shell bed about 85 ft (26 m) above Mf2077.
	Mf2179: Careaga Sandstone, Graciosa Coarse-Grained Member (upper Pliocene); 3- to 4-ft (1-m) sandy shell bed about 170 ft (52 m) above Foxen-Careaga contact.
Mf2180:	Road cut at Fugler Point; on south side of road from Santa Maria to Garey, Calif.; Twitchell Dam 7.5' quad., 1959 (middle of north side of sec. 35, T. 10 N., R. 33 W.). Locality 178 of Woodring and Bramlette, 1950. (See their p. 47 for measured section.) Careaga Sandstone (upper Pliocene) consists of about 50 ft (15 m) of fine-grained marine sands containing shell beds, often impregnated with asphalt.
	Mf2180: Careaga Sandstone, Cebada Fine Grained Member (upper Pliocene); fine-grained sandy shell bed about 6 ft (2 m) thick near base of exposure; containing many brachiopods and impregnated with asphalt.

All samples except Mf2170 collected in 1971 by Page Valentine and J. W. Valentine, Dept. Geology, Univ. of California, Davis, Calif.; Mf2170 was provided by J. H. Lipps of the same department.

#### STRATIGRAPHY AND AGE OF PLIOCENE AND PLEISTOCENE UNITS SAN DIEGO FORMATION

The San Diego Formation is exposed in the mesas which extend eastward of San Diego, Calif., and southward past the International Boundary. The formation also crops out north of Mission Bay on Mount Soledad and in sea cliffs at Pacific Beach. Hertlein and Grant (1944) provide a review of earlier stratigraphic and paleontologic studies of these beds.

The gently dipping San Diego Formation lies unconformably between Eocene marine sandstone below and Pliocene conglomerates and horizontal Pleistocene marine terrace deposits and nonmarine alluvium above. The formation varies in thickness from over 1,000 ft (300 m) in the mesas to the east to about 400 ft (120 m) at Pacific Beach; lithologically, the sediments range from fine-grained marine sands containing scattered conglomeratic lenses to a white, sandy marl. The exposures in the north-trending cliffs at Pacific Beach, from which samples for the present study were collected, are the most fossiliferous. Here yellow-brown marine sands containing shell beds are overlain by white, sandy, some-

what indurated marls. These beds lie unconformably on Eocene marine sandstones and are capped by horizontal marine terrace deposits of the Bay Point Formation (upper Pleistocene).

According to Hertlein and Grant (1944), W. H. Dall in 1874 first referred these sediments to the Pliocene on the basis of their molluscan fauna; Hertlein and Grant consider the San Diego Formation to be of middle Pliocene age. Woodring and others (1940, p. 112) indicate (in a correlation chart) a probable late Pliocene age for the San Diego Formation at Pacific Beach, while considering other exposures to be early and middle Pliocene; Woodring (1957) still considered the upper part of the San Diego Formation (Pacific Beach) to be of late Pliocene age. J. W. Valentine (1961) cites vertebrate as well as invertebrate faunal evidence in assigning a tentative age of Pliocene and Pleistocene to the San Diego Formation, and this would indicate a possible Pleistocene age for the Pacific Beach beds. Allison (1964) considers the formation to be probably Pleistocene on the basis of vertebrate (horse tooth) evidence. For the purposes of this report, the San Diego Formation at Pacific Beach is considered to be late Pliocene in age.

Sample Mf2165 of this study was collected from a shell bed in marine sands about 100 ft (30 m) above the Eocene-Pliocene contact at Pacific Beach. Samples Mf2166<sup>1</sup> and Mf2167 were collected from the coarse sandy marls about 100 ft above Mf2165 and somewhat above the middle of the exposure which is approximately 400 ft (120 m) thick at Pacific Beach.

#### SAN PEDRO FORMATION AND PALOS VERDES SAND

The San Pedro Formation and the Palos Verdes Sand are exposed in the Palos Verdes Hills, an anticlinal, coastal fault block which rises to about 1,500 ft (460 m) in altitude on the southwest border of the Los Angeles basin. These units crop out chiefly on the north and east slopes of the Palos Verdes Hills, the best exposures occurring in and around the city of San Pedro. Woodring and others (1946) made an exhaustive study of the geology and paleontology of the area; J. W. Valentine (1961) contributed paleoecologic interpretations of the molluscan fauna found in these units. The following summary of the stratigraphy of these two formations has been taken in large part from these two studies.

The gently folded San Pedro Formation is 350–600 ft (105–180 m) thick and includes three mem-

<sup>1</sup> Mf—microfossil.

bers which have been assigned to the lower Pleistocene: the basal Lomita Marl Member, the middle Timms Point Silt Member, and an unnamed upper member ("San Pedro Sand" of Woodring and others, 1946). The Lomita Marl Member is composed of 60–70 ft (20 m) of glauconitic sands, marls, and calcareous sands and lies unconformably on lower Pliocene rocks or Fernando Formation or on the Monterey Shale (Miocene). The age of the Lomita is in dispute. Woodring (1952) assigns it an early Pleistocene age and places the Pliocene-Pleistocene boundary at its base. Obradovich (1968) assigns it an age of 3 million years on the basis of radiometric dating of glauconite, and this would make it Pliocene according to current usage. Fanale and Schaeffer (1965) used helium-uranium ratios to date the Lomita at about 155,000 years or late Pleistocene. Bandy (1967) places it in the lower Pleistocene on the basis of foraminiferal coiling ratios; Bandy and Wilcoxon (1970), however, assign it to the upper Pleistocene on the basis of planktonic foraminiferal and paleomagnetic stratigraphy. Zinsmeister (1970) correlates the upper Pliocene deposits of Newport, Calif., with the Lomita and cites molluscan and fish faunal evidence for a late Pliocene age of the Lomita. The San Pedro Formation is considered to be of early Pleistocene age in this report.

The Timms Point Silt Member is composed of 30–80 ft (9–24 m) of marine silts and sandy silts containing fossiliferous horizons and lies either unconformably or in gradational contact with the Lomita Marl Member below and the "San Pedro Sand" above. The Timms Point is believed to be essentially equivalent in age to the Lomita, but the succession of the two formations documents a radical change in the sedimentary environment.

The "San Pedro Sand" is composed of about 175 ft (55 m) of sands, often crossbedded, which include fossiliferous horizons and beds of silt and gravel; it is truncated by upper Pleistocene terrace deposits.

The Palos Verdes Sand (upper Pleistocene) is a marine terrace deposit consisting of essentially horizontal, fossiliferous, coarse sands and gravels, silty sands and silt. It is as much as 15 ft (5 m) thick and lies unconformably on sediments of Miocene to Pleistocene age.

Samples used in this study were collected from the Lomita Marl and Timms Point Silt Members (lower Pleistocene), which crop out on 2d Street in San Pedro. The Lomita here consists of about 50 ft (15 m) of marls and calcareous sands; sample Mf2168 was taken at the base of the section, and Mf2169 in the middle. The Timms Point was sampled in a basal

shell bed (Mf2171) above the burrowed contact with the Lomita and again 20 ft (6 m) above the contact (Mf2172). A sample (Mf2170) from the Lomita was taken near the top of the formation in the Lomita Quarry ("upper foram bed" of Galloway and Wissler, 1927) on the north side of the Palos Verdes Hills. The "San Pedro Sand" was not sampled. A collection was also made (Mf2173) in a sandy shell bed of the Palos Verdes Sand (upper Pleistocene) which crops out in San Pedro.

#### SANTA BARBARA FORMATION

The Santa Barbara Formation is exposed near the coast southwest of Santa Barbara, Calif., and also at Rincon Point to the east of the city. It has a maximum thickness of about 2,000 ft (600 m), is composed of marine sand, silt, and clay, and lies unconformably on older Tertiary sedimentary rocks (Upson, 1951). Woodring and others (1946) and Woodring (1952, 1957) consider the Santa Barbara Formation to be correlative with the San Pedro Formation (lower Pleistocene), and J. W. Valentine (1961) indicates that the Santa Barbara Formation and the Lomita Marl Member of the San Pedro Formation are equivalent in age.

Collections were made in the lower part of the Santa Barbara Formation at the Bathhouse Beach exposures which dip gently south and lie unconformably on the Sespe Formation (Oligocene?). The beds are about 70 ft (20 m) thick and comprise highly fossiliferous, silty, bryozoan marls. Samples Mf2174, Mf2175, and Mf2176 were collected in sequence from the lower to the upper part of the exposure.

#### FOXEN MUDSTONE AND CAREAGA SANDSTONE

The Foxen Mudstone and the Careaga Sandstone belong to a sequence of marine and nonmarine sediments deposited in the late Tertiary Santa Maria basin. These formations are exposed around and within the Santa Maria district, a northwest-trending lowland on the California coast north of Point Conception. The geography and paleontology of units found in the Santa Maria district have been described by Woodring and Bramlette (1950).

The Foxen Mudstone is a sequence of fossiliferous mudstones, siltstones, and fine-grained sandstones as much as 800 ft (245 m) thick. It is conformable with the Sisquoc Formation (upper Miocene to middle Pliocene) below and the Careaga Sandstone above. On the basis of its molluscan and foraminiferal assemblages, the Foxen has been assigned an age of middle to late Pliocene. The Careaga Sandstone is

composed of two members, a lower fine-grained sandstone of 1,000 ft (300 m) maximum thickness, the Cebada Fine-Grained Member, and an upper coarse-grained sandstone and conglomerate of 425 ft (130 m) maximum thickness, the Graciosa Coarse-Grained Member. The formation lies conformably under the nonmarine Paso Robles Formation of Pliocene(?) and Pleistocene age. Molluscan fossils indicate the Careaga was deposited in late Pliocene time. Woodring and Bramlette (1950) correlate the Careaga with the upper part of the San Diego Formation (exposures at Pacific Beach).

Collections for the present study were made in the upper two-thirds of the Foxen Mudstone and in the Careaga Sandstone which crops out in the Casmalia Hills in the western part of the Santa Maria district. Here about 285 ft (85 m) of the Foxen and 290 ft of the Careaga are exposed. Samples Mf2177 and Mf2178 were collected in the Foxen 95 and 180 ft (29 and 55 m) from the bottom of the exposure. Sample Mf2179 was collected in the Careaga (Graciosa Coarse-Grained Member) 170 ft (52 m) above the Foxen-Careaga contact. An additional collection (Mf2180) was made in the Careaga (Cebada Fine-Grained Member) at Fugler Point on the northeastern edge of the Santa Maria district.

#### COMPARISON OF HOLOCENE AND FOSSIL ASSEMBLAGES

##### FAUNAL COMPOSITION OF FOSSIL UNITS

The Holocene fauna treated in this study comprises 50 genera; of these, 38 also occur in the Pliocene and Pleistocene units. Six genera occur only as fossils (tables 3, 4).

The 12 Holocene genera which are not represented in the Pliocene and Pleistocene are principally those occurring along the coast north or south of the fossil localities which are situated in the Californian province from San Diego to just north of Point Conception. *Bythoceratina*, *Costa*?, *Eucytherura*, *Hemicythere*?, "*Loxoconcha*," *Orionina*, *Pterygocythereis*?, "*Trachyleberis*," two of the three species of *Puriana*, and one of two species of *Cytherella* occur only in the Surian or Panamanian province; *Neocaudites*? occurs south of San Diego; and *Hemicythere* occurs only in the Oregonian province. One species in particular, *Puriana pacifica*, does not occur in fossil assemblages, although it ranges from the Panamanian province north to just south of Point Piedras Blancas at the Californian-Oregonian boundary and is a ubiquitous element of the Holocene assemblages in this area. *Cativella* sp. A is another common Holocene species which is not found

in the fossil assemblages although it ranges from the northern Surian subprovince to just south of Point Piedras Blancas. The absence of these two species as fossils may be due to collecting bias, but the richness of the fossil deposits, especially the Lomita Marl Member of the San Pedro Formation and the Santa Barbara Formation, make this unlikely. Perhaps these species have migrated northward, at least into the shelf areas off San Pedro and Santa Barbara, since the early Pleistocene. The solution of this problem will have to wait until fossil ostracode assemblages along the coast become better known; then it will be feasible to determine movements of species along the shelf through time and possibly to identify the origin of new elements of the fauna.

Paleoecological interpretations of fossil units commonly rely on comparisons of living and fossil assemblages. One must assume, of course, that fossil representatives of a species had environmental tolerances or limits similar to those of the modern representatives of that species. Of the 123 species occurring in fossil units that are included in this investigation, only 19 are not living today; 85 percent of the Pliocene and Pleistocene assemblages under study is extant and forms a broad data base.

Table 7 indicates that practically the entire assemblage of each unit is composed of species living today. Older units generally contain greater percentages of extinct species, except for the Careaga Sandstone. This unit yielded the smallest fauna (27 species) and contains the most extinct species (6). Discovery of several of the fossil species in the Holocene would markedly increase the percentage of the Careaga fauna having living representatives, and it is probable that several of the "extinct" species exist today but have not yet been found in Holocene samples.

#### CLUSTER ANALYSIS OF HOLOCENE AND FOSSIL SAMPLES

The fossil and the Holocene shelf samples were subjected to a cluster analysis similar to that performed on the Holocene samples alone. It has been emphasized that faunal assemblages and provinces change character through time in response to evolutionary and migratory events and to the influences of climatic variations and therefore cannot be replicated, but it still is possible to compare assemblages of differing age and obtain an indication of the distance in time and environment separating them. An affinity to modern faunal provinces will provide a qualitative measure of the marine climate which

TABLE 7.—*Faunal diversity, generic and specific, of each fossil unit and the percentage of the fauna having living representatives*

Formation (age)	Samples	Genera	Fossil species in Holocene	Fossil only	Total species	Percentage of fauna extant
Foxen Mudstone (middle to late Pliocene).	Mf2177, Mf2178	24	35	4	39	90
Careaga Sandstone (late Pliocene).	Mf2179, Mf2180	22	21	6	27	77
San Diego Formation (late Pliocene).	Mf2165, Mf2166, Mf2167	26	56	4	60	93
Lomita Marl Member of San Pedro Formation (early Pleistocene).	Mf2168, Mf 2169, Mf 2170	31	68	5	73	93
Timms Point Silt Member of San Pedro Formation (early Pleistocene).	Mf2171, Mf2172	20	28	2	30	93
Santa Barbara Formation (early Pleistocene).	Mf2174, Mf2175, Mf2176	25	48	5	53	91
Palos Verdes Sand (late Pleistocene).	Mf2173	20	39	0	39	100

prevailed during deposition of the fossil unit.

This analysis was based on 16 fossil samples and 105 Holocene 15-minute samples (006–110). The 15-minute samples located in the Panamanian province, and the 15 species which occur almost exclusively in these samples, were deleted from the analysis to accommodate 19 species that occur only as fossils. The deleted samples are clearly different from the other Holocene samples (fig. 8). The deletion of the 15 Holocene species allowed the data matrix to remain sufficiently small, and it was felt that inclusion of these species would not have altered the results of the cluster analysis, as the fossil samples are obviously most similar to samples occurring north of the Panamanian province. (See table 3 for alphabetical list of ostracode species included in cluster analyses).

The results of the analysis are illustrated in the dendrogram of figure 10. The fossil samples are most similar to samples from the southern Californian subprovince, the Californian province, and the combined Californian–Oregonian provinces, in that order. The assemblages from south of Point Conception (San Diego Formation, Lomita Marl and Timms Point Silt Members of San Pedro Formation, Palos Verdes Sand, and Santa Barbara Formation) indicate a similarity to those of the Californian province, whereas assemblages from the Santa Maria district, to the north, (Foxen Mudstone and Careaga Sandstone) show a relationship to both the Californian and Oregonian provinces. This cluster pattern corroborates other evidence, which will be discussed later, regarding the marine temperatures prevailing during deposition of these units.

It is doubtful that age plays a significant role in determining the affinities between fossil and Holocene assemblages, as most species have living representatives. Age is a factor only insofar as it is expressed in altered climatic conditions and corresponding changes in the composition of assemblages.

#### PALEOTEMPERATURE DETERMINATIONS BASED ON ZOOGEOGRAPHIC EVIDENCE

The determination of yearly marine paleotemperature ranges is based on interpretation of temperature ranges of Holocene species that occur in fossil units. As a first approximation, one might simply plot these ranges and infer that the area of overlap of temperature ranges of cryophiles versus thermophiles represented the possible maximum yearly temperature range and the endpoints the maximum and minimum yearly temperatures. This procedure is based on the assumption that the temperature tolerances determined for Holocene species represent the maximum and minimum temperatures at which they can survive. However, Hutchins (1947) has pointed out that the distributions of marine organisms are limited by temperature in at least two ways. Survival temperatures (minimum and maximum) encompass the widest temperature range within which a species may live. A narrower range is bounded by the maximum and minimum temperatures required by the organism for repopulation, which includes reproduction and larval development.

With regard to the geographic distribution of a species, the minimum survival temperature would occur poleward during the winter, and the minimum temperature required for repopulation would occur poleward in the summer (that is, the water must warm up enough to allow repopulation to occur). The maximum survival temperature occurs equatorward during the summer, and the maximum temperature required for repopulation occurs equatorward in the winter (that is, the water must be cool enough to allow repopulation to occur). As each species may be limited at each end of its geographic range by only one of the two types of temperature limits, four types of species distribution or zonation were established by Hutchins (1947).

Zonal type	Poleward temperature limits	Equatorward temperature limits
1. winter survival		summer survival
2. summer repopulation		winter repopulation
3. summer repopulation		summer survival
4. winter survival		winter repopulation

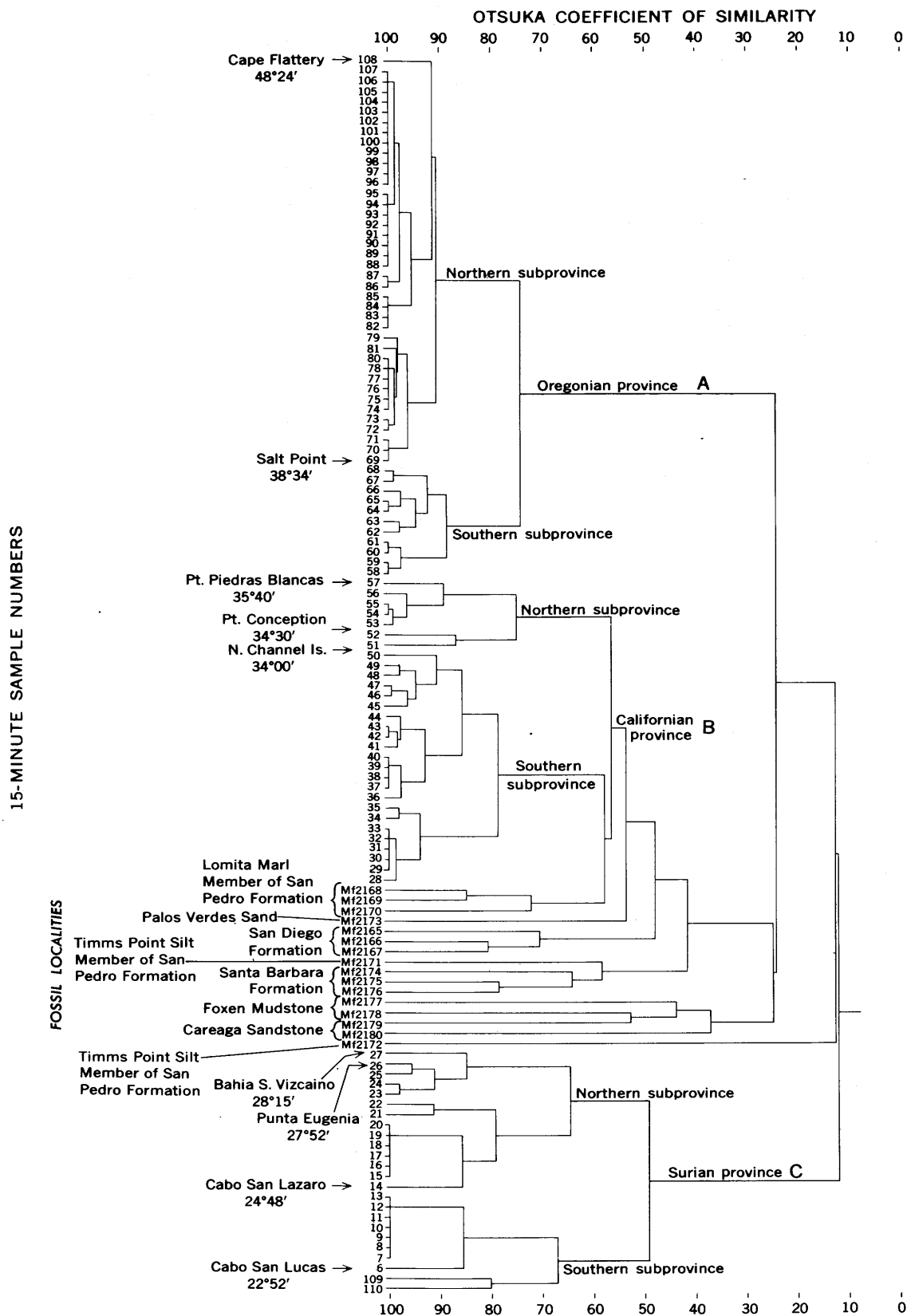


FIGURE 10.—Dendrogram of Holocene and fossil sample clusters. Samples are compared on the basis of their ostracode species composition using the Otsuka similarity coefficient  $(C/\sqrt{N_1N_2}) \times 100$ ; clustering was by the unweighted pair-group method.

That species can be limited in their distribution by temperature tolerances other than maximum and minimum survival temperatures introduces complexity into the interpretation of paleotemperature. Inferences are even more uncertain if the type of zonation represented by any given species cannot be determined. Hutchins (1947) shows that zonal type may be determined for a species that occurs along more than one coast by comparing winter and summer temperature minima and maxima at its range endpoints. Hazel (1970) has successfully ascertained the zonal type for many amphiatlantic ostracode species.

Where the types of zonation represented by species cannot be determined, one does not know whether the temperatures controlling species distribution are survival limits or repopulation limits or both. Both cryophiles and thermophiles may occur in the same fossil deposit, and when the temperature ranges of living representatives of these species are compared, they usually overlap. The range of overlap and the bounds of this range are of interest in determining the possible maximum and minimum paleotemperatures which occurred during deposition of the fossil unit. There are four kinds of temperature limit involved where thermophiles and cryophiles approach each other and overlap in temperature tolerances: for the cryophile there are two temperature limits, summer survival and winter repopulation; for the thermophile there are two possible limits, winter survival and summer repopulation. Although we cannot always identify the nature of these temperature limits, it is still of interest to know the possibilities that the limits represent survival maxima and minima and therefore convey the temperature limits that could have occurred at a fossil locality.

In the following model, the temperature ranges of a pair of species, one thermophile and one cryophile, are allowed to approach each other and overlap. The possible interactions of the temperature limitations are illustrated in figure 11. Thirteen configurations occur, 7 of which are impossible owing to constraints applied by the survival and the repopulation temperature tolerances of one or both of the two species. For example, two species can occur together only if the repopulation temperature limits are equal to or lie within the survival tolerances. Obviously, two species cannot coexist if the temperature needed for repopulation by one lies above the maximum or below the minimum survival temperatures of the other species.

For each of the six configurations in which a cryophile and a thermophile can coexist, there are four subcases. The first subcase involves the situation where the cryophile is limited by a summer survival temperature and the thermophile is limited by a winter survival temperature (fig. 11, configuration 11A). This temperature overlap then incorporates a possible maximum and minimum yearly temperature which would be defined if this situation could be identified in a fossil unit. The other three subcases involve two situations in which one of the species is limited by survival temperatures and the other by repopulation temperatures, and a third situation in which both are limited by repopulation temperatures (fig. 11, configurations 11B, C, D). Of the 24 possible subcases, 4 involve temperature range disjunctions.

In practice, when the temperature ranges of a cryophile and a thermophile are being compared, the overlapping temperature range endpoints represent, respectively, the maximum summer temperature and the minimum winter temperature they experience in their geographic distribution. Now, we do not know whether these temperatures actually represent summer survival maxima and winter survival minima or whether the particular species are limited by repopulation temperatures inside these limits. If all temperature limits in 15 theoretical subcases are counted (excluding four subcases of disjunct temperature ranges, and five subcases of coincident temperature endpoints), 10 of the 15 possible upper temperature limits are real survival maxima and 5 are repopulation limits; all these are upper limits exhibited by cryophiles (that is, the real survival maxima are summer survival temperatures of cryophiles). And 10 of the 15 possible lower temperature limits are real winter survival minima of thermophiles. In this model, therefore, 67 percent of the maxima and minima represented by overlapping temperature ranges of pairs of cryophiles and thermophiles are survival temperatures and should outline the possible yearly maxima and minima.

When subcases involving disjunct temperature ranges are considered, there are four minima and four maxima, and two of each are real survival maxima and minima. When temperature range endpoints of a cryophile and a thermophile are coincident (five subcases), 40 percent always represent survival maxima of the cryophile, 40 percent represent survival minima of the thermophile, and 20 percent represent repopulation boundaries. Their relationship to pairs of overlapping temperature ranges should indicate which they are.



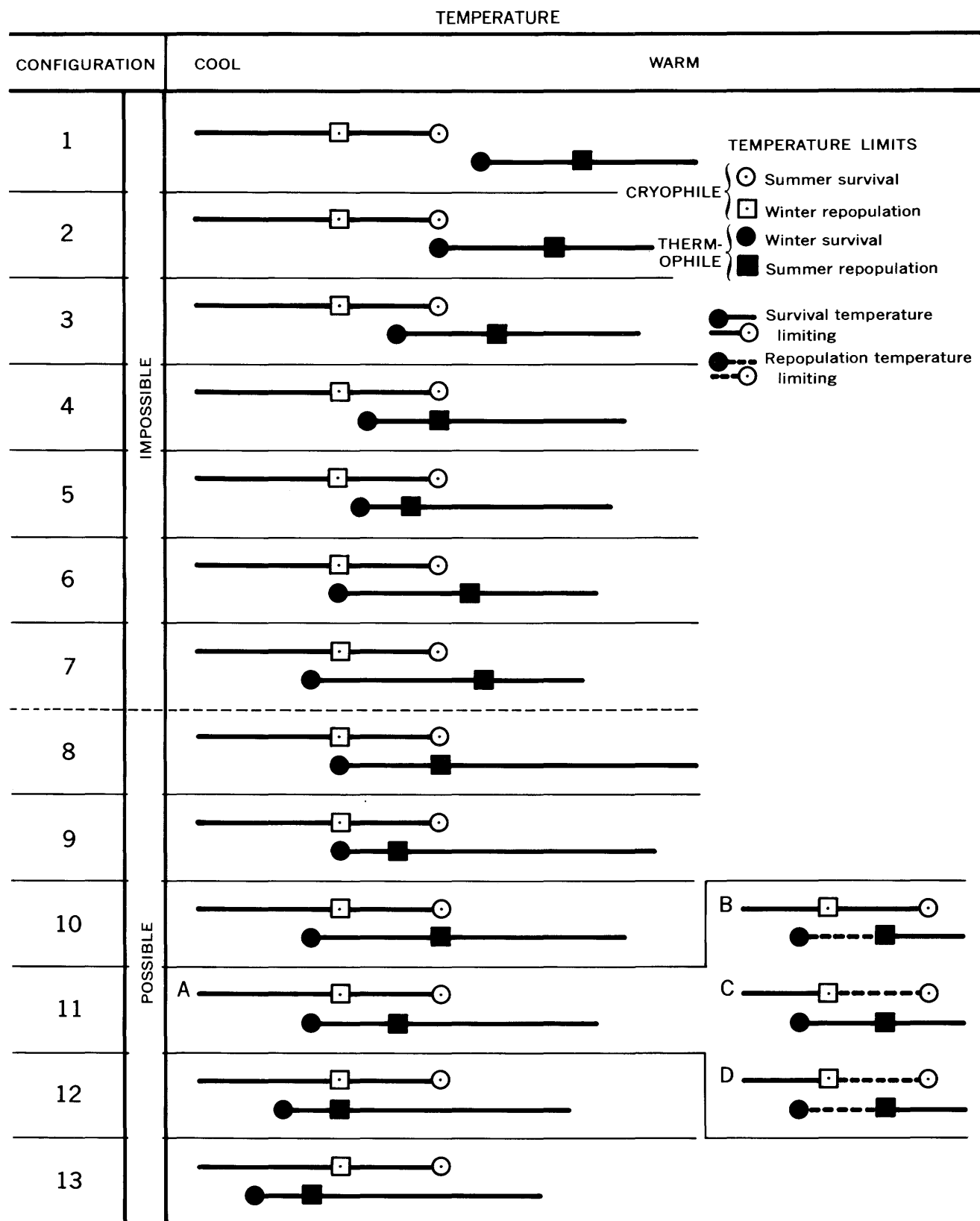


FIGURE 11.—Interactions of temperature limits (survival and repopulation) of a cryophile and a thermophile. Configurations 1–7 cannot occur because of constraints applied by temperature limits of one or both species. Configuration 11 is expanded to include four subcases. See text for further explanation.

The purpose of all this discussion is to establish a basis for the interpretation of temperature range overlaps of Holocene species occurring together in fossil deposits. (For examples, see figs. 12, 14–19). It may be noted that the species do not have to actually occur together in the Holocene—and depending on the configuration of the marine isotherms they may not—but theoretically they must be able to coexist in some thermal regime. The temperature ranges of species occurring as fossils usually overlap each other in a stepwise manner, each step including many species. It would seem from the foregoing discussion that about two-thirds of the temperature range endpoints of cryophiles could represent actual summer survival maxima, and that a similar percentage of the temperature range endpoints of thermophiles could represent actual winter survival minima, thus outlining the yearly temperature maxima and minima that could occur at that locality and still allow the species to coexist. If two steps of temperature range endpoints, each for cryophiles and thermophiles, are allowed to delineate the temperature range, there would be a good chance of including actual maxima and minima. In this case, the possible yearly minimum and maximum paleotemperatures would bound a wider temperature range than might actually have occurred.

An important constraint must be placed on this technique. We have assumed until now that the occurrence of each of the species zonal types is equally probable. This may not be a valid assumption in all situations. For example, northward-ranging thermophiles may be limited by a summer temperature which has to reach a certain value to allow repopulation to occur. In this case many of the geographic range endpoints of thermophiles would be attributable to summer repopulation limits and not winter survival minima. Consequently, the inferred possible yearly minimum paleotemperature would be higher and the possible yearly paleotemperature range narrower than if there were random occurrence of species zonal types. Of course, if the zonation type of certain species can be ascertained, the above procedure can be simplified and more confidence placed in the inferred yearly paleotemperatures.

The paleotemperatures of southern California fossil assemblages, which are discussed in the subsequent section, were determined using the method outlined above.

#### PALEOCLIMATIC IMPLICATIONS OF FOSSIL ASSEMBLAGES FROM SOUTHERN CALIFORNIA

A common assumption in paleoclimatic analyses of fossil assemblages is that fossil representatives of a species had environmental tolerances similar to those of the living representatives of the species. With progressively older faunas, fewer species or even genera are living, and confidence in analyses based only on this assumption rapidly decreases. Recent zoogeographic studies dealing with marine paleotemperatures of the eastern Pacific which review earlier work and provide new interpretations include reports by J. W. Valentine (1961), J. W. Valentine and Meade (1961), Addicott (1966), and Kern (1973).

The following discussion incorporates information from the literature (mainly molluscan and foraminiferal studies) with new evidence, principally regarding marine temperatures, derived from investigations on the Ostracoda. The temperature tolerances of Holocene ostracode species were developed by comparing their distribution to marine temperature maps (figs. 6, 7). Two sets of maps were used, one based on –10-m temperatures along the coasts of Baja California and California to San Francisco (Lynn, 1967) and the other based on surface temperatures from San Francisco to Cape Flattery (Robinson, 1957). The data presented by Lynn are considered to be the more accurate in reflecting bottom temperatures, and fortunately his maps cover the areas most critical to this report. The temperature tolerances of all ostracode species ranging through at least 2° of latitude were used in the paleotemperature determinations, and the number of species employed varied from 19 to 55 depending on the fossil unit involved. Species from all samples of a particular formation were combined in determining the paleotemperature range of that unit (determinations based on separate samples gave similar results). Depth ranges of ostracode species in the study area are not yet known, so that depth determinations are based on previous interpretations of other organisms.

#### SAN DIEGO FORMATION

The San Diego Formation at Pacific Beach, of late Pliocene age, is inferred to represent a depositional environment no deeper than 300 m (Hertlein and Grant, 1944). The samples from Pacific Beach are indicative of two different environments of deposition. Sample Mf2165 was collected in terrigenous sands containing scattered shell beds typical of an

open shelf environment. Samples Mf2166 and Mf2167, on the other hand, were collected in coarse sandy marls indicative of an environment receiving little inorganic debris from rivers and coastal erosion processes. Highly calcareous sediments are known to be presently accumulating off the eastern (leeward) shore of Santa Catalina Island (Shephard and Wrath, 1937), while the windward shelf exhibits chiefly terrigenous sediments. The three samples from the San Diego Formation cluster together (fig. 10); the assemblages from the calcareous sediments show more affinity for each other and may reflect habitat similarity. Together these assemblages cluster with the combined subprovinces of the Californian province, in spite of the fact that the San Diego Formation lies on the coast well within the limits of the southern California subprovince.

A comparison of the present temperature tolerances of 46 ostracode species from the San Diego Formation (figs. 12, 13) shows that the marine temperatures could have ranged from 14° to 18° C, no different from the marine temperatures off that part of the coast today (figs. 6, 7). The cluster analysis shows, however, that the Pliocene and modern assemblages at that latitude are different, probably the result of a change in the overall climatic regime not apparent in the marine temperatures at that point, but reflected in the range of species responding to the change.

#### FOXEN MUDSTONE AND CAREAGA SANDSTONE

In the Santa Maria district, the Foxen Mudstone (middle to upper Pliocene) contains molluscan and foraminiferal assemblages which suggest deposition in an inner sublittoral marine environment (50 m maximum depth); molluscan evidence indicates the Careaga Sandstone (upper Pliocene) was deposited in shallow water (to about 30–60 m) (Woodring and Bramlette, 1950). On the basis of inferences from foraminifers, Natland (1957) also regards both units to represent inner sublittoral depths. The ostracode collections are from fine sands and sandy shell beds suggestive of an open shelf environment.

The Foxen and Careaga samples cluster together but at relatively low values, possibly indicating somewhat different habitats. These samples cluster at a low level with the Californian province; in fact they show only slightly more affinity for the Californian province than do the Californian and Oregonian provinces for each other (fig. 10). This low correlation is clearly due to the presence of northern elements in these fossil assemblages.

The Santa Maria district lies on the coast within the modern northern Californian subprovince. The water temperatures along this part of the coast annually range from 12° to 15° C. Natland (1957) inferred, on the basis of foraminiferal assemblages, temperatures ranging from 8° to 13° C for the upper part of the Foxen Mudstone, and from 13° to 15° C for the Careaga Sandstone. Thirty-two ostracode species from the Foxen (figs. 13, 14) and 19 species from the Careaga (figs. 13, 15) indicate the yearly temperatures could have ranged from 12° to 15° C. These results agree with those of Natland (1957) for the Careaga and are identical with present marine temperatures off that coast (figs. 6, 7).

#### LOMITA MARL AND TIMMS POINT SILT MEMBERS OF THE SAN PEDRO FORMATION

The Lomita Marl and Timms Point Silt Members of the San Pedro Formation at San Pedro are of early Pleistocene age. Though closely associated in time, they represent two radically different sedimentary environments which are similar to those of the San Diego Formation at Pacific Beach. Studies of the molluscan fauna by Woodring and others (1946) and J. W. Valentine (1961) indicate shoaling towards the top of the Lomita; the lower beds of the Lomita represent the outer sublittoral (deeper than 100 m) whereas the upper beds generally represent depths of 50–100 m. Molluscan evidence indicates that the Lomita was deposited on the lee side of an offshore island in a sedimentary environment notably low in terrigenous detritus; the water temperature at the time of deposition was similar to that in the region today, except that the outer sublittoral was probably cooler.

The mollusks of the Timms Point Silt Member represent an outer sublittoral association (100–200 m), equivalent in depth to the lower part of the Lomita. The sedimentary regime was radically different, however, since the Timms Point, in contrast to the Lomita, is composed almost entirely of terrigenous sediments. These sediments resemble the silts and sandy silts which are at present derived from the Coast Ranges and being deposited on large areas of the continental shelf. The molluscan fauna represents a marine climate somewhat cooler than that of the region today.

The ostracode genus *Perissocytheridea* occurs as a minor constituent of the Lomita and Timms Point assemblages. This genus lives in shallow, brackish to normal marine environments. During this study it

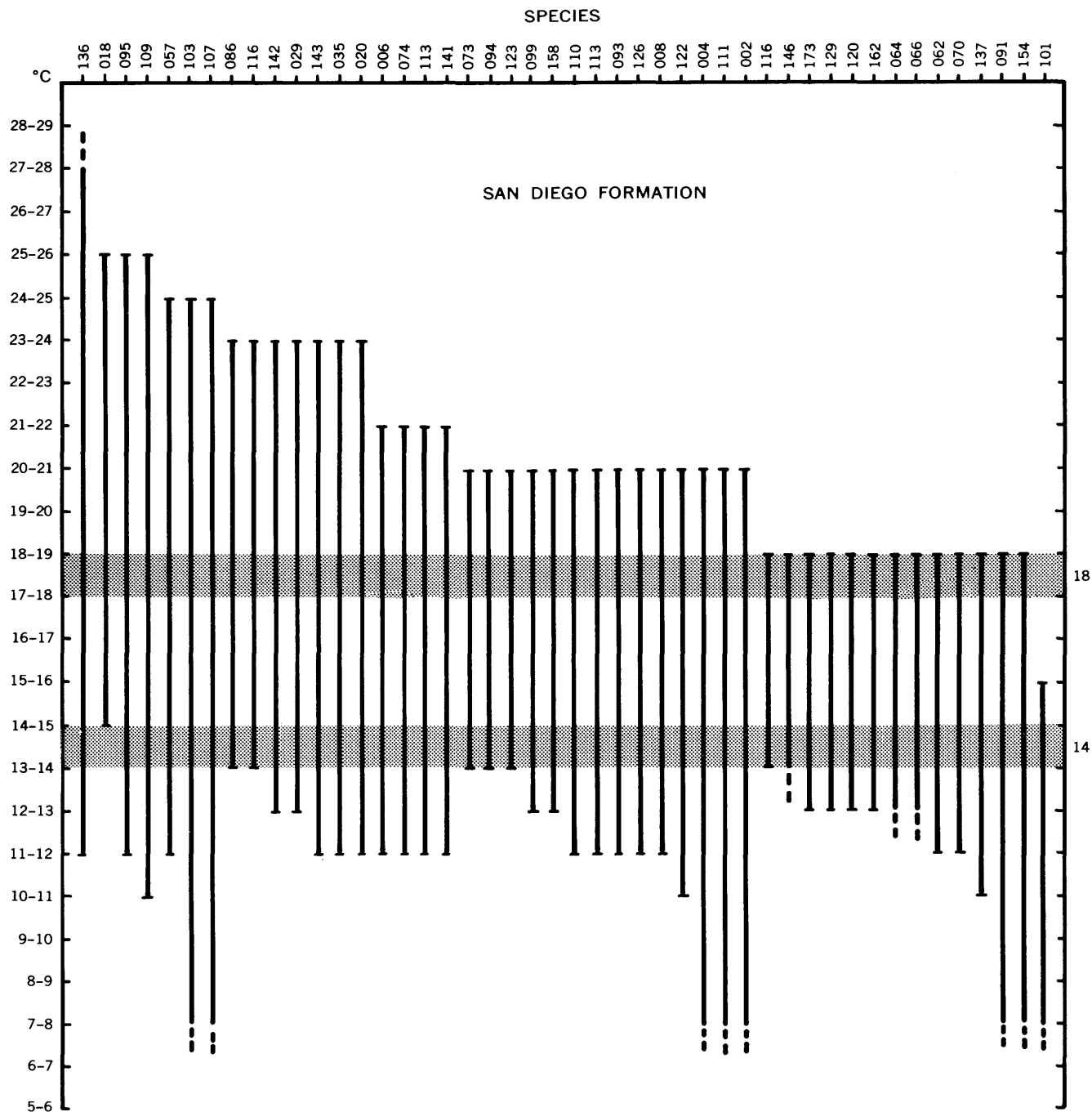


FIGURE 12.—Modern temperature tolerances for 46 ostracode species that occur in the San Diego Formation (upper Pliocene); inferred possible yearly minimum and maximum paleotemperatures, to the nearest 1°C are 14° and 18°, as indicated by the patterning. See table 4 for numerical list of ostracode species.

was found to occur only in samples from shallow depths (usually 20 m or less) seaward of harbor entrances. Although *Perissocytheridea* may be a transported element in the fossil assemblages, it indicates proximity to a bay or estuary.

Molluscan studies show that the assemblages from the Lomita and Timms Point are not equivalent. The

cluster analysis (fig. 10) based on ostracode samples also indicates that the assemblages are different; the Lomita samples cluster with the southern Californian subprovince, whereas the Timms Point sample shows more affinity to samples from the Santa Barbara Formation which, in turn, cluster with the Californian province. Sample Mf2172 from the

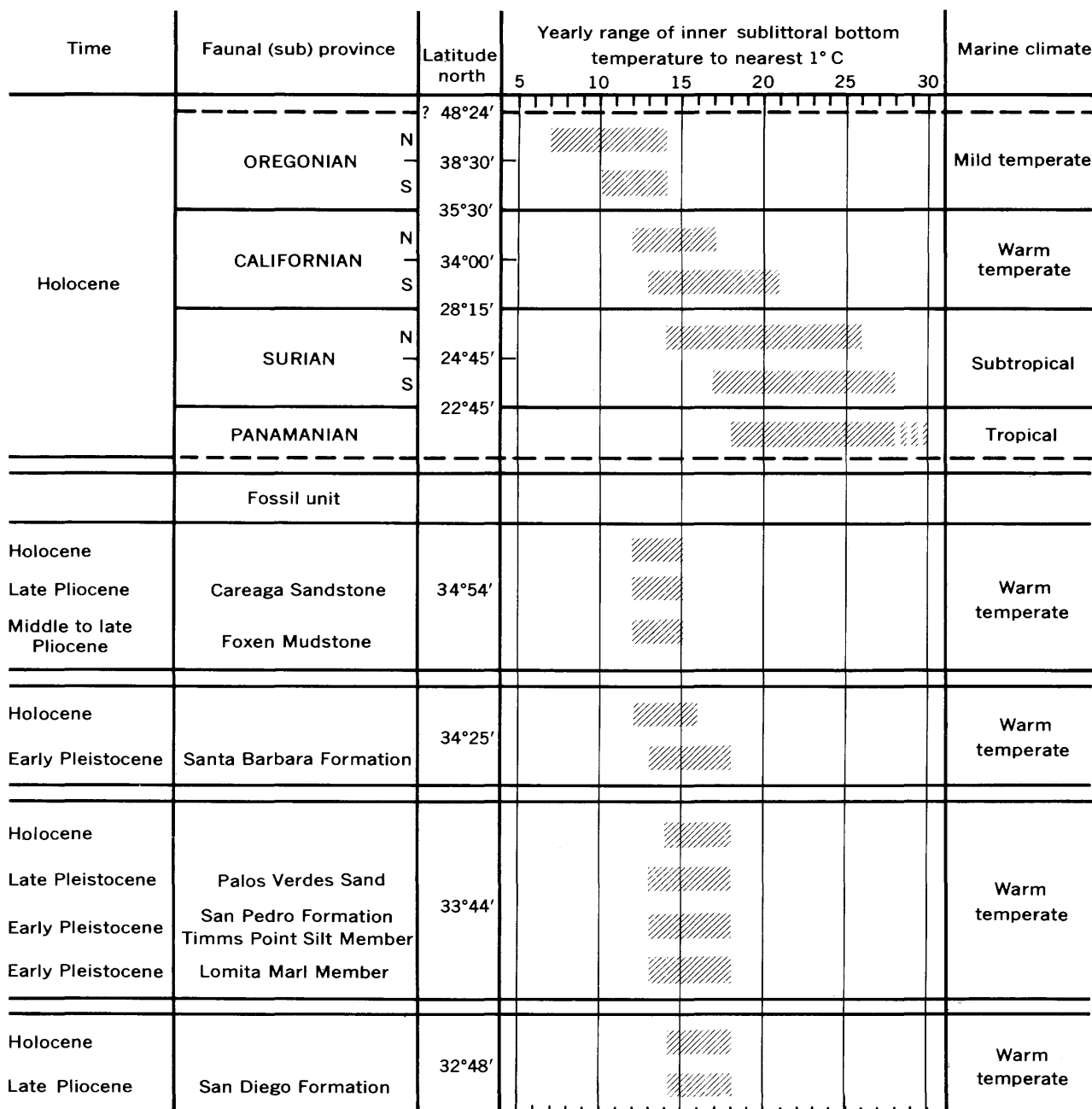


FIGURE 13.—Yearly marine temperature to the nearest 1° C occurring in the ostracode faunal provinces of the eastern Pacific shelf; and possible yearly temperature ranges in fossil units of southern California inferred from ostracode species distributions.

Timms Point contains a very small assemblage and, consequently, shows little similarity to other fossil and Holocene samples; it is disregarded in paleoecological interpretations. The dissimilarity between the Lomita and Timms Point samples may be due to differences in habitat represented by the two units. A determination of temperature tolerances of 19 ostracode species of the Timms Point indicates that the yearly temperatures could have ranged from 13°

to 18° C (figs. 13, 16), identical to water temperatures determined for the Lomita (figs. 13, 17; based on 55 species) and very similar to those prevailing off the coast today (figs. 6, 7).

J. W. Valentine and Meade (1961, table 12) determined paleotemperatures for these two units at San Pedro based on zoogeographic as well as oxygen isotope temperature techniques. The zoogeographic evidence yields paleotemperatures ranging from 11° to

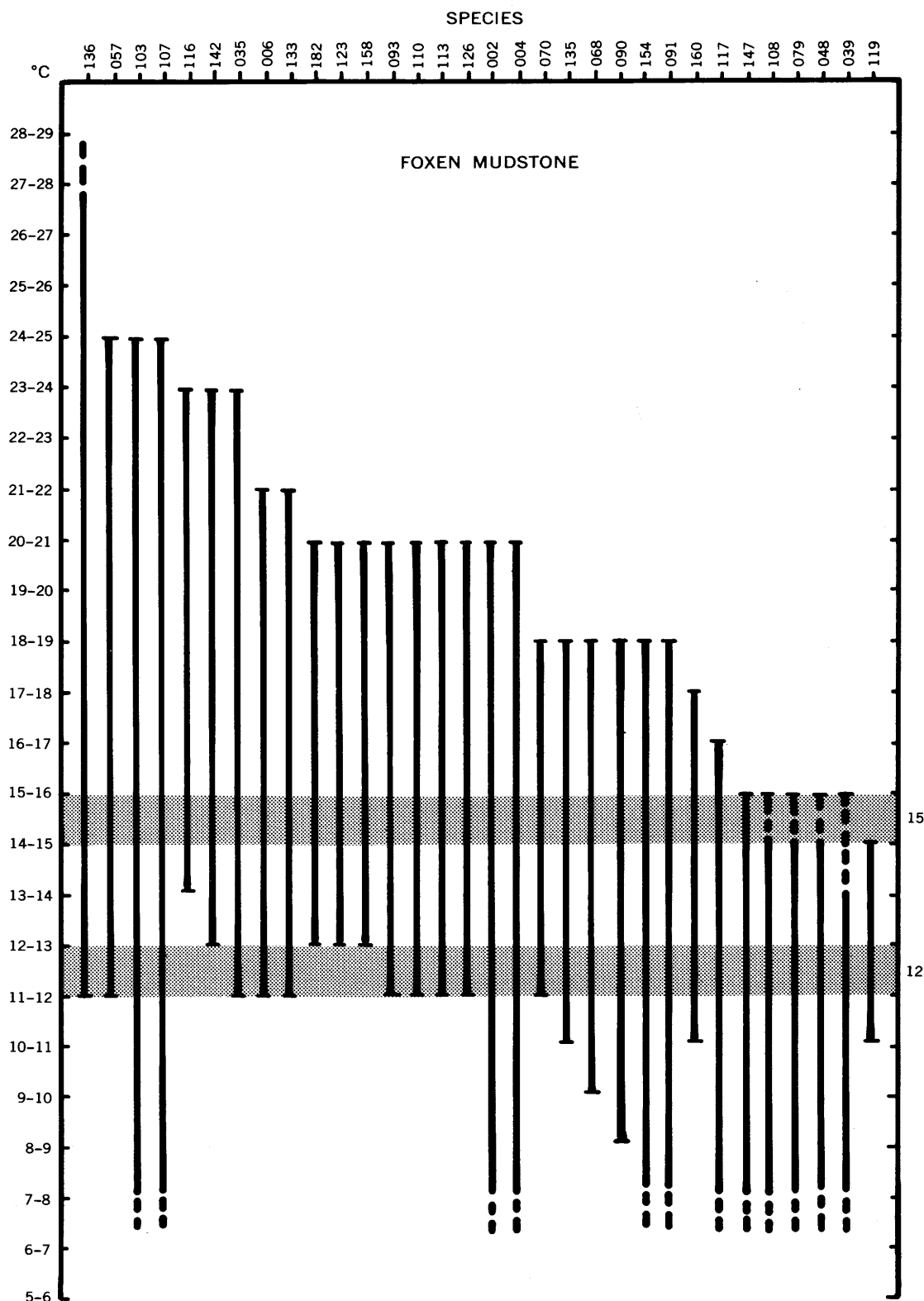


FIGURE 14.—Modern temperature tolerances for 32 ostracode species that occur in the Foxen Mudstone (middle to upper Pliocene); inferred possible yearly minimum and maximum paleotemperatures, to the nearest 1° C, are 12° and 15° C, as indicated by the patterning. See table 4 for numerical list of ostracode species.

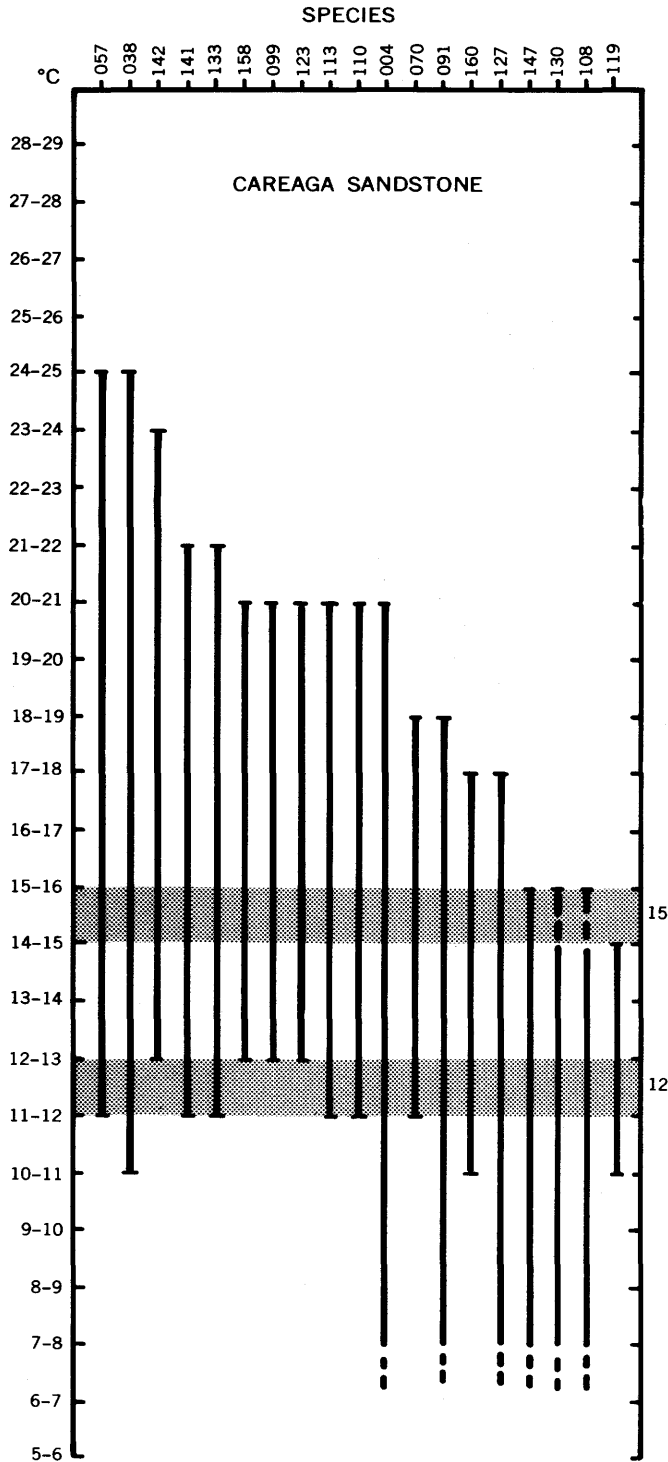


FIGURE 15.—Modern temperature tolerances for 19 ostracode species that occur in the Careaga Sandstone (upper Pliocene); inferred possible yearly minimum and maximum paleotemperatures, to the nearest 1° C, are 12° and 15° C, as indicated by the patterning. See table 4 for numerical list of ostracode species.

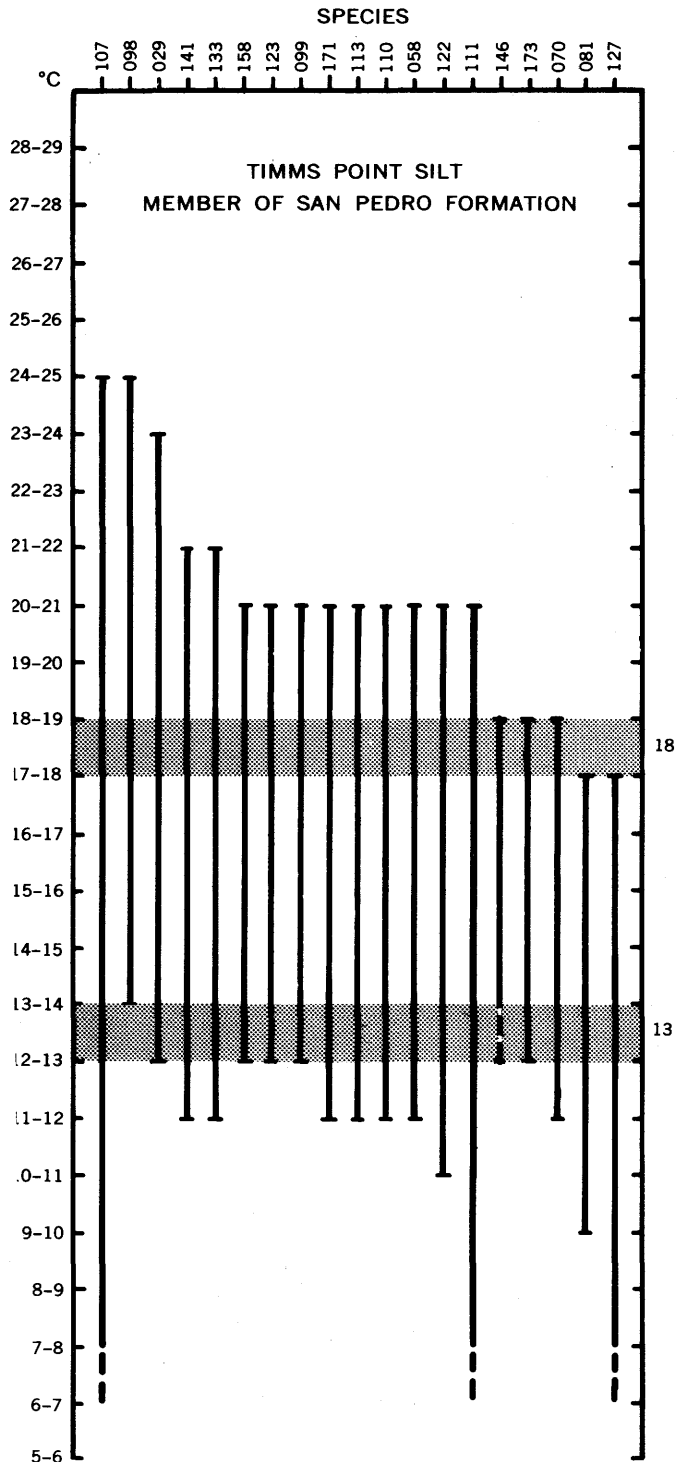


FIGURE 16.—Modern temperature tolerances for 19 ostracode species that occur in the Timms Point Silt Member of the San Pedro Formation (lower Pleistocene); inferred possible yearly minimum and maximum paleotemperatures, to the nearest 1° C, are 13° and 18° C, as indicated by the patterning. See table 4 for numerical list of ostracode species.

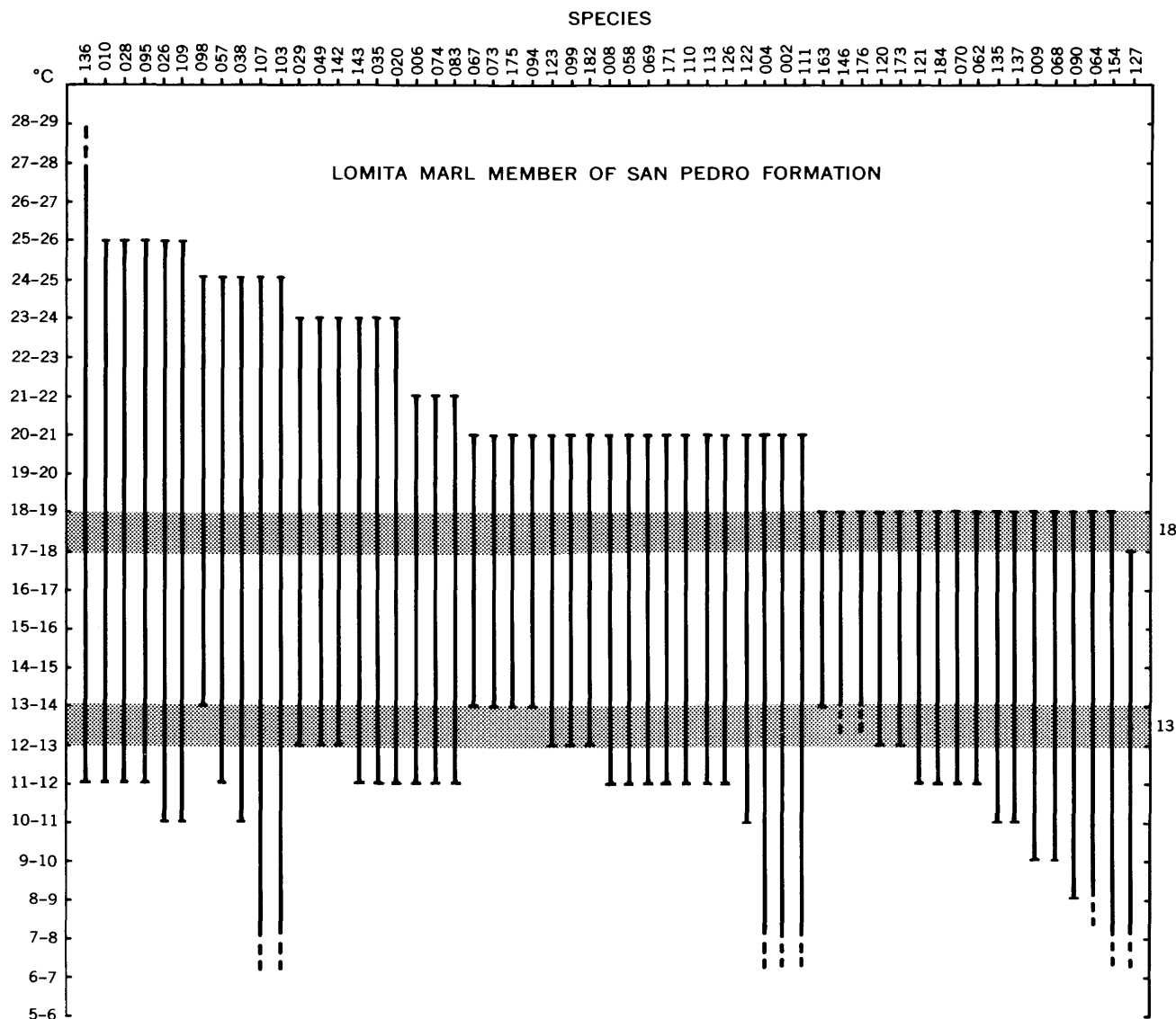


FIGURE 17.—Modern temperature tolerances for 55 ostracode species that occur in the Lomita Marl Member of the San Pedro Formation (lower Pleistocene); inferred possible yearly minimum and maximum paleotemperatures, to the nearest 1° C, are 13° and 18° C, as indicated by the patterning. See table 4 for numerical list of ostracode species.

21° C for the Lomita. The molluscan temperature tolerances were determined by these authors from marine temperature data that have since been revised. Regarding the Lomita, their 21° C temperature was believed to be the minimum temperature experienced by Panamanian forms (which occur in the Lomita) at Cabo San Lucas. According to the latest data (Lynn, 1967; fig. 6), this temperature should be revised to 18° C; the paleotemperature range of 11° to 18° C is more in line with the results of the present study (13° to 18° C). Isotopic temperatures from the Lomita fossils range from at least 13.2° to 19.0° C, also in agreement with paleotemperatures based on ostracode tolerances. Paleo-

temperatures for the Timms Point (J. W. Valentine and Meade, 1961) based on the molluscan distributions range from 11° to 14° C and based on isotopic analyses from 5.7° to 13.8° C. These temperatures are below the range of 13° to 18° C determined from ostracode distributions and may reflect the deeper environment of deposition indicated by the molluscan assemblages of the Timms Point.

#### SANTA BARBARA FORMATION

The Santa Barbara Formation is correlative with the Lomita Marl Member (lower Pleistocene); it is richly fossiliferous, especially in the lower part, and the molluscan fauna has been partially documented.



(See references in J. W. Valentine, 1961; Woodring and others, 1946.) These molluscan assemblages are interpreted to represent inner sublittoral depths in the lower part of the unit, whereas the fauna of the upper beds is indicative of somewhat deeper conditions. Samples for this study were collected in the bryozoan marls in the lower part of the formation at the Bathhouse Beach locality. J. W. Valentine (1961) interpreted the molluscan assemblages here to be indicative of depths between 30 and 70 m. Bullivant (1969) examined the same beds, and on the basis of their faunal and lithological character interpreted them to represent an offshore bioherm deposited at 40–60 m in a marine climate similar to or perhaps a little cooler than that found offshore today.

The Santa Barbara samples cluster with those of the Californian province at a low level but not as low as the Foxen and Careaga samples (fig. 10), which have a more northern aspect. Paleotemperatures of the Santa Barbara Formation (figs. 13, 18; based on 36 ostracode species) could have ranged from 13° to 18° C, similar to water temperatures found off that coast today (figs. 6, 7).

#### PALOS VERDES SAND

The Palos Verdes Sand at San Pedro is of late Pleistocene age. The molluscan fauna is indicative of an inner sublittoral habitat. The ostracode assemblage is distinctive, as can be seen in the cluster analysis (fig. 10); the sample clusters with no other fossil sample and shows similarity to samples of the Californian province. Temperature tolerances of 31 ostracode species of the Palos Verdes Sand indicate that the yearly temperatures could have ranged from 13° to 18° C (figs. 13, 19), equivalent to the present annual temperature range off that coast (figs. 6, 7).

J. W. Valentine and Meade (1961) have also calculated paleotemperatures for this unit. The molluscan temperature tolerances indicate a range from 14° to 21° C, and the isotopic analyses give a temperature range from at least 12.3° to 18.2° C. If, as explained during discussion of the Lomita Marl Member above, the 21° C temperature is lowered to 18° C to reflect the latest marine temperature studies, then Valentine and Meade's determinations agree well with those based on ostracode temperature tolerances.

#### DISCUSSION

The marine climates prevailing during deposition of the Pliocene and Pleistocene units treated here were probably not very different from those existing

today off those sites. That the Holocene and fossil assemblages in those areas do not show a strong resemblance, although most species occurring as fossils have living representatives, leads one to believe that the marine climate off southern California has indeed changed, even though the change is not easily detectable in the paleotemperature determinations for particular localities. This situation is understandable, even expected, in view of the complex systems involved as well as the fragmentary nature of the climatic record.

The basic patterns of faunal distribution existing on the shelf can be attributed to the interaction of two very complex systems. One is the marine climatic system, simplistically expressed in the configuration of marine isotherms; the other is a system of ecological units ranging in organizational complexity from the individual organism to the provincial assemblage.

Both systems alter their character very gradually. The marine climate is, in fact, a highly buffered system, and directional changes in the properties and effects of atmospheric wind systems, oceanic current patterns, solar radiation, and other major and minor environmental determinants are required to modify the climatic regime. Modifications that are of interest here would include alteration of annual water temperature ranges and the appearance of new isothermic configurations. Isotherms probably would not merely shift position along the coast in concert; movement might take place in some areas and not in others, and bunching and dispersion of isotherms would also occur, producing new thermal gradients and dissipating others. The magnitude and duration of thermal barriers might change. Climatic alteration would not necessarily have to be great to influence considerably the distribution of marine organisms.

Individual organisms, populations, communities, and provincial assemblages together form another highly complex system, each ecological unit or component of the system responding somewhat differently to environmental stimuli (J. W. Valentine, 1968, 1973). A change in the marine climate will elicit a different degree of response at each level of organization, the less inclusive ecological units generally reacting more rapidly. Ultimately, a rearrangement or reorganization of these ecological units will occur. Although ecological systems are capable of withstanding short-term climatic changes, an enduring modification of the marine climate, however minor, should result in the appearance of new faunal associations and distributions.

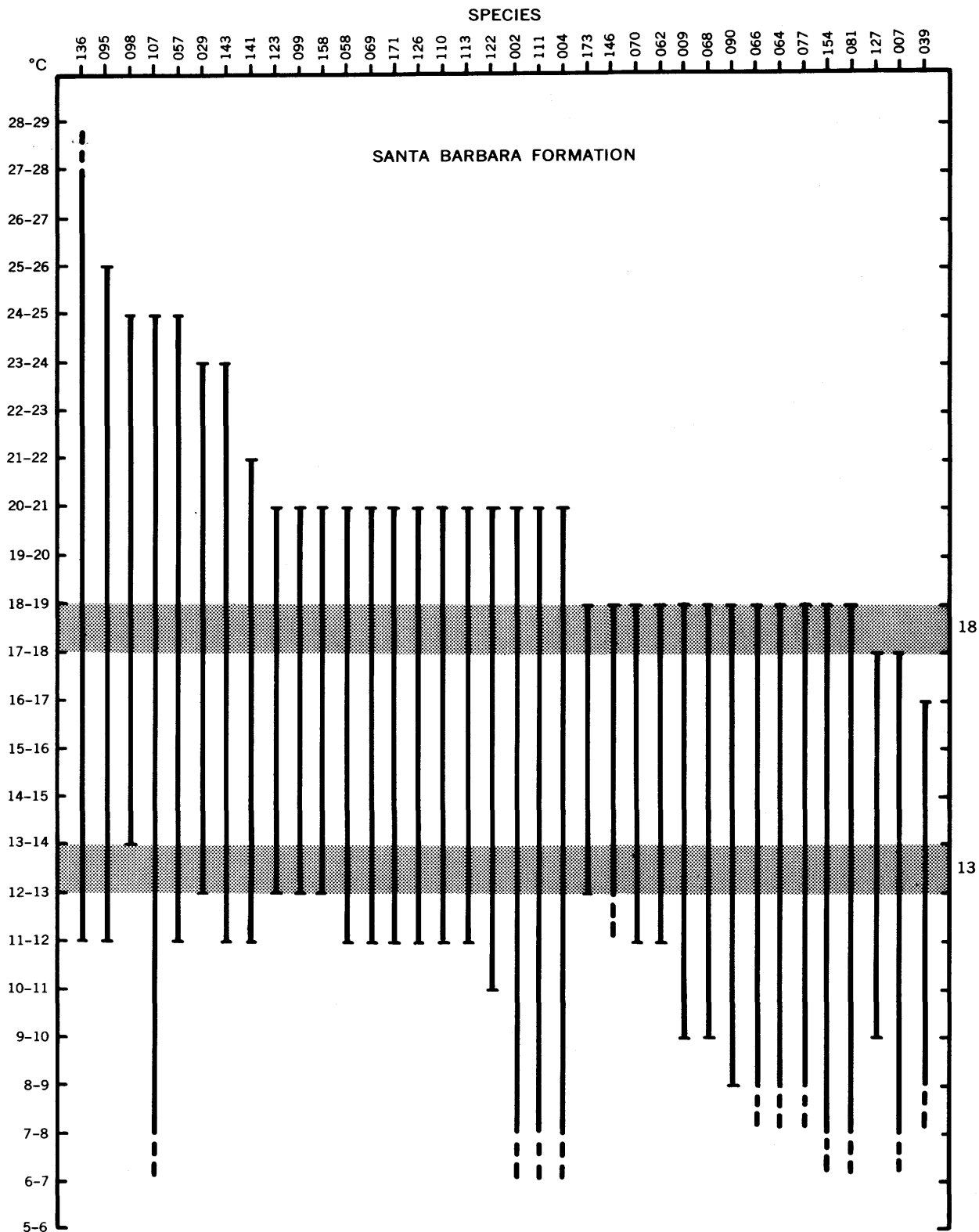


FIGURE 18.—Modern temperature tolerances for 36 ostracode species that occur in the Santa Barbara Formation (lower Pleistocene); inferred possible yearly minimum and maximum paleotemperatures, to the nearest 1° C, are 13° and 18° C, as indicated by the patterning. See table 4 for numerical list of ostracode species.

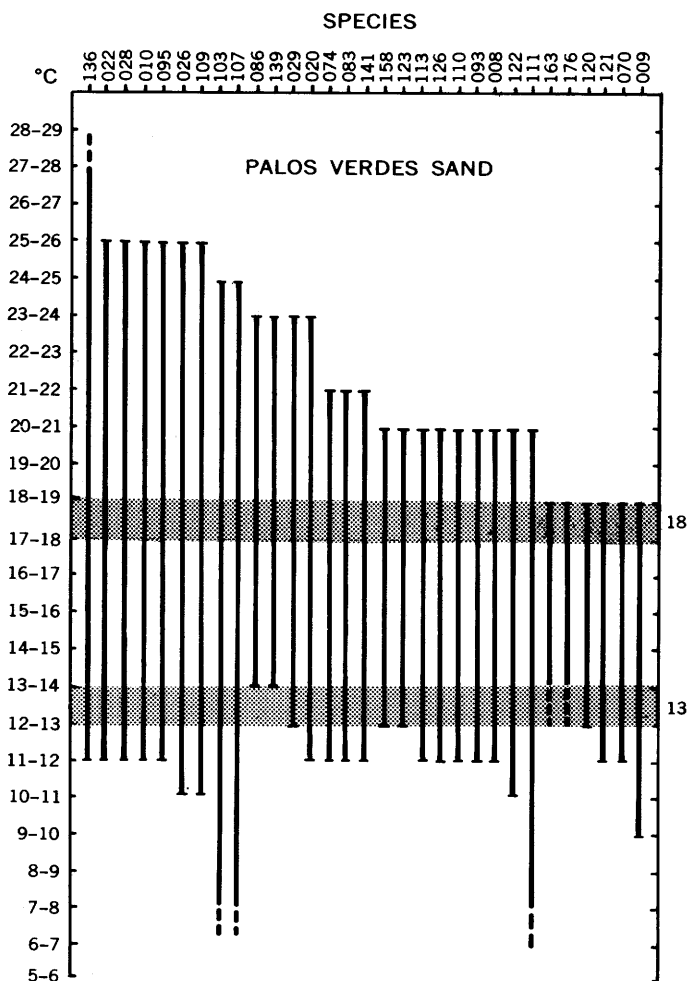


FIGURE 19.—Modern temperature tolerances for 31 ostracode species that occur in the Palos Verdes Sand (upper Pleistocene); inferred possible yearly minimum and maximum paleotemperatures, to the nearest 1° C, are 13° and 18° C, as indicated by the patterning. See table 4 for numerical list of ostracode species.

It would appear from this study that marine climates in the study area have been fluctuating during the past several million years within a narrow spectrum of configurations which, while influencing the distribution of organisms, remain difficult to discern from each other and from the present climate. We know, however, that at times the marine climate fluctuates far enough in one direction to produce more obvious effects in the fossil record. For example, during the glacial advances of the Pleistocene, thermal barriers and provincial boundaries were relocated and shifted far enough along the coast so that marked differences between present and past climates are discernible. But glacial age deposits were laid down at lower sea levels, and they are generally accessible today only through drilling

or in uplifted sections of the coast. The patchiness and limited exposure of the fossil record, then, places a great constraint on climatic reconstructions. If a number of geographically dispersed fossil assemblages of equivalent age could be studied, it would be possible, by using the present as a model, to reconstruct an ancient climatic regime over a large shelf area. Studies of this nature necessarily demand many well-preserved fossil assemblages and are thus confined to the recent past. Only two such investigations have been conducted in the eastern Pacific (J. W. Valentine, 1961; Addicott, 1966), and these complementary reports employ molluscan zoogeography to reconstruct the marine climate of the late Pleistocene shelf off the west coast of the United States. As a result of the present study, the Holocene zoogeography of the Ostracoda can now serve as a datum for similar paleoclimatic reconstructions.

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## PLATES 1-14

Contact photographs of the plates in this report are available, at  
cost, from U.S. Geological Survey Library, Federal Center,  
Denver, Colorado 80225

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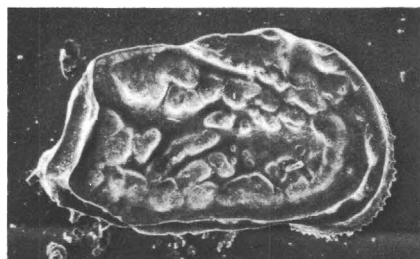
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## PLATE 1

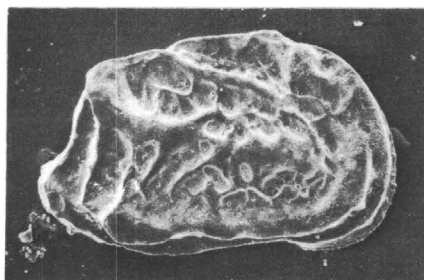
[All figures are lateral views; all  $\times 60$ ]

- FIGURES 1, 2, 4, 5. *Ambostracon costatum* Hazel, 1962.
1. Right valve, male. Santa Barbara Formation. USNM 207779.
  2. Right valve, female. Santa Barbara Formation. USNM 207780.
  4. Left valve, male. Santa Barbara Formation. USNM 207781.
  5. Left valve, female. Santa Barbara Formation. USNM 207782.
- 3, 6. *Ambostracon* sp. M.
3. Right valve, female. Sample 164. USNM 207783.
  6. Right valve, male. Sample 164. USNM 207784.
- 7, 8. *Ambostracon* sp. A.
7. Left valve, male. Sample 1. USNM 207785.
  8. Left valve, female. Sample 10. USNM 207786.
- 9, 12. *Ambostracon* sp. B.
9. Left valve, male. Sample 101. USNM 207787.
  12. Left valve, female. Sample 101. USNM 207788.
- 10, 11, 13, 14. *Ambostracon* sp. G.
10. Left valve, male. Sample 177. USNM 207789.
  11. Left valve, female. Sample 177. USNM 207790.
  13. Left valve, male. Sample 117. USNM 207791.
  14. Left valve, female. Sample 117. USNM 207792.
- 15, 18. *Ambostracon glaucum* (Skogsberg, 1928).
15. Left valve, female. Sample 193. USNM 207793.
  18. Left valve, male. Sample 193. USNM 207794.
- 16, 17. *Ambostracon* sp. E.
16. Left valve, male. Sample 59. USNM 207795.
  17. Left valve, female. Sample 59. USNM 207796.

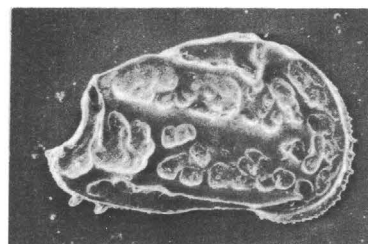




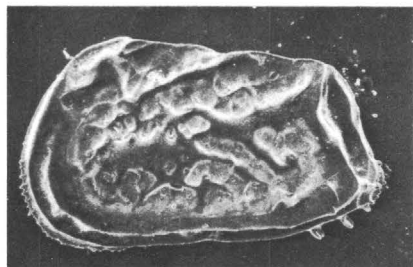
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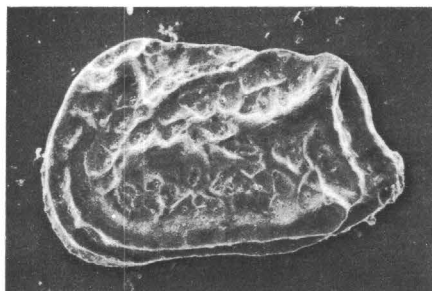
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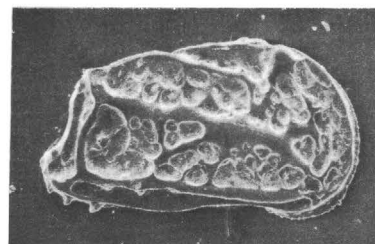
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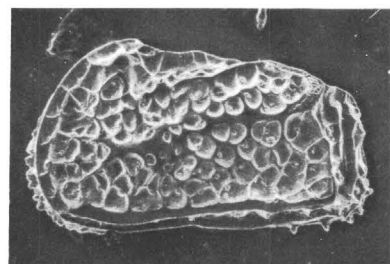
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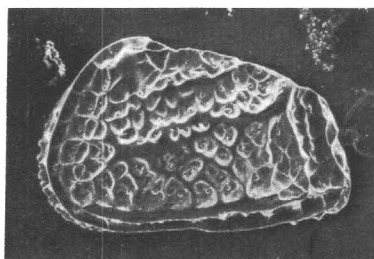
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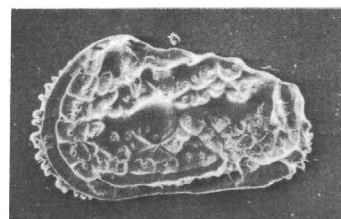
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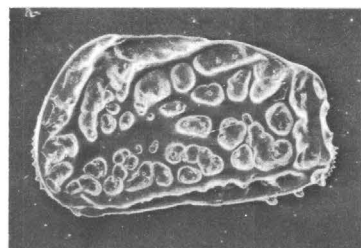
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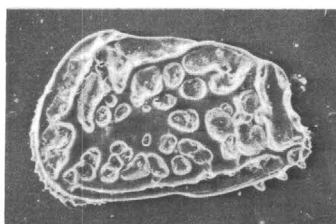
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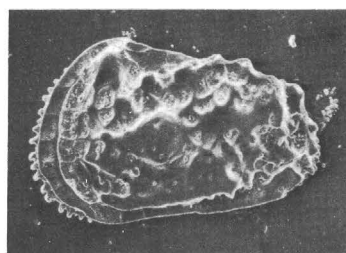
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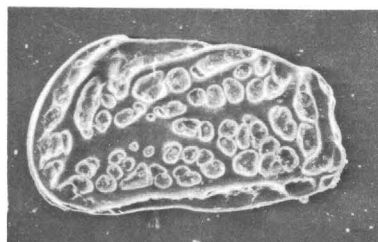
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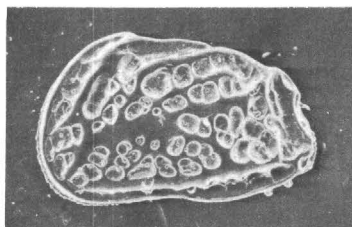
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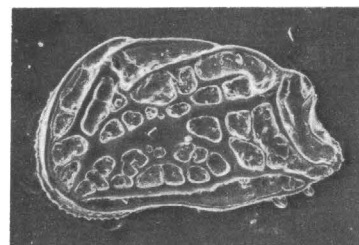
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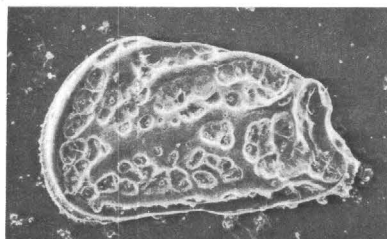
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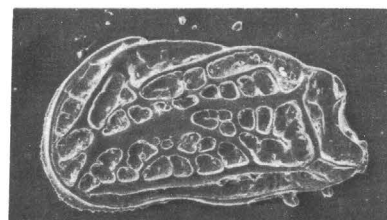
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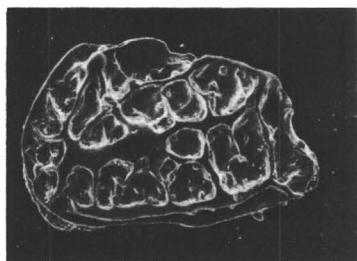
*AMBOSTRACON*

## PLATE 2

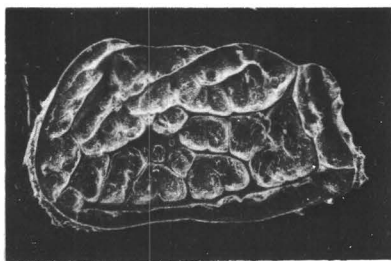
[All figures are lateral views; all  $\times 60$ ]

### FIGURES

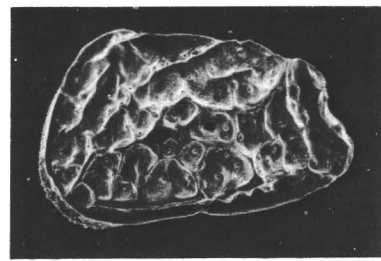
- 1, 4. *Ambostracon* sp. J.
  1. Left valve, female. Sample 193. USNM 207797.
  4. Left valve, male. Sample 193. USNM 207798.
- 2, 3. *Ambostracon* sp. O.
  2. Left valve, male. Sample 222. USNM 207799.
  3. Left valve, female. Sample 222. USNM 207800.
- 5, 6, 8, 9. *Ambostracon* sp. L.
  5. Left valve, male. Sample 164. USNM 207801.
  6. Left valve, female. Sample 164. USNM 207802.
  8. Left valve, male. Sample Mf2176. USNM 207803.
  9. Left valve, female. Sample Mf2176. USNM 207804.
- 7, 10. *Ambostracon diegoensis* (LeRoy, 1943).
  7. Left valve, female. Sample 201. USNM 207805.
  10. Left valve, male. Sample 201. USNM 207806.
- 11, 14. *Ambostracon* sp. K.
  11. Left valve, female. Sample 244. USNM 207807.
  14. Left valve, male. Sample 244. USNM 207808.
- 12, 13. *Ambostracon californicum* (Hazel, 1962).
  12. Left valve, male. Sample Mf2169. USNM 207809.
  13. Left valve, female. Sample Mf2169. USNM 207810.
- 15, 16. *Ambostracon* sp. D.
  15. Left valve, male. Sample Mf2174. USNM 207811.
  16. Left valve, female. Sample Mf2174. USNM 207812.



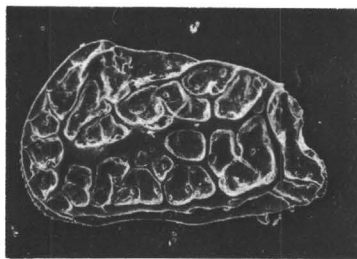
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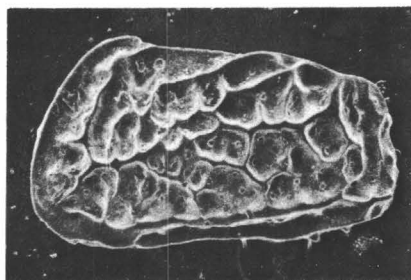
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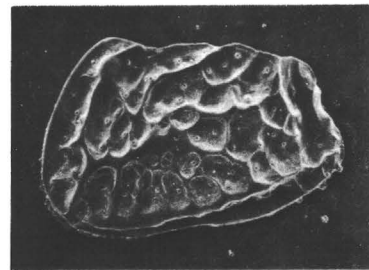
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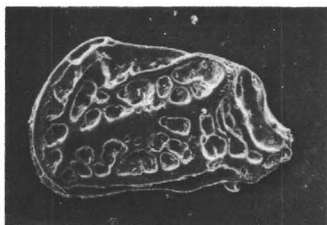
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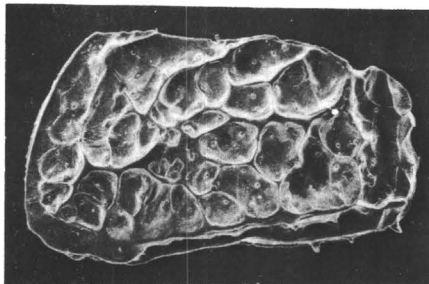
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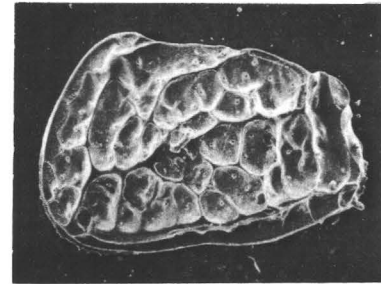
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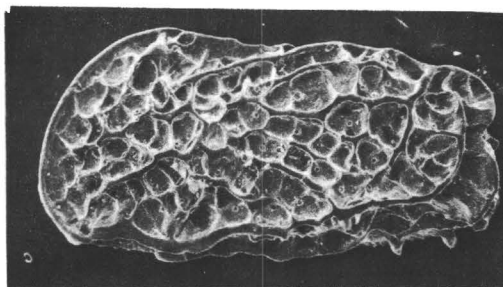
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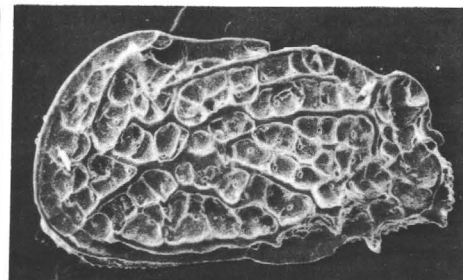
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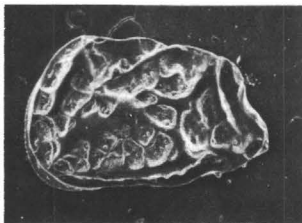
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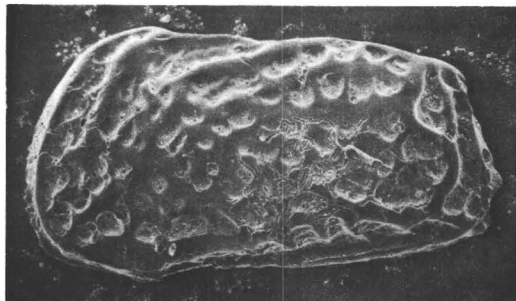
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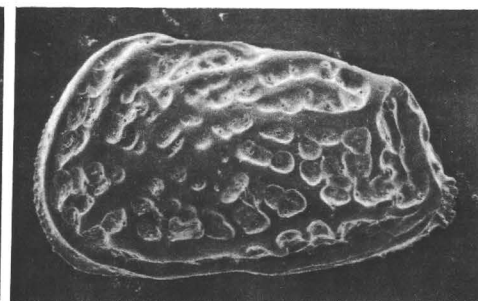
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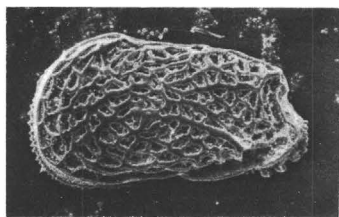
AMBOSTRACON

### PLATE 3

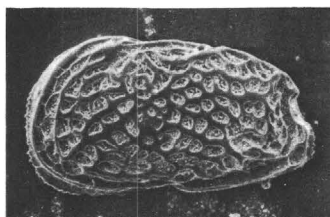
[All figures are lateral views; all  $\times 60$ ]

#### FIGURES

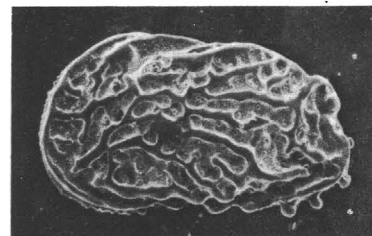
1. *Ambostracon microreticulatum* (LeRoy, 1943).  
Left valve, female. Sample 201. USNM 207813.
2. *Ambostracon* sp. Q.  
Left valve, female. Sample 242. USNM 207814.
3. *Ambostracon* sp. F.  
Left valve, female. Sample 202. USNM 207815.
- 4, 7, 10. *Coquimba* sp. A.
  4. Left valve, male. Sample Mf2174. USNM 207816.
  7. Left valve, female. Sample Mf2174. USNM 207817.
  10. Right valve, female. Sample Mf2174. USNM 207818.
- 5, 8, 11. *Coquimba schencki* (LeRoy, 1943).
  5. Left valve, male. Sample Mf2174. USNM 207819.
  8. Left valve, female. Sample Mf2174. USNM 207820.
  11. Right valve, female. Sample Mf2174. USNM 207821.
- 6, 9. New genus F sp. A.
  6. Right valve. Sample 1. USNM 207822.
  9. Left valve. Sample 15. USNM 207823.
12. *Buntonia* sp. B.  
Left valve, female. Sample 154. USNM 207824.
- 13, 14. *Puriana pacifica* Benson, 1959.
  13. Left valve, female. Sample 197. USNM 207825.
  14. Right valve, female. Sample 197. USNM 207826.
- 15, 18. *Buntonia* sp. A.
  15. Left valve, female. Sample Mf2180. USNM 207827.
  18. Right valve, female. Sample Mf2180. USNM 207828.
- 16, 17. *Puriana* sp. A.
  16. Left valve, female. Sample 254. USNM 207829.
  17. Right valve, female. Sample 254. USNM 207830.



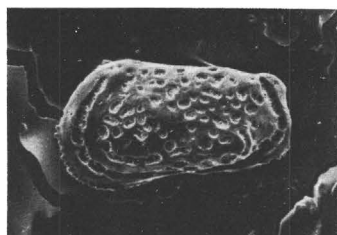
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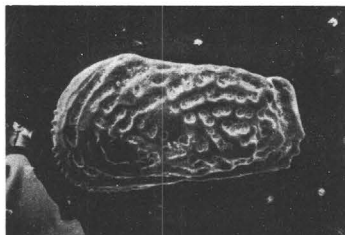
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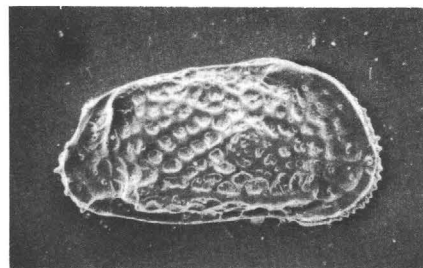
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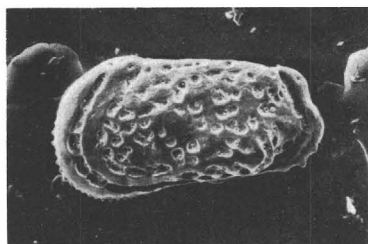
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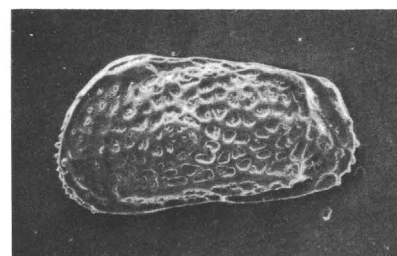
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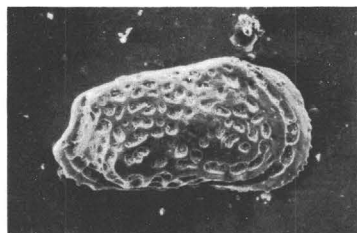
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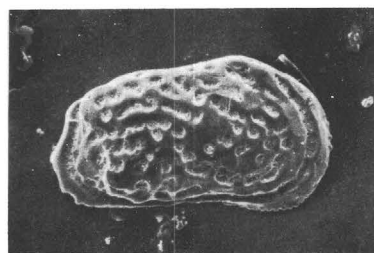
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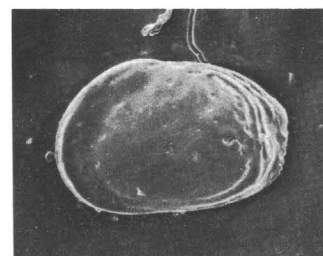
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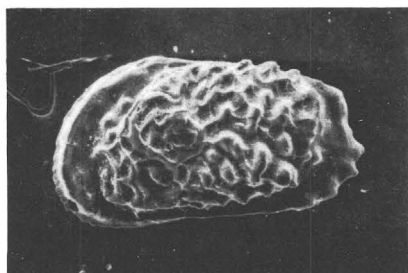
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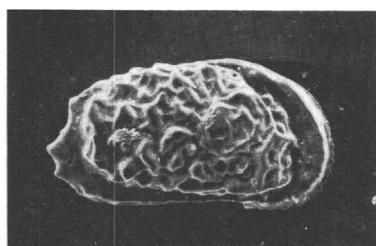
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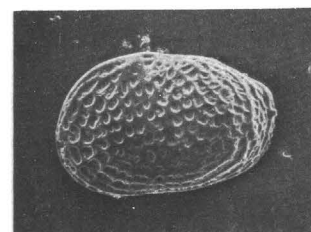
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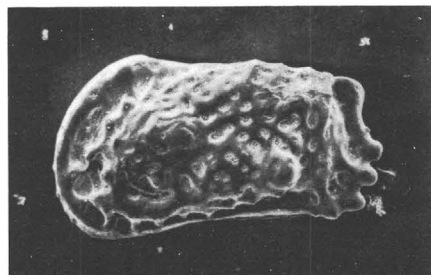
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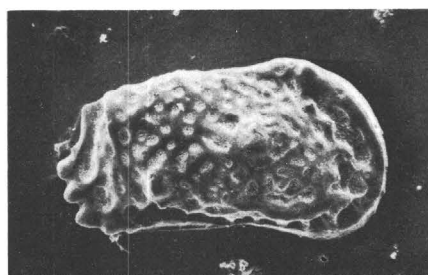
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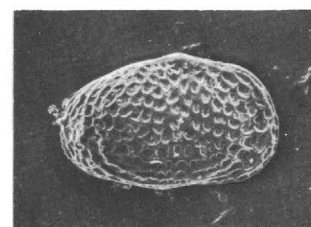
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AMBOSTRACON, BUNTONIA, COQUIMBA, NEW GENUS F, AND PURIANA

## PLATE 4

[All figures are lateral views; all  $\times 60$ ]

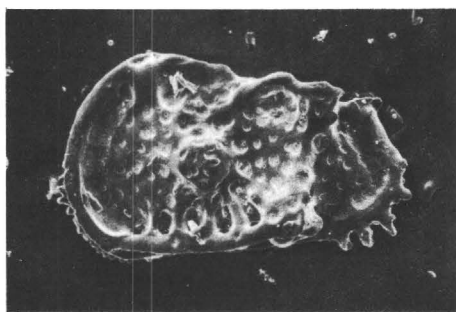
### FIGURES

1. *Hermanites* sp. E.  
Left valve, male. Sample 215. USNM 207831.
- 2, 5. *Hermanites kewi* (LeRoy, 1943).  
2. Left valve, female. Sample Mf2174. USNM 207832.  
5. Left valve, female. Sample Mf2180. USNM 207833.
3. *Sahnia* sp. A.  
Left valve. Sample 197. USNM 207834.
4. *Hermanites* sp. G.  
Left valve, female. Sample 203. USNM 207835.
- 6, 7. *Pulmilocytheridea pseudoguardensis* McKenzie and Swain, 1967.  
6. Left valve, female. Sample 233. USNM 207836.  
7. Right valve, female. Sample 233. USNM 207837.
8. *Hermanites* sp. D.  
Left valve, female. Sample 215. USNM 207838.
9. *Hermanites* sp. C.  
Left valve, female. Sample 193. USNM 207839.
- 10, 14. "*Cytheretta*" sp. B.  
10. Right valve, male. Sample 141. USNM 207840.  
14. Right valve, female. Sample 141. USNM 207841.
11. *Hermanites* sp. A.  
Left valve, male. Sample 215. USNM 207842.
- 12, 15. *Cytheropteron* sp. A.  
12. Left valve, female. Sample 35. USNM 207843.  
15. Right valve, female. Sample 35. USNM 207844.
- 13, 16, 17. "*Cytheretta*" sp. A.  
13. Right valve, male. Sample 61. USNM 207845.  
16. Right valve, female. Sample 61. USNM 207846.  
17. Left valve, female. Sample 61. USNM 207847.

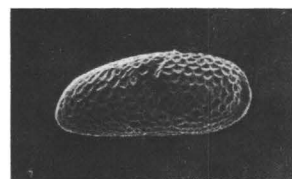




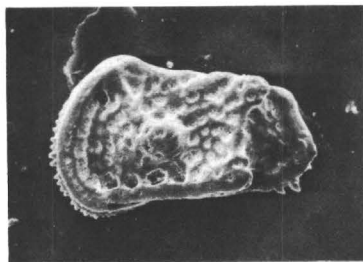
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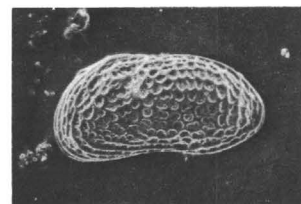
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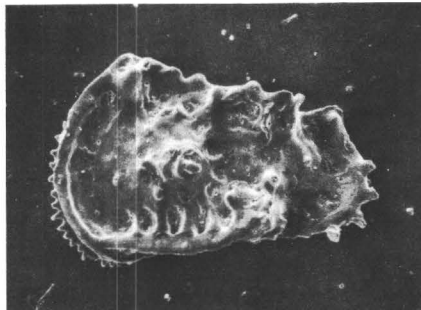
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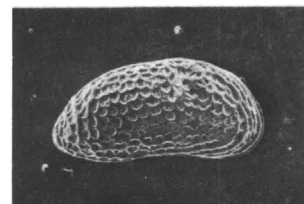
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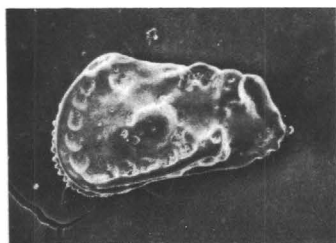
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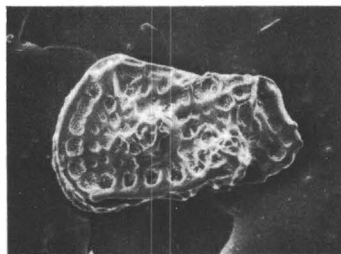
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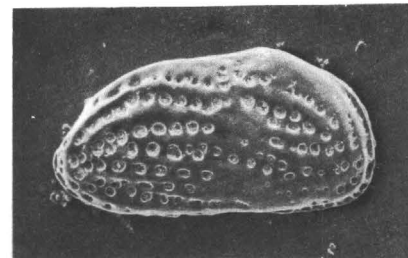
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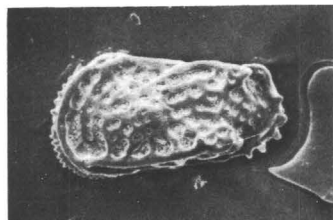
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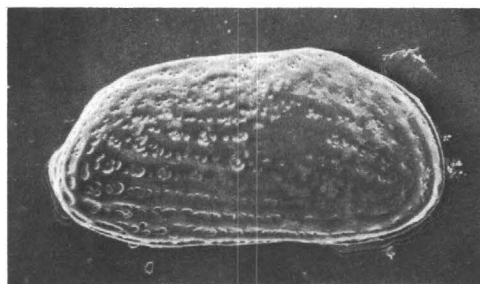
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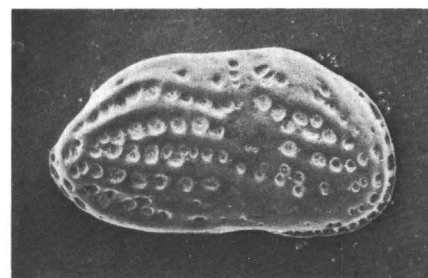
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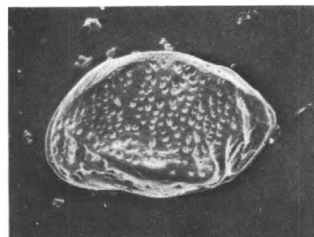
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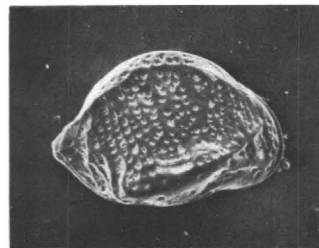
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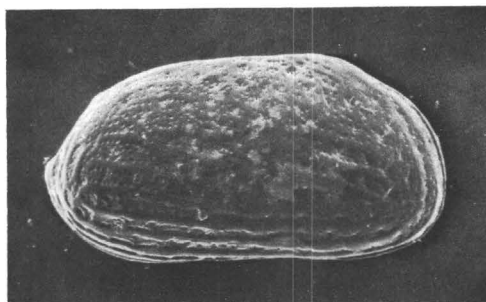
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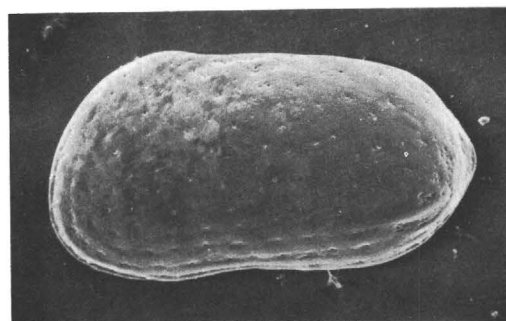
12



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"CYTHERETTA," CYTHEROPTERON, HERMANITES, PULMILOCYTHERIDEA, AND SAHNIA

## PLATE 5

[All figures are lateral views; all  $\times 60$  except where noted]

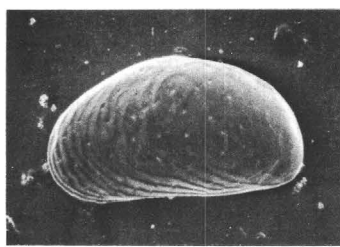
### FIGURES

- 1, 2. *Pontocythere* sp. C.
  1. Right valve, female. Sample 15. USNM 207848.
  2. Left valve, female. Sample 15. USNM 207849.
- 3, 8. *Paracytheridea granti* LeRoy, 1943.
  3. Right valve, female. Sample 122. USNM 207850.
  8. Left valve, female. Sample 122. USNM 207851.
- 4, 5. *Pontocythere* sp. A.
  4. Right valve, female. Sample 197. USNM 207852.
  5. Left valve, female. Sample 197. USNM 207853.
- 6, 7. *Pontocythere* sp. B.
  6. Right valve, female. Sample 197. USNM 207854.
  7. Left valve, female. Sample 197. USNM 207855.
- 9, 10. *Paracytheridea* sp. B.
  9. Right valve, female. Sample 221. USNM 207856.
  10. Left valve, female. Sample 221. USNM 207857.
- 11, 14. *Paracytheridea* sp. A.
  11. Left valve, female. Sample 164. USNM 207858.
  14. Right valve, female. Sample 164. USNM 207859.
- 12, 13. "*Kangarina*" sp. A.
  12. Left valve. Sample 109.  $\times 120$ . USNM 207860.
  13. Right valve. Sample 2.  $\times 120$ . USNM 207861.
15. *Kangarina* sp. B.
  - Right valve, female. Sample 215.  $\times 120$ . USNM 207862.
16. *Kangarina* sp. C.
  - Right valve, female. Sample 99.  $\times 120$ . USNM 207863.
17. *Kangarina* aff. *K. quellita* Coryell and Fields, 1937.
  - Right valve, female. Sample 242.  $\times 120$ . USNM 207864.

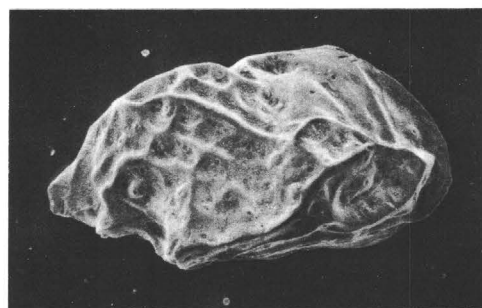




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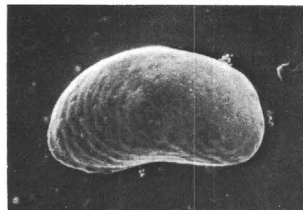
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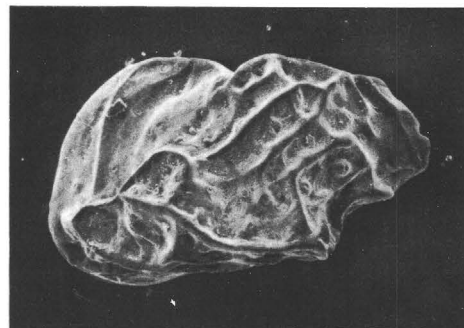
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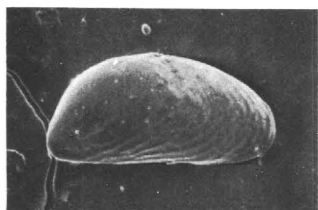
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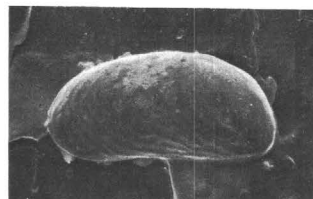
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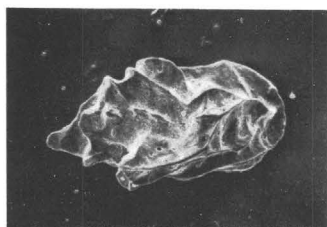
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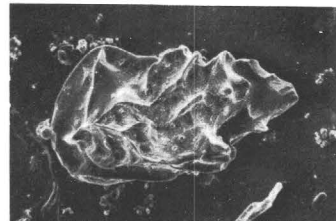
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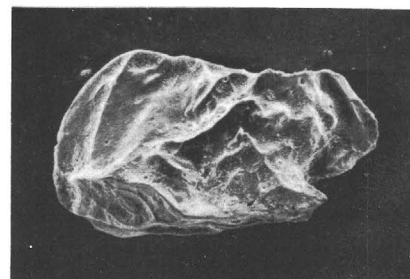
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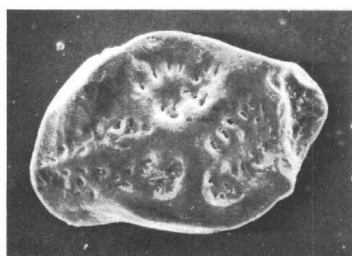
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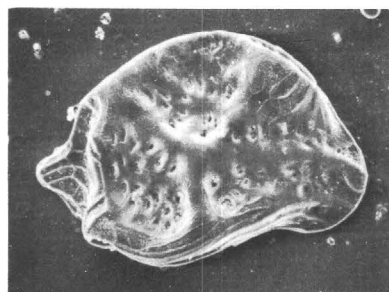
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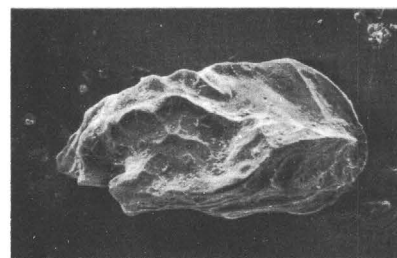
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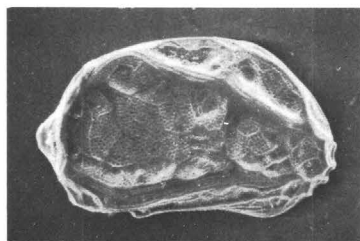
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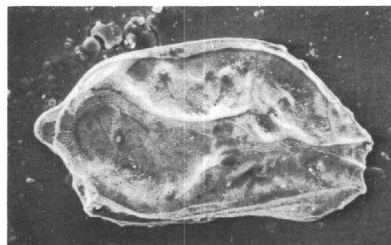
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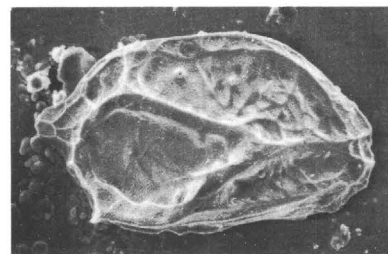
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15



16



17

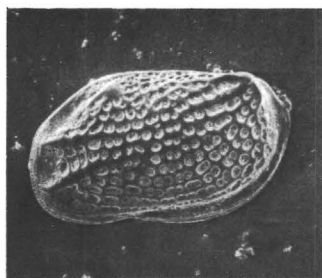
*KANGARINA, "KANGARINA," PARACYTHERIDEA, AND PONTOCYTHERE*

## PLATE 6

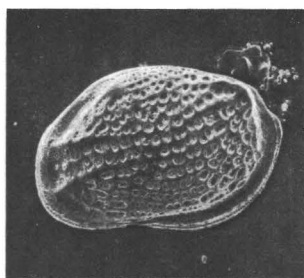
[All figures are lateral views; all  $\times 120$  except where noted]

### FIGURES

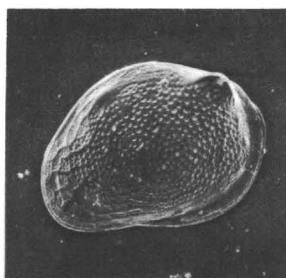
- 1, 2. *Loxocorniculum* sp. A.
  1. Left valve, male. Sample 221.  $\times 60$ . USNM 207865.
  2. Left valve, female. Sample 221.  $\times 60$ . USNM 207866.
3. *Loxocorniculum* sp. B.
  - Left valve, female. Sample 251.  $\times 60$ . USNM 207867.
4. "*Loxoconcha*" *emaciata* Swain, 1967.
  - Left valve, female. Sample 251.  $\times 60$ . USNM 207868.
5. *Hemicytherura* sp. D.
  - Right valve, female. Sample 57. USNM 207869.
6. *Hemicytherura* sp. F.
  - Right valve, female. Sample 215. USNM 207870.
7. *Hemicytherura* sp. G.
  - Right valve, female. Sample 244. USNM 207871.
8. *Hemicytherura* sp. L.
  - Right valve, female. Sample 108. USNM 207872.
9. *Hemicytherura* sp. H.
  - Right valve, female. Sample 108. USNM 207873.
10. *Hemicytherura* sp. K.
  - Right valve, female. Sample 215. USNM 207874.
11. *Hemicytherura* sp. J.
  - Right valve, female. Sample 202. USNM 207875.
12. *Hemicytherura* sp. C.
  - Right valve, female. Sample 222. USNM 207876.
13. *Hemicytherura* sp. I.
  - Right valve, female. Sample 215. USNM 207877.
14. *Hemicytherura* sp. B.
  - Right valve, female. Sample 109. USNM 207878.
- 15, 16. *Hemicytherura* sp. A.
  15. Right valve, female. Sample 2. USNM 207879.
  16. Left valve, female. Sample 2. USNM 207880.



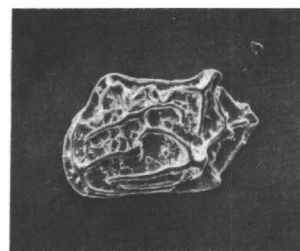
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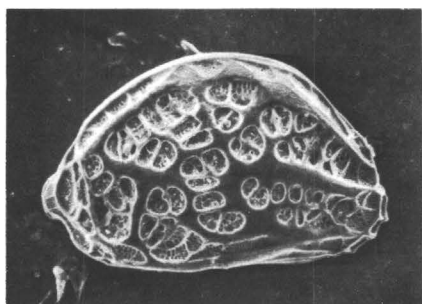
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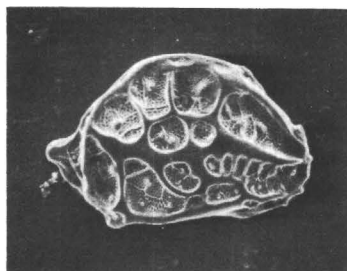
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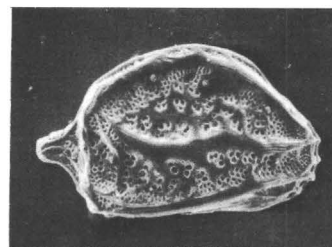
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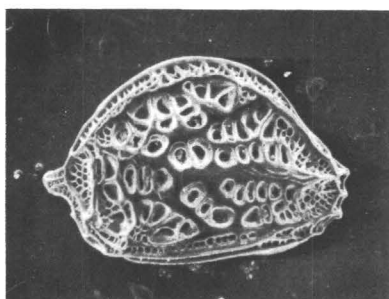
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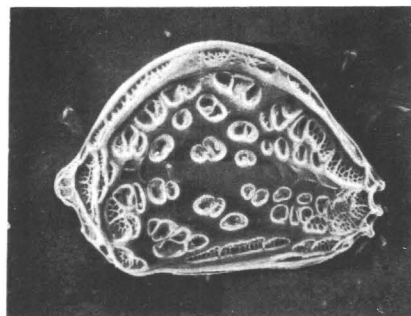
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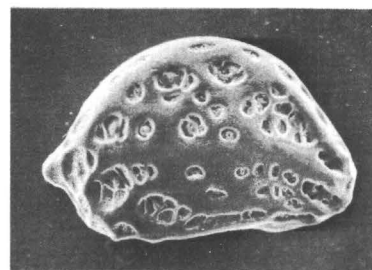
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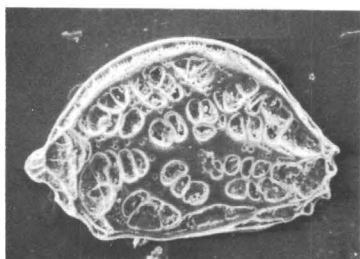
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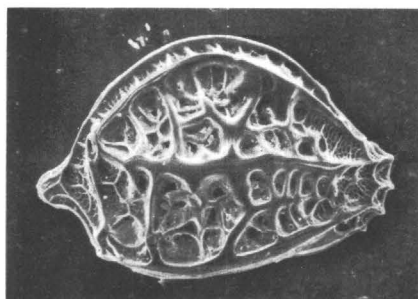
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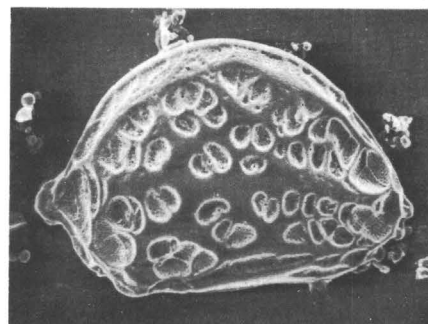
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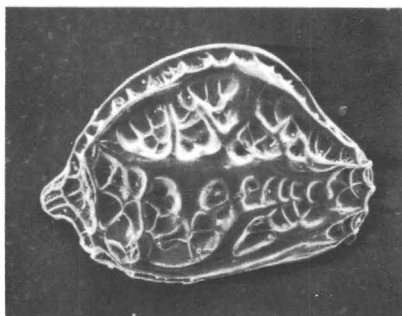
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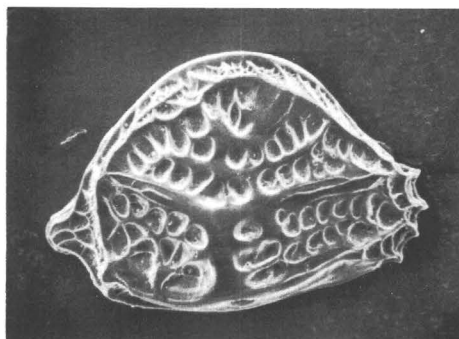
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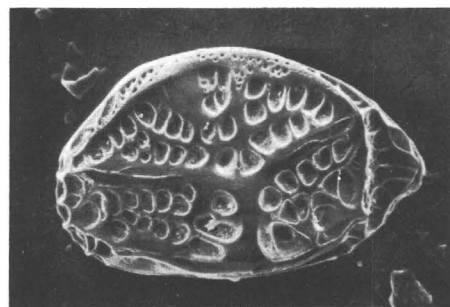
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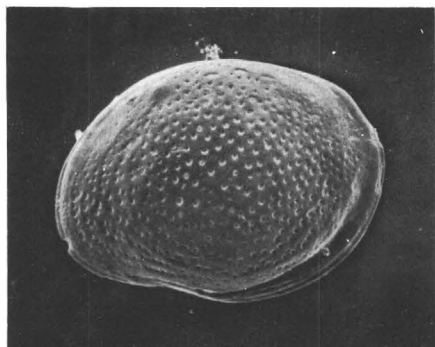
HEMICYTHERURA, "LOXOCONCHA," AND LOXOCORNICULUM

## PLATE 7

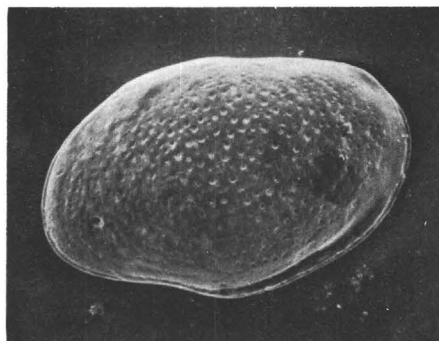
[All figures are lateral views; all  $\times 60$ ]

### FIGURES

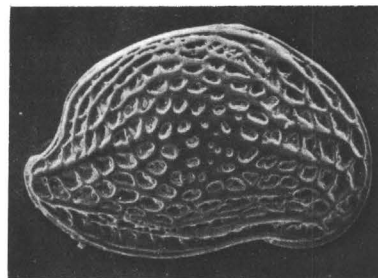
- 1, 2. *Loxoconcha lenticulata* LeRoy, 1943.
  1. Left valve, female. Sample Mf2174. USNM 207881.
  2. Left valve, male. Sample Mf2174. USNM 207882.
- 3, 7. "*Aurila*" sp. C.
  3. Right valve, female. Sample 193. USNM 207883.
  7. Left valve, female. Sample 193. USNM 207884.
- 4, 5. *Loxoconcha* sp. A.
  4. Right valve, female. Sample 15. USNM 207885.
  5. Left valve, female. Sample 15. USNM 207886.
6. *Loxoconcha helenae* Crouch, 1949.
  - Left valve, female. Sample 82. USNM 207887.
- 8, 12. *Loxoconcha* sp. B.
  8. Left valve, female. Sample 193. USNM 207888.
  12. Left valve, male. Sample 193. USNM 207889.
9. *Loxoconcha* sp. E.
  - Left valve, female. Sample 184. USNM 207890.
- 10, 11. *Aurila* sp. B.
  10. Right valve, female. Sample 211. USNM 207891.
  11. Left valve, female. Sample 211. USNM 207892.
- 13, 16. "*Aurila*" sp. E.
  13. Left valve, male. Sample 40. USNM 207893.
  16. Left valve, female. Sample 40. USNM 207894.
- 14, 17. "*Aurila*" *driveri* (LeRoy, 1943).
  14. Right valve, female. Sample Mf2176. USNM 207895.
  17. Left valve, female. Sample Mf2176. USNM 207896.
15. "*Aurila*" *schumannensis* (LeRoy, 1943).
  - Left valve, female. Sample 96. USNM 207897.



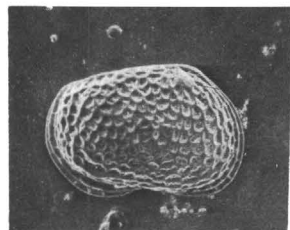
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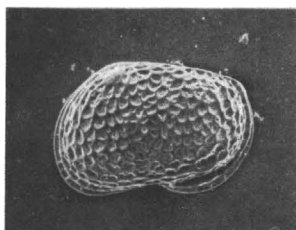
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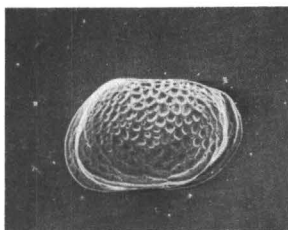
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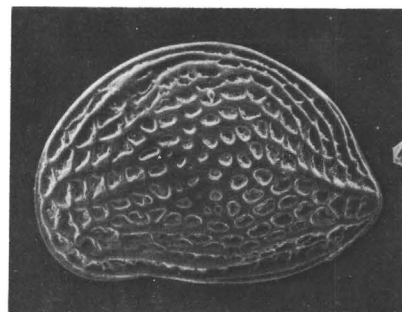
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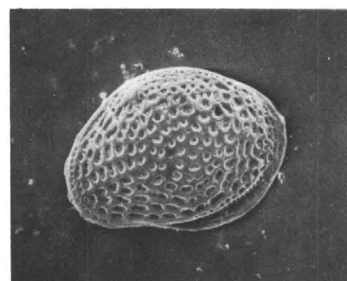
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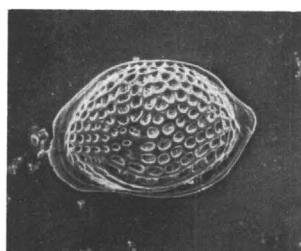
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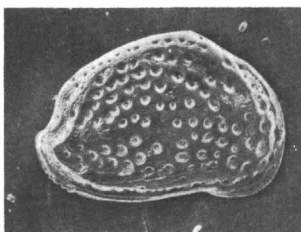
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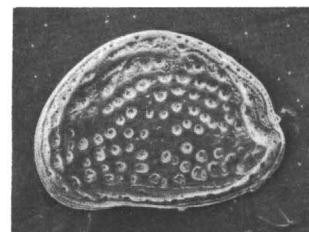
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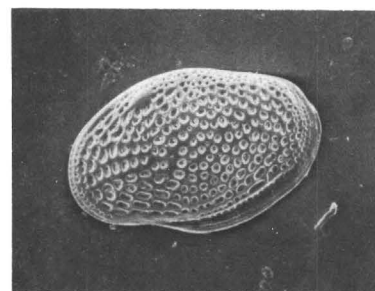
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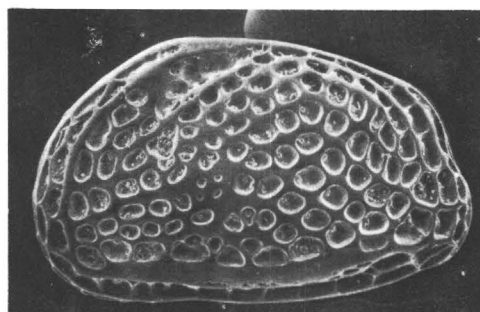
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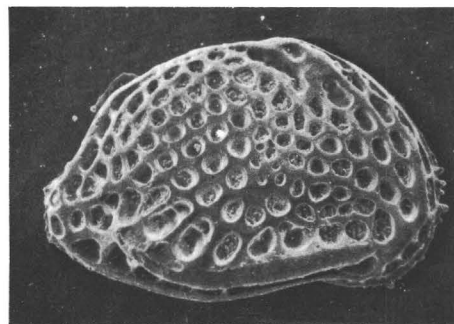
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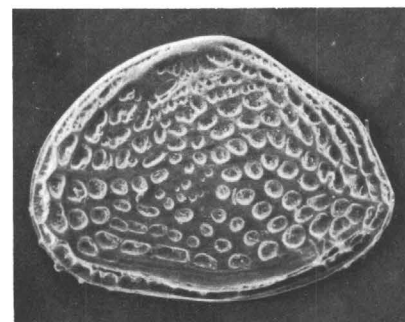
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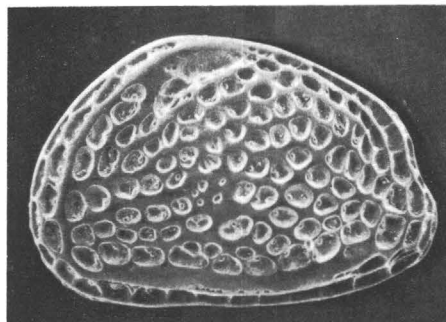
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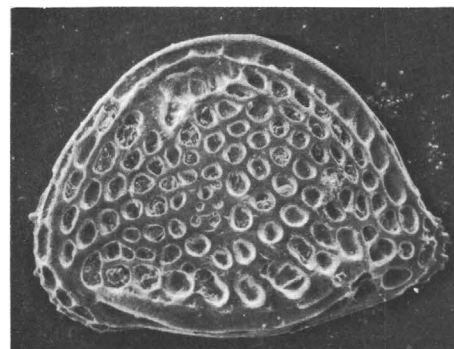
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15



16



17

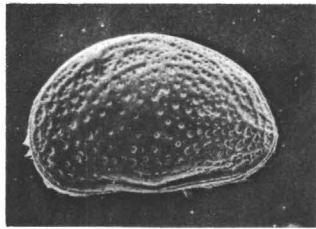
AURILA, "AURILA," AND LOXOCONCHA

## PLATE 8

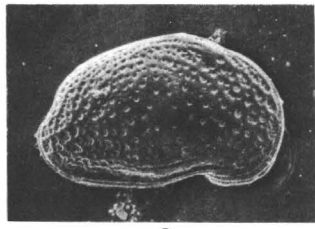
[All figures are lateral views; all  $\times 60$ ]

- |         |  |
|---------|--|
| FIGURES | <p>1-4. <i>Aurila</i> sp. C.</p> <p style="padding-left: 20px;">1. Left valve, male. Sample 109. USNM 207898.</p> <p style="padding-left: 20px;">2. Right valve, male. Sample 109. USNM 207899.</p> <p style="padding-left: 20px;">3. Right valve, female. Sample 109. USNM 207900.</p> <p style="padding-left: 20px;">4. Left valve, female. Sample 109. USNM 207901.</p> <p>5-8. <i>Aurila lincolnensis</i> (LeRoy, 1943).</p> <p style="padding-left: 20px;">5. Left valve, male. Sample 67. USNM 207902.</p> <p style="padding-left: 20px;">6. Right valve, male. Sample 67. USNM 207903.</p> <p style="padding-left: 20px;">7. Right valve, female. Sample 67. USNM 207904.</p> <p style="padding-left: 20px;">8. Left valve, female. Sample 67. USNM 207905.</p> <p>9, 10, 12, 13, 15, 16, 18, 19. <i>Aurila</i> sp. A.</p> <p style="padding-left: 20px;">9. Left valve, male. Sample 67. USNM 207906.</p> <p style="padding-left: 20px;">10. Right valve, male. Sample 67. USNM 207907.</p> <p style="padding-left: 20px;">12. Left valve, female. Sample 67. USNM 207908.</p> <p style="padding-left: 20px;">13. Right valve, female. Sample 67. USNM 207909.</p> <p style="padding-left: 20px;">15. Left valve, male. Sample 3. USNM 207910.</p> <p style="padding-left: 20px;">16. Right valve, male. Sample 3. USNM 207911.</p> <p style="padding-left: 20px;">18. Left valve, female. Sample 3. USNM 207912.</p> <p style="padding-left: 20px;">19. Right valve, female. Sample 3. USNM 207913.</p> <p>11, 14. <i>Aurila</i> sp. D.</p> <p style="padding-left: 20px;">11. Left valve, female. Sample 109. USNM 207914.</p> <p style="padding-left: 20px;">14. Right valve, female. Sample 109. USNM 207915.</p> <p>17, 20. <i>Aurila montereyensis</i> (Skogsberg, 1928).</p> <p style="padding-left: 20px;">17. Right valve, female. Sample 108. USNM 207916.</p> <p style="padding-left: 20px;">20. Left valve, female. Sample 108. USNM 207917.</p> |
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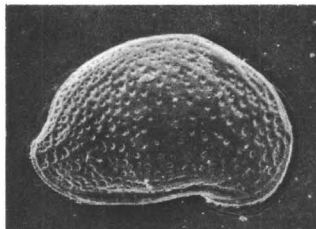




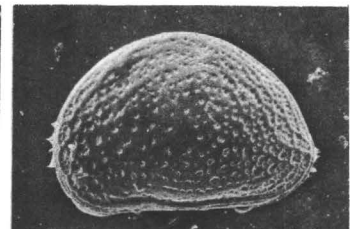
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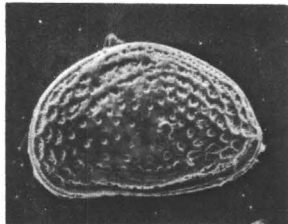
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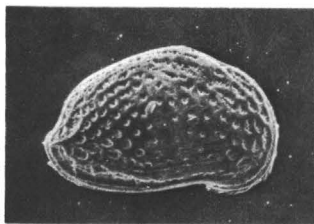
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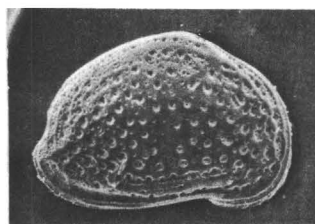
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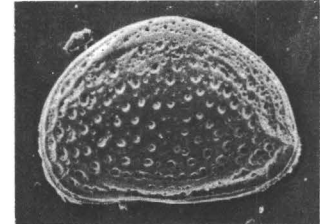
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6



7



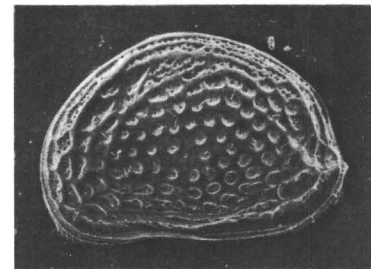
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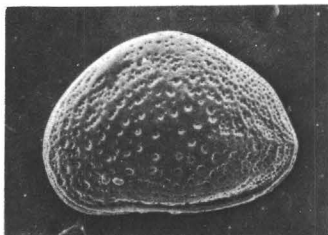
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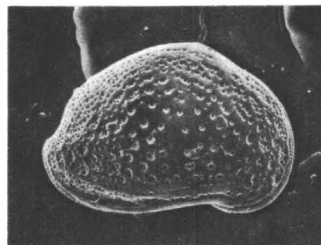
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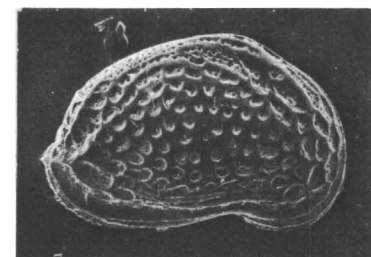
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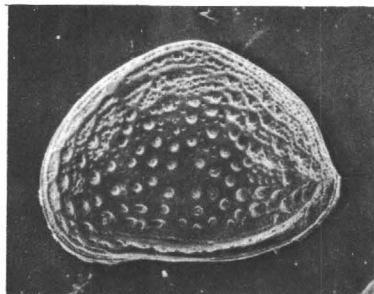
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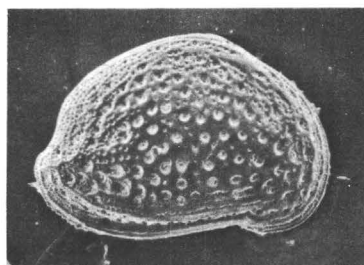
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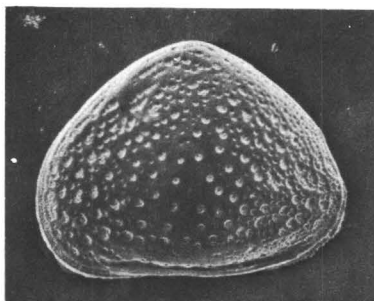
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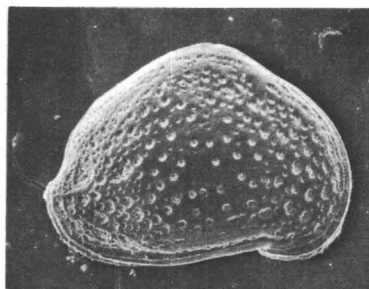
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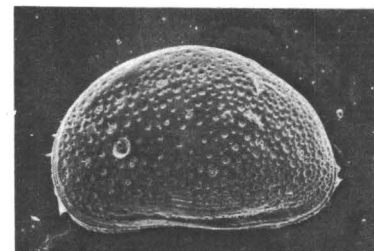
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18



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20

*AURILA*

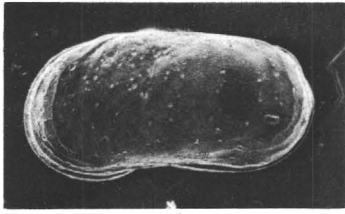
## PLATE 9

[All figures are lateral views; all  $\times 60$ ]

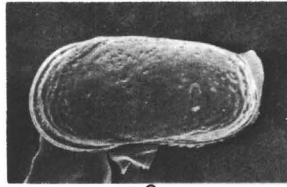
### FIGURES

- 1, 4. *Cytheromorpha* sp. A.
  1. Left valve, male. Sample 2. USNM 207918.
  4. Left valve, female. Sample 2. USNM 207919.
- 2, 3. *Cytheromorpha* sp. B.
  2. Left valve, male. Sample 2. USNM 207920.
  3. Left valve, female. Sample 2. USNM 207921.
- 5, 6. "*Radimella*" *aurita* (Skogsberg, 1928).
  5. Left valve, female. Sample 177. USNM 207922.
  6. Left valve, male. Sample 177. USNM 207923.
- 7, 10. *Radimella palosensis* (LeRoy, 1943).
  7. Left valve, female. Sample 101. USNM 207924.
  10. Left valve, male. Sample 101. USNM 207925.
- 8, 11. *Radimella* sp. B.
  8. Left valve, female. Sample 244. USNM 207926.
  11. Left valve, male. Sample 244. USNM 207927.
- 9, 12. *Radimella* sp. A.
  9. Left valve, female. Sample 202. USNM 207928.
  12. Left valve, male. Sample 202. USNM 207929.
- 13, 16. "*Radimella*" *jollaensis* (LeRoy, 1943).
  13. Left valve, female. Sample 177. USNM 207930.
  16. Left valve, male. Sample 177. USNM 207931.
- 14, 17. "*Radimella*" sp. A.
  14. Left valve, female. Sample 67. USNM 207932.
  17. Left valve, male. Sample 67. USNM 207933.
15. "*Radimella*" *pacifica* (Skogsberg, 1928).
  - Left valve, female. Sample 108. USNM 207934.
18. "*Radimella*" sp. B.
  - Left valve, female. Sample 201. USNM 207935.

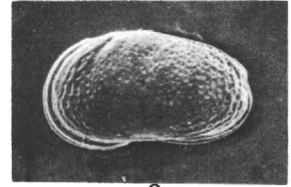




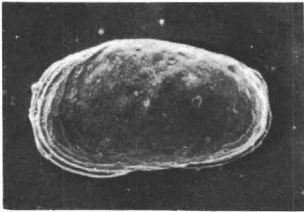
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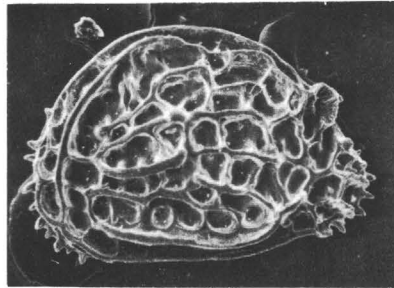
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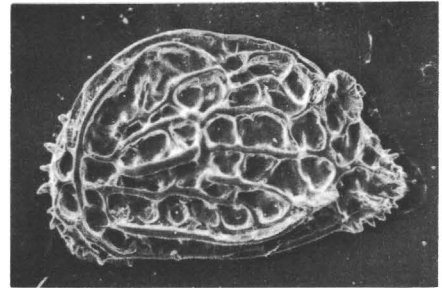
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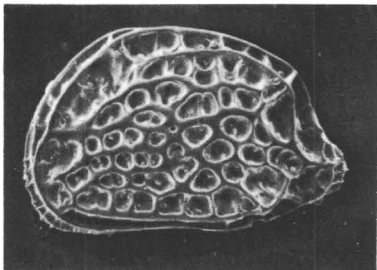
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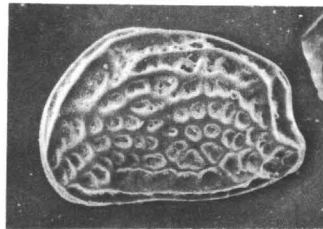
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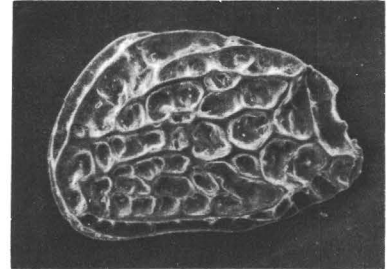
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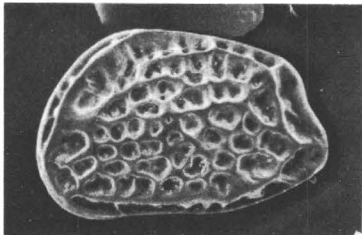
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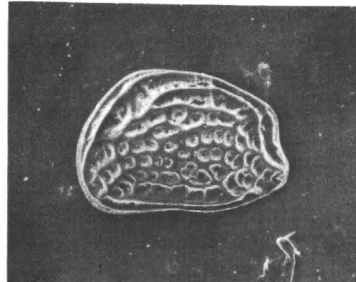
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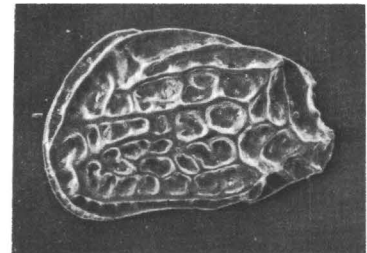
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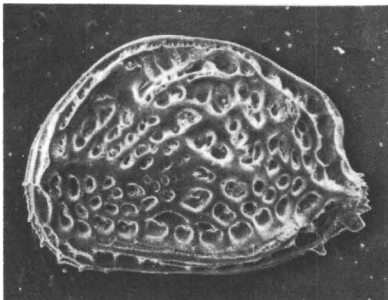
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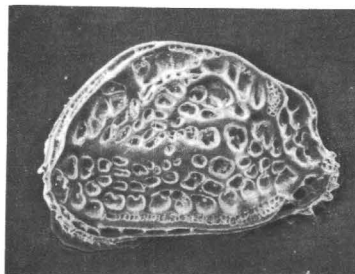
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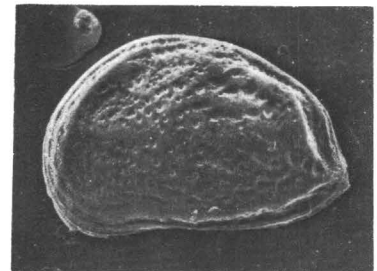
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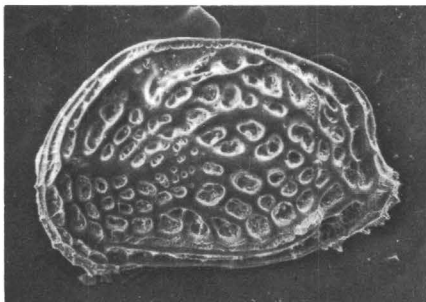
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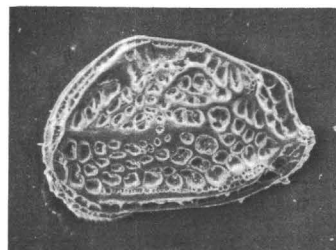
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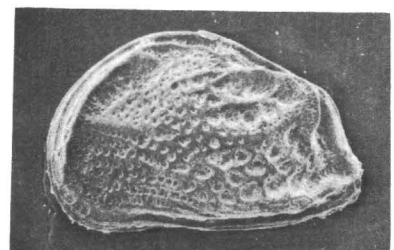
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## PLATE 10

[All figures are lateral views; all  $\times 60$  except where noted]

### FIGURES

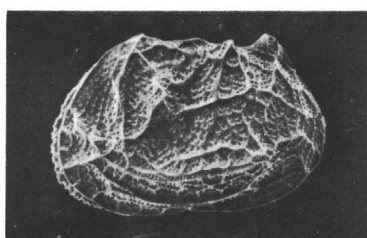
- 1, 2. *Munseyella* sp. A.
  1. Right valve, female. Sample 197. USNM 207936.
  2. Left valve, female. Sample 197. USNM 207937.
- 3, 4. *Palmenella californica* Triebel, 1957.
  3. Left valve, female. Sample 141. USNM 207938.
  4. Right valve, female. Sample 141. USNM 207939.
- 5, 6. *Munseyella* sp. B.
  5. Left valve, female. Sample 96. USNM 207940.
  6. Right valve, female. Sample 96. USNM 207941.
- 7, 12. *Munseyella similis*? Triebel, 1957.
  7. Left valve, male. Sample Mf2180.  $\times 120$ . USNM 207942.
  12. Left valve, female. Sample Mf2180.  $\times 120$ . USNM 207943.
- 8-11. *Pectocythere* sp. A.
  8. Left valve, female. Sample Mf2180. USNM 207944.
  9. Right valve, female. Sample Mf2180. USNM 207945.
  10. Left valve, male. Sample 2. USNM 207946.
  11. Right valve, male. Sample 2. USNM 207947.
- 13, 14. *Pectocythere clavata* (Triebel, 1957).
  13. Left valve, female. Sample 117. USNM 207948.
  14. Right valve, female. Sample 117. USNM 207949.
- 15, 18. *Munseyella pedroensis* Triebel, 1957.
  15. Left valve, female. Sample Mf2174.  $\times 120$ . USNM 207950.
  18. Right valve, female. Sample Mf2174.  $\times 120$ . USNM 207951.
- 16, 17. *Pectocythere tomalensis* Watling, 1970.
  16. Left valve, female. Sample 68. USNM 207952.
  17. Right valve, female. Sample 68. USNM 207953.



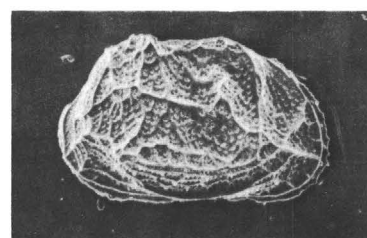
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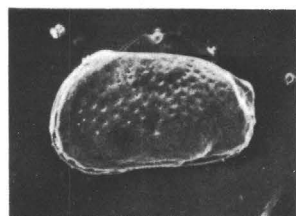
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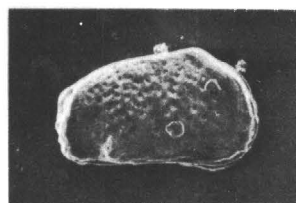
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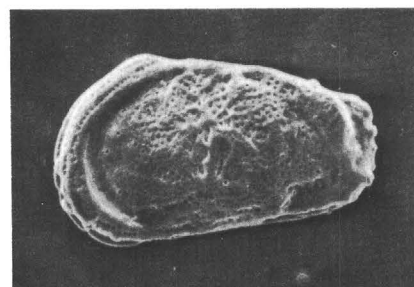
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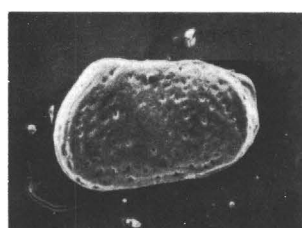
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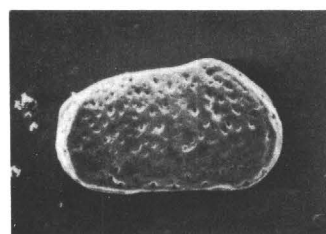
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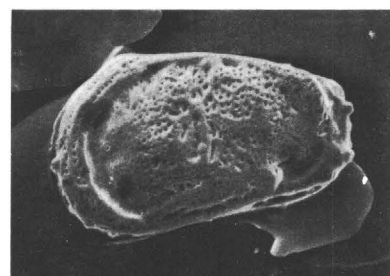
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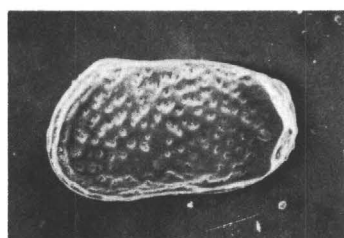
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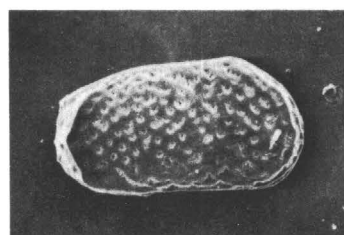
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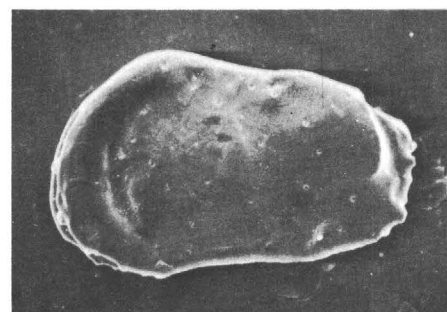
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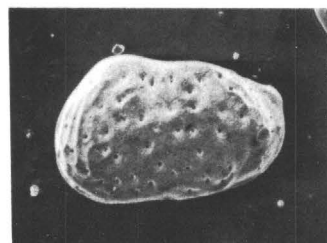
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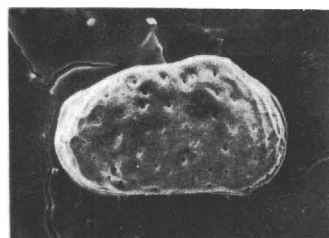
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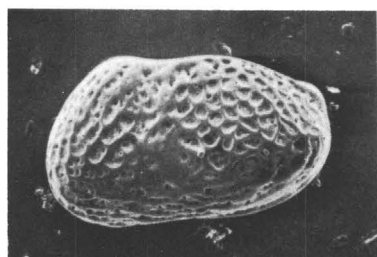
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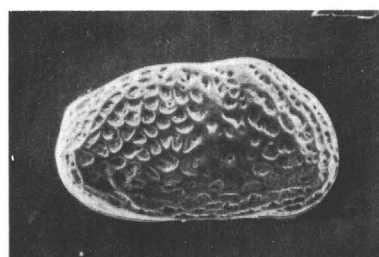
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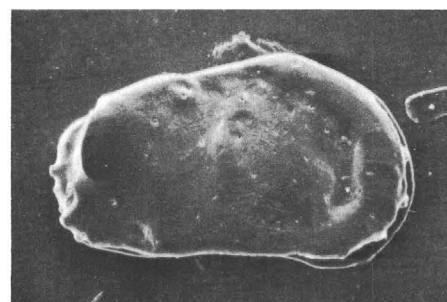
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*MUNSEYELLA, PALMENELLA, AND PECTOCYTHERE*

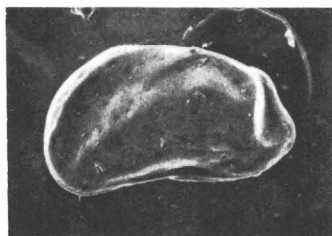
## PLATE 11

[All figures are lateral views; all  $\times 60$ ]

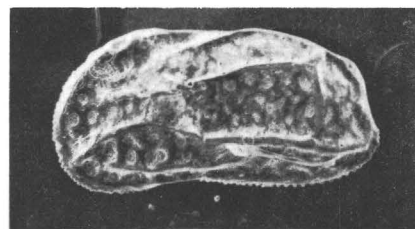
- |         |  |
|---------|--|
| FIGURES | <p>1, 4. <i>Palaciosia</i> sp. A.</p> <p style="padding-left: 20px;">1. Left valve, female. Sample 108. USNM 207954.</p> <p style="padding-left: 20px;">4. Right valve, female. Sample 108. USNM 207955.</p> <p>2, 5. <i>Palaciosia</i> sp. B.</p> <p style="padding-left: 20px;">2. Left valve, female. Sample 101. USNM 207956.</p> <p style="padding-left: 20px;">5. Left valve, male. Sample 101. USNM 207957.</p> <p>3, 6. <i>Orionina pseudovaughni</i> Swain, 1967.</p> <p style="padding-left: 20px;">3. Left valve, female. Sample 233. USNM 207958.</p> <p style="padding-left: 20px;">6. Right valve, female. Sample 233. USNM 207959.</p> <p>7, 11. <i>Caudites</i> sp. B.</p> <p style="padding-left: 20px;">7. Left valve, female. Sample 221. USNM 207960.</p> <p style="padding-left: 20px;">11. Right valve, female. Sample 221. USNM 207961.</p> <p>8, 12. <i>Caudites fragilis</i> LeRoy, 1943.</p> <p style="padding-left: 20px;">8. Left valve, female. Sample 197. USNM 207962.</p> <p style="padding-left: 20px;">12. Right valve, female. Sample 197. USNM 207963.</p> <p>9, 13. <i>Caudites</i> sp. D.</p> <p style="padding-left: 20px;">9. Left valve, female. Sample 242. USNM 207964.</p> <p style="padding-left: 20px;">13. Right valve, female. Sample 242. USNM 207965.</p> <p>10, 14. <i>Caudites</i> sp. E.</p> <p style="padding-left: 20px;">10. Left valve, female. Sample 241. USNM 207966.</p> <p style="padding-left: 20px;">14. Right valve, female. Sample 241. USNM 207967.</p> <p>15, 16, 18, 19. <i>Caudites purii</i> (McKenzie and Swain, 1967).</p> <p style="padding-left: 20px;">15. Left valve, female. Sample 242. USNM 207968.</p> <p style="padding-left: 20px;">16. Right valve, female. Sample 242. USNM 206969.</p> <p style="padding-left: 20px;">18. Left valve, male. Sample 233. USNM 207970.</p> <p style="padding-left: 20px;">19. Right valve, male. Sample 233. USNM 207971.</p> <p>17, 20. <i>Triebelina reticulopunctata</i> Benson, 1959.</p> <p style="padding-left: 20px;">17. Right valve, female. Sample 221. USNM 207972.</p> <p style="padding-left: 20px;">20. Left valve, female. Sample 221. USNM 207973.</p> |
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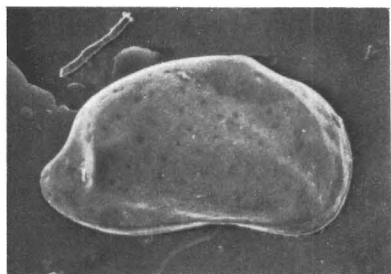
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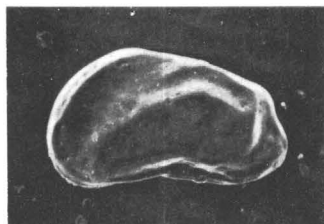
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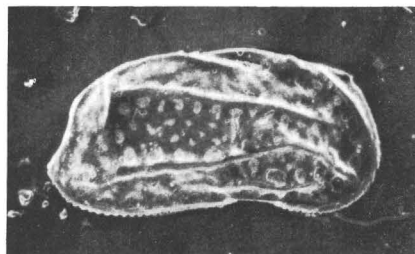
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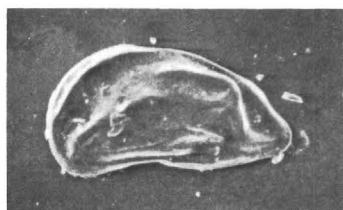
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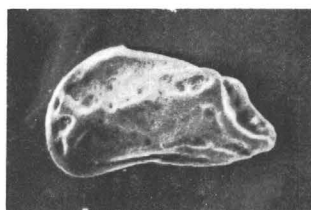
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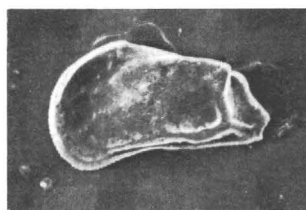
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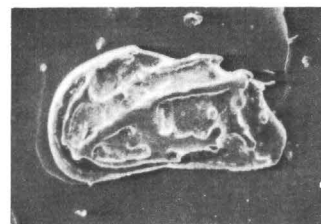
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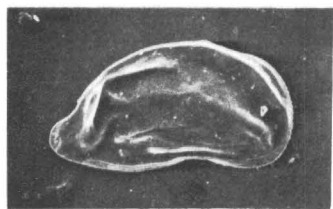
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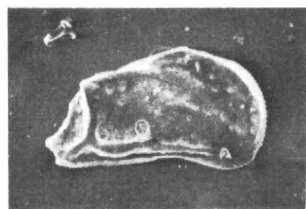
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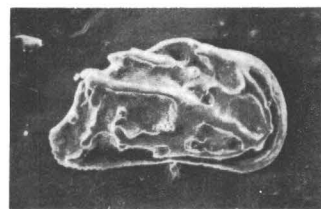
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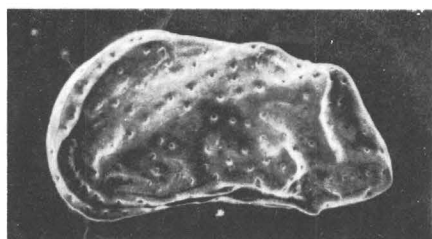
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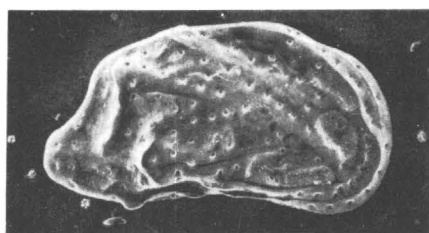
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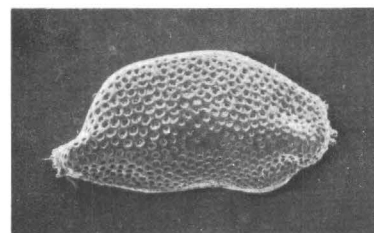
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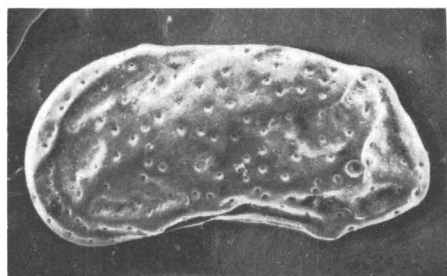
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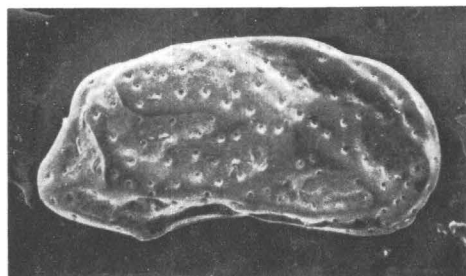
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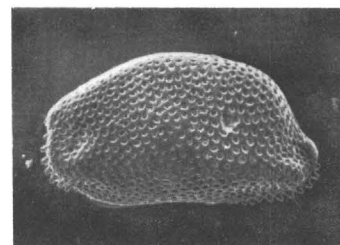
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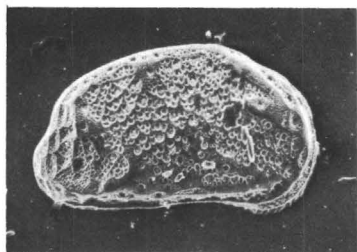
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## PLATE 12

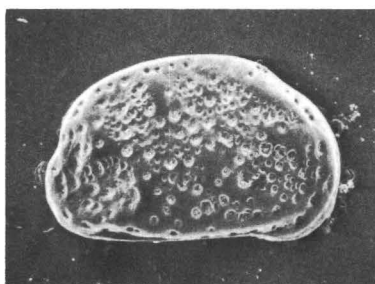
[All figures are lateral views; all  $\times 60$ ]

- FIGURES 1, 4, 7, 10. *Hemicythere* sp. A.
1. Right valve, female. Sample 32. USNM 207974.
  4. Left valve, female. Sample 32. USNM 207975.
  7. Right valve, male. Sample 32. USNM 207976.
  10. Left valve, male. Sample 32. USNM 207977.
- 2, 5, 8, 12. *Hemicythere* sp. B.
2. Right valve, female. Sample 40. USNM 207978.
  5. Left valve, female. Sample 40. USNM 207979.
  8. Right valve, male. Sample 40. USNM 207980.
  12. Left valve, male. Sample 40. USNM 207981.
- 3, 6. *Cythere maia* (Benson, 1959).
3. Right valve, female. Sample 109. USNM 207982.
  6. Left valve, female. Sample 109. USNM 207983.
- 9, 13. *Cythere* sp. B.
9. Right valve, female. Sample 40. USNM 207984.
  13. Left valve, female. Sample 40. USNM 207985.
11. *Basslerites thlipsuroidea* Swain, 1967.  
Left valve. Sample 255. USNM 207986.
14. *Basslerites delreyensis* LeRoy, 1943.  
Left valve, female. Sample 215. USNM 207987.
- 15, 16. *Cythere* sp. A.
15. Right valve, female. Sample 31. USNM 207988.
  16. Left valve, female. Sample 31. USNM 207989.





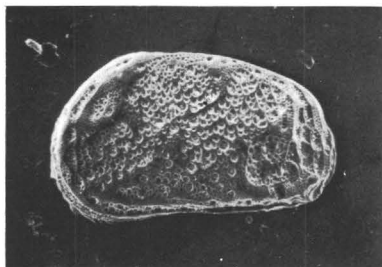
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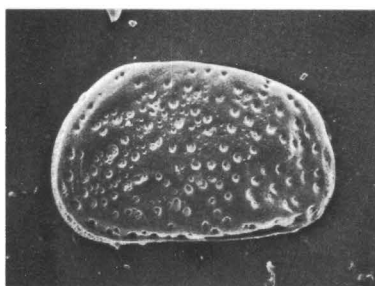
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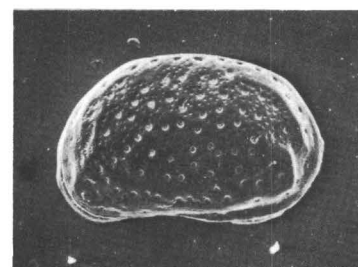
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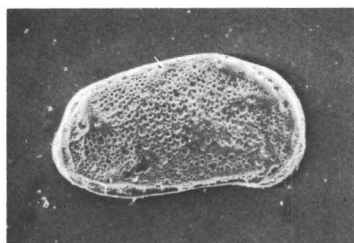
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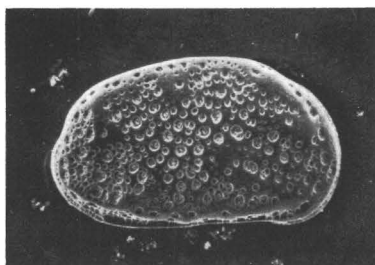
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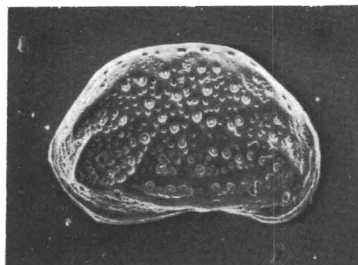
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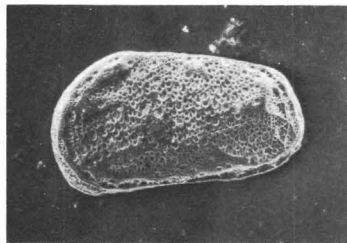
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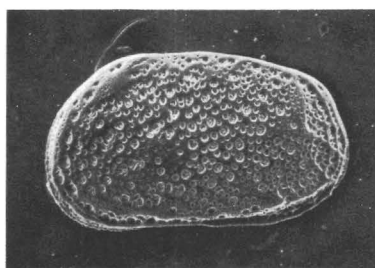
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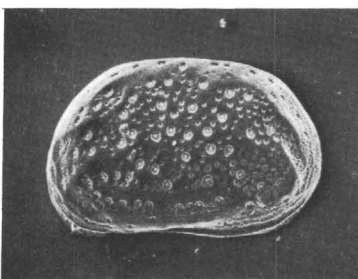
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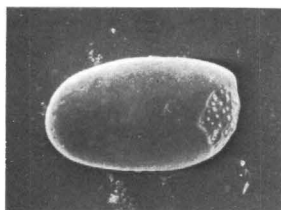
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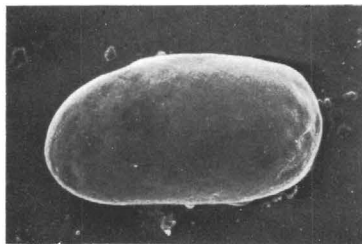
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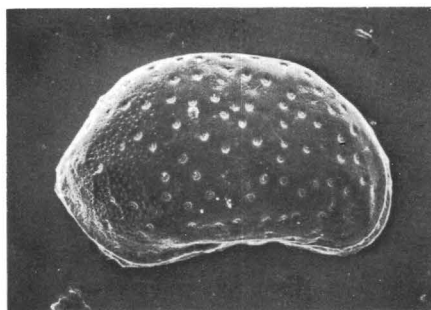
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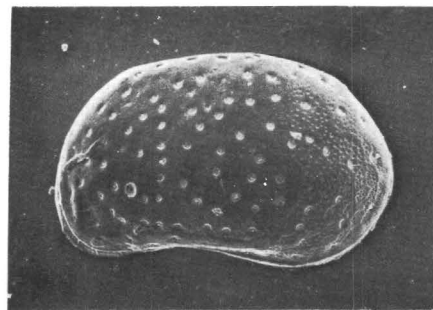
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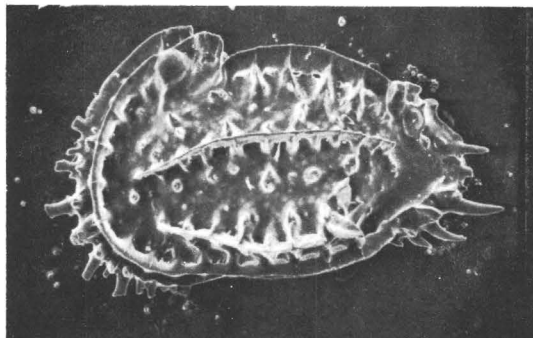
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# PLATE 13

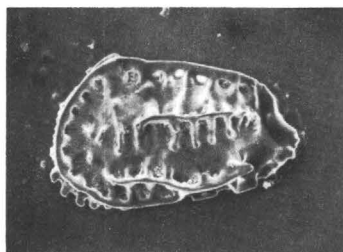
[All figures are lateral views; all  $\times 60$ ]

- FIGURES
- 1, 6. *Cativella semitranslucens* (Crouch, 1949).
    1. Left valve, female. Santa Barbara Formation. USNM 207990.
    6. Right valve, female. Santa Barbara Formation. USNM 207991.
  2. *Cativella* sp. A.
    - Left valve, female. Sample 222. USNM 207992.
  3. *Cativella* sp. B.
    - Left valve, female. Sample 255. USNM 207993.
  - 4, 5, 7. "*Paijenborchella*" sp. B.
    4. Right valve, female. Sample 101. USNM 207994.
    5. Left valve, female. Sample 101. USNM 207995.
    7. Right valve, female. Sample Mf2180. USNM 207996.
  - 8, 11. "*Paijenborchella*" sp. A.
    8. Right valve, female. Sample 8. USNM 207997.
    11. Left valve, female. Sample 8. USNM 207998.
  - 9, 12. "*Trachyleberis*" sp. A.
    9. Left valve, male. Sample 255. USNM 207999.
    12. Left valve, female. Sample 255. USNM 208000.
  10. *Neocaudites?* *henryhowei* (McKenzie and Swain, 1967).
    - Left valve, female. Sample 215. USNM 208001.
  - 13, 14. *Costa?* *sanfelipensis* Swain, 1967.
    13. Left valve, male. Sample 255. USNM 208002.
    14. Left valve, female. Sample 255. USNM 208003.

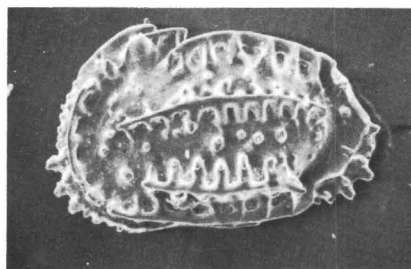




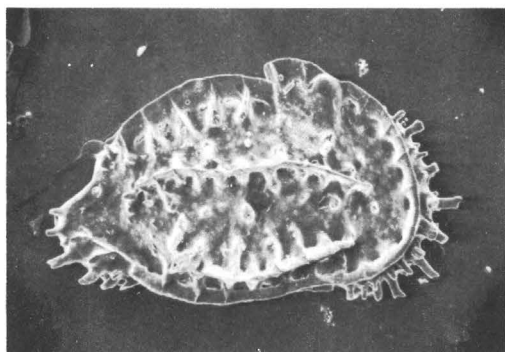
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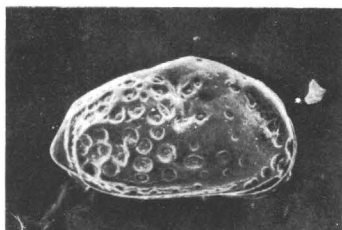
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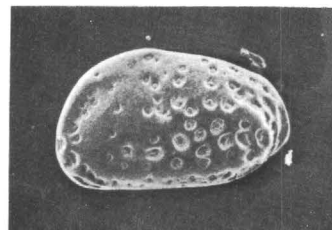
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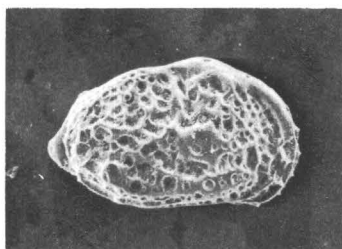
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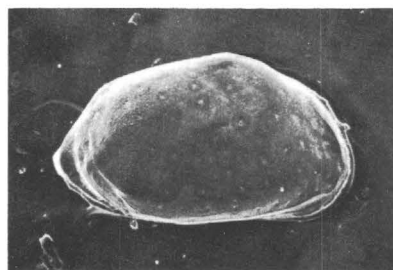
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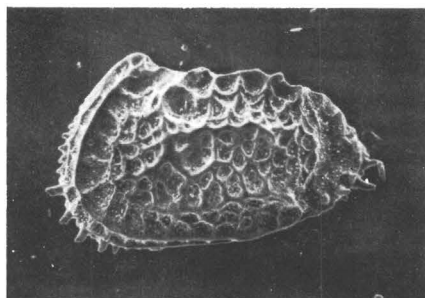
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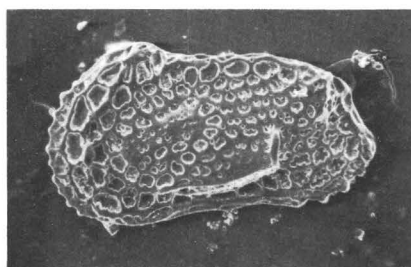
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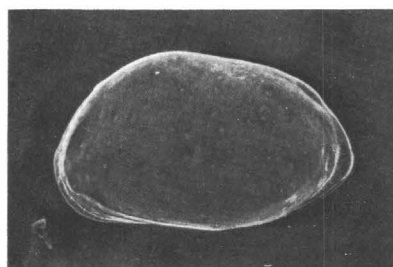
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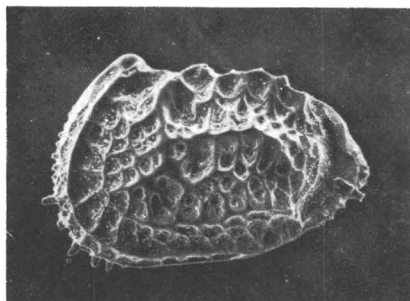
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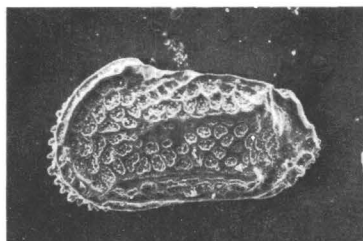
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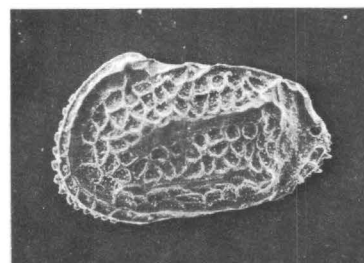
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12



13



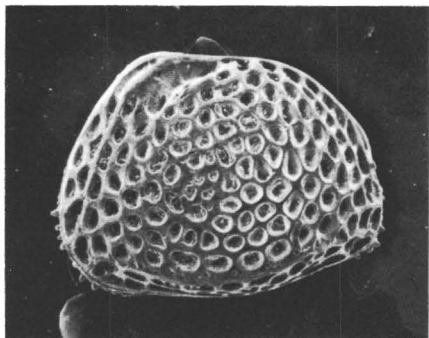
14

*CATIVELLA*, *COSTA*?, *NEOCAUDITES*?, "PAIJENBORCHELLA," AND "TRACHYLEBERIS"

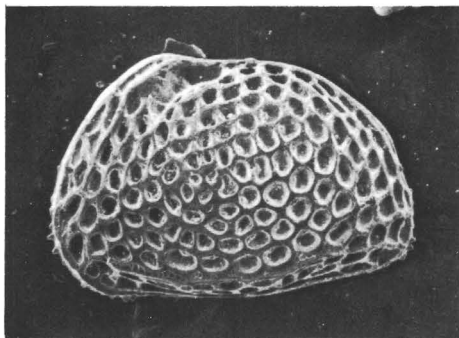
## PLATE 14

[All figures are lateral views; all  $\times 60$ ]

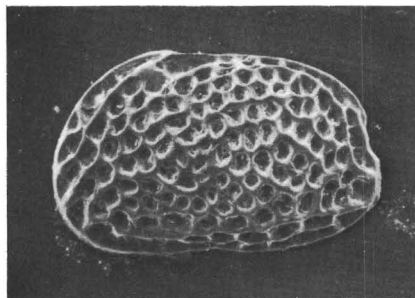
- FIGURES 1, 2, 4, 5. "*Hemicythere*" sp. A.
1. Left valve, female. Sample Mf2176. USNM 208004.
  2. Left valve, male. Sample Mf2176. USNM 208005.
  4. Left valve, female. Sample 164. USNM 208006.
  5. Left valve, male. Sample 164. USNM 208007.
- 3, 6. "*Hemicythere*" sp. B.
3. Left valve, female. Sample 203. USNM 208008.
  6. Left valve, male. Sample 203. USNM 208009.
- 7, 8. "*Hemicythere*" *californiensis* LeRoy, 1943.
7. Left valve, female. Sample Mf2176. USNM 208010.
  8. Left valve, male. Sample Mf2176. USNM 208011.
9. "*Hemicythere*" sp. C.
- Left valve, male. Sample 222. USNM 20812.
- 10, 11. "*Hemicythere*" *hispida* LeRoy, 1943.
10. Left valve, female. Sample Mf2174. USNM 208013.
  11. Left valve, male. Sample Mf2176. USNM 208014.



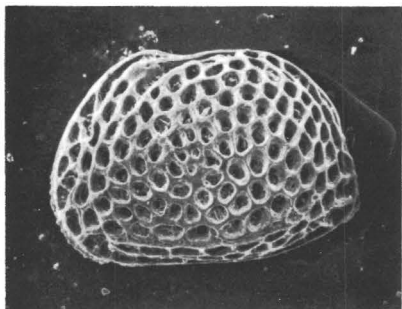
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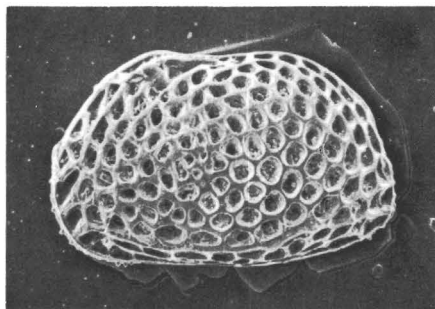
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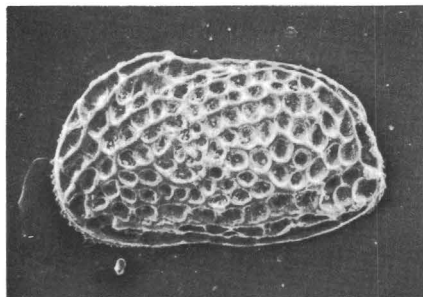
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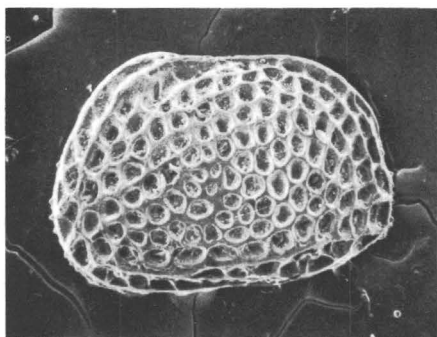
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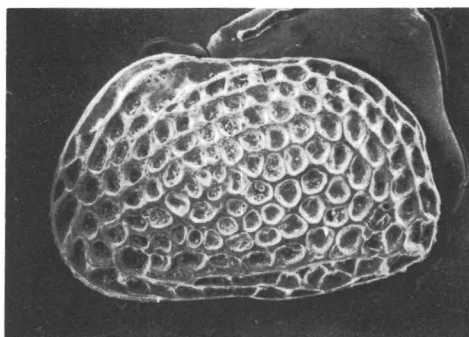
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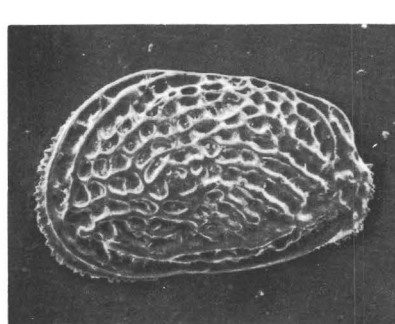
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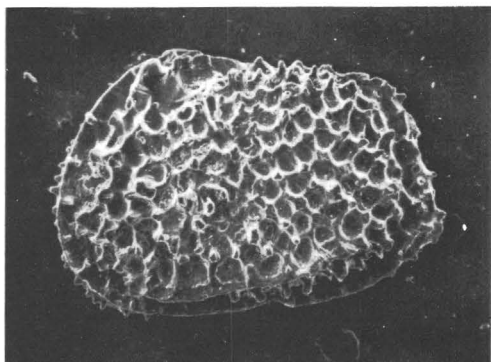
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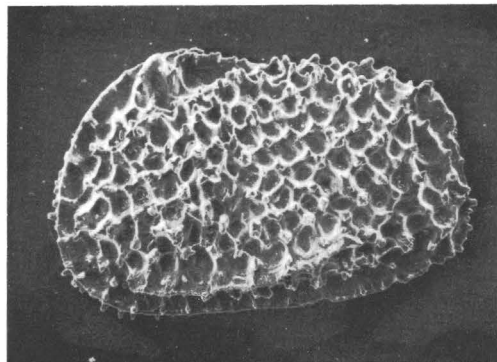
8



9



10



11

*"HEMICYTHERE"*

