BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 43, NO. 9 (SEPTEMBER, 1959), PP. 2100-2166, 32 FIGS., 6 PLS.

MACRO-INVERTEBRATE ASSEMBLAGES OF CENTRAL TEXAS COASTAL BAYS AND LAGUNA MADRE[1]

ROBERT H. PARKER[2]
La Jolla, California

ABSTRACT

A study of the distribution of macrofauna and the ecological factors affecting their distribution in the bays and lagoons of the central and south Texas coast has made it possible to formulate a series of criteria for interpreting modern and ancient depositional environments. The observations reported in this paper cover a 7-year period. In addition, some information was available covering a period of 30 years. The central Texas bays are situated in a variable climate, and the faunas reflect long-term changes in rainfall and temperature.

Four major environments are recognized on the basis of macro-invertebrate assemblages: (1) river-influenced low-salinity bays and estuaries characterized by *Rangia* and amnicolids; (2) enclosed bays, dominated by oyster reefs composed of *Crassostrea virginica;* (3) open bays and sounds characterized by *Tagelus divisus*, *Chione cancellata*, and *Macoma constricta;* and (4) bay and lagoon regions strongly influenced by inlets characterized by a mixed Gulf and bay fauna. Smaller "sub-facies" needing more information for recognition are: (1) bay margins, (2) oyster reefs exhibiting marine influence, (3) bay centers, and (4) shallow grassy bays in the vicinity of inlets.

Five assemblages were recognized in Laguna Madre which are related to the physiography of the Laguna Madre: (1) shallow hypersaline area near inlet characterized by forms common to the Gulf and normal salinity bays on the north; (2) open hypersaline lagoon characterized by *Amygdalum papyria* and other forms attaching to vegetation; (3) enclosed hypersaline lagoon with tremendous numbers of two pelecypods, *Anomalocardia cuneimeris* and *Mulinia lateralis;* (4) relatively deep hypersaline bay with clayey substrate with virtually no living macro-invertebrates; and (5) hypersaline lagoon with normal bay influence, occupied by many of the species typical of an open bay plus *Anomalocardia* and *Mulinia.*

The application of macrofaunal assemblages to the interpretation of older sediments was demonstrated in a study of a series of borings taken in the Rockport area. The macrofaunal evidence indicates that the Rockport bays have undergone at least one marine transgression in the past 9,000 years.

INTRODUCTION[3]

The purpose of this study is to establish criteria for the identification of shallow-water marine environments based on the distribution of the present-day macro-invertebrates, which may be useful in interpreting the ancient depositional environments. A previous study in the Mississippi Delta region (Parker, 1956) established macrofaunal criteria for the recognition of sedimentary environments in an area of rapid deposition, comparatively high rainfall and extremely variable hydrography. The Rockport, Texas, area (Fig. 1), with low rainfall, a slow rate of deposition and comparatively stable hydrography was selected as a contrasting depositional setting. The sediments, microfauna, and geologic setting of the Rock-

---

[1] Contribution from the Scripps Institution of Oceanography. This investigation was supported by a grant from the American Petroleum Institute, Project 51. Manuscript received, October 13, 1958.

[2] Scripps Institution of Oceanography, University of California.

[3] Most of the past and present staff of the American Petroleum Institute Project 51 have assisted in collecting and analyzing the data which are used in the report. The writer is particularly grateful to W. K. Emerson and E. L. Puffer for permission to make use of their data. Among the staff, past and present, of the Marine Laboratory of the Texas Game and Fish Commission at Rockport, Texas, who have contributed considerable time and information are Howard T. Lee, Cecil Reed, Joseph Breuer, William Guest, Robert Hofstettor, H. Hoese, Ernest Simmons, and Terrance Leary. At Scripps Institution, considerable assistance and advice were given by Joseph R. Curray, William Fager, Joel W. Hedgpeth, Fred B Phleger, Gene A. Rusnak, Francis P. Shepard, and T. J. Van Andel. Robert Winsett, Howard Taylor and James R. Moriarty prepared the illustrations.

port region have been discussed by other investigators (Shepard and Moore, 1955; Shepard, 1953, 1956; F. L. Parker, Phleger and Peirson, 1953; Phleger, 1956; Phleger and Lankford, 1957; and Swain, 1955).

Studies were also carried out in the Laguna Madre of Texas (Fig. 1). This area provides an even greater contrast to the Mississippi Delta, both in hydrography and fauna. The sediments, hydrography, and geologic history of the Laguna Madre are discussed by Rusnak (in press).

The investigation of the macro-invertebrate assemblages of the Rockport, Texas, bays was initiated by this project in 1951 by Puffer (1953) and Puffer and Emerson (1953). Most of their work was based on one set of samples taken over a 6-week period in July and August, 1951. Preliminary studies indicated to the writer that a sampling program of such a short duration would be insufficient to give a detailed picture of bay assemblages.

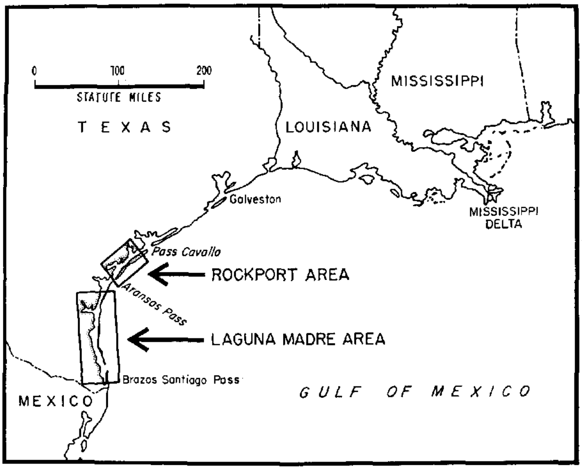

FIG. 1.—Location of study areas on coast of northwest Gulf of Mexico.

The Rockport region, 30 miles northeast of Corpus Christi, includes several shallow connected bays, separated from the open Gulf of Mexico by wide barrier islands, occasionally interrupted by very narrow inlets (Fig. 2). During the present study these bays have remained relatively free of pollution or human disturbance, except from numerous oil wells in Copano Bay (not studied in detail) and the dredging of semi-fossil oyster reefs in San Antonio Bay. The bays in this area are well suited for a study of the effects of environmental factors, particularly salinity, on the distribution of invertebrates, since there is a wide range of salinity from river mouth to open Gulf.

Numerous papers have been published on the faunal assemblages present in Texas under climatic conditions different from those of the past 7 years. These papers have been useful in interpreting the presence of the large amount of shell

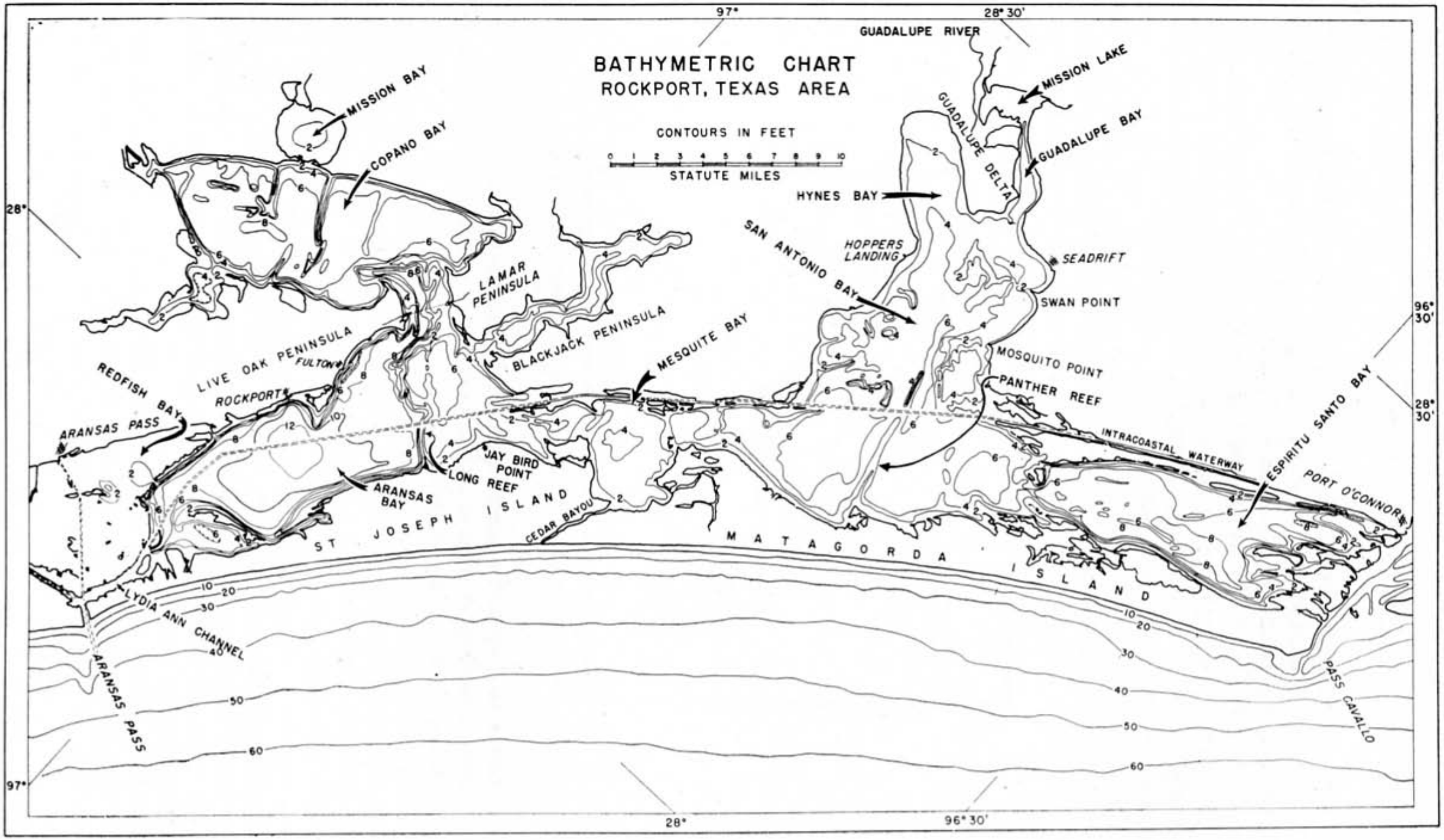

FIG. 2.—Bottom topography and locality names, Rockport area. Bay contour interval 2 feet. (After Shepard and Moore, 1955)

material not found living during the present study (Mitchell, 1894; Galtsoff, 1931; Gunter, 1950; Pulley, 1952; Ladd, 1951; and Hedgpeth, 1953). Except for Mitchell's study, the other surveys were carried out when salinity values were considerably lower than during the period covered by this study. The hydrography of the Rockport region during times of reduced salinity is discussed by Collier and Hedgpeth (1950) and discussion of the high salinity values obtained in the early stages of the present study may be found in Hildebrand and Gunter (1953), Puffer and Emerson (1953), and Parker (1955). Extensive bibliographies on the geology, biology, and ecology of the central Texas coast can be found in Hedgpeth (1953), Galtsoff *et al.* (1954), Shepard and Moore (1955), and Ladd, Hedgpeth, and Post (1957). A geographic and geologic description of the Rockport region is given in Shepard and Moore (1955) and the post-Pleistocene-Recent history of the area has been discussed by Shepard (1956).

METHODS

Salinity measurements were taken intermittently throughout the period of study (Mohr method of titration and hydrometer). The majority of salinity measurements made since 1954 were made at the Marine Laboratory of the Texas Game and Fish Commission, while others were obtained as part of a seasonal study of Foraminifera (Phleger, 1956). Other physical and chemical measurements are given by Shepard and Moore (1955, pp. 1491–98, 1519–28).

During the first few years of the project, biological samples were taken with the "orange-peel" grab and otter trawl. Although not used for quantitative bottom sampling, these devices obtained large enough samples for a reconnaissance survey of the area. During the latter half of the study, the Van Veen bottom grab and minidredge replaced the previous sampling gear. As in similar work in the Mississippi Delta region (Parker, 1956), the coarse fraction of the sediment from the top 10–20 cm. of cores taken for the geological studies was analyzed to obtain information on the past range of many species not found alive at the time of sampling. Samples were also taken by beachcombing and wading along the shores, especially in the shallow Redfish Bay area.

Most of the invertebrates were identified by the writer and checked at the U. S. National Museum, Washington, D. C., and the Museum of Comparative Zoology, Harvard University. The invertebrates collected during the 1951 field season were identified and checked by Puffer and Emerson.

The number of living and dead individuals of each species of mollusk, echinoderm, crustacean, and certain coelenterates was determined for all biological samples, except for the samples taken by Puffer and Emerson and the staff of the Marine Laboratory at Rockport. Most of the indicator species were found at more than 9 stations, and taken alive at more than 30 per cent of the stations falling within the boundary of the environment for which each was thought to be indicative. It must be stressed, however, that no one or two indicator species by themselves can be considered a positive criterion for environmental interpretation. There is a subjective element in interpretation, since it is the character (comparative abundance of living and dead of a number of species) of the assemblage which has a specific "appearance," that can not be expressed in quantitative terms. All species with more than 9 station occurrences were plotted on small distribution maps, and the centers of abundance of these populations selected. These distribution maps were then compared with the known variance of physical and chemical factors, as well as published distributions of the fauna at times of reduced salinity and high rainfall. These basic data permit the establishing of faunal boundaries, which may fluctuate considerably. The environmental boundaries were established from the observations of both physical and biological data.

Tables with all of the invertebrate species with their station occurrences and comparative abundance are on file at the Library of Scripps Institution of Oceanography.

ENVIRONMENTAL DESCRIPTION OF ROCKPORT AREA

The Rockport region is a suitable one for the study of the faunas in relation to environmental factors, as there are records of the distribution of temperature and salinity from 1926 (Galtsoff, 1931) to the present time. A detailed study of the hydrography of the Rockport area was made by Collier and Hedgpeth (1950) during the period from 1936 through 1946, and the salinity and temperature data from 1946 to 1953 have been discussed by Parker (1955). Restricted hydrographic surveys have also been carried out from 1953 to 1957 by members of the A.P.I. Project 51 staff, and the staff of the Marine Laboratory at Rockport. Since there is very little communication between these bays and the Gulf of Mexico, it is possible to observe the effects of high river discharge and lowered salinity, and conversely, low river discharge, high evaporation rate, and resultant hypersalinities. In both extreme cases, most of the bay system becomes essentially isohaline; while intermediate cases of runoff produce a series of salinity regimes, ranging from very low salinities at the river mouths to normal Gulf salinities at the entrance of the various inlets.

Salinity.—The central Texas bays are considerably more stable than the Mississippi Delta region in regard to short-period salinity variations, although the total range of salinity is much greater. Salinity measurements in the Delta region ranged from about 2 to $36^{\circ}/_{oo}$, while in the Rockport area salinity values ranged from less than 1 to more than $42^{\circ}/_{oo}$. If the Laguna Madre is included, the upper range of salinity measured is about $114^{\circ}/_{oo}$. In the Mississippi Delta, these variations take place in periods ranging from a few days to a few weeks, and the increase from low to high takes place over a fairly short distance. In the Rockport region, the change from low to high salinity usually takes place over a period of several years, although a change from high to low may occur suddenly, as in the spring of 1957 when salinity in Mesquite and Aransas bays dropped from over $40^{\circ}/_{oo}$ to as low as $2\text{–}4^{\circ}/_{oo}$ in less than 3 weeks. The gradual rise in salinity permits the invasion of the bays by a marine fauna, whereas the sudden drops in salinity cause mass mortalities.[4] Both of these phenomena have been recorded during this study.

In order to visualize the general circulation patterns in the Rockport area, it is best to examine surface isohaline maps from several different climatic periods. The first attempt to establish the pattern of the distribution of salinity in the Aransas-San Antonio Bay system was made by Galtsoff (1931) who published a series of isohalines for the period between January and February, 1926. These isohalines (Fig. 3) reflect an intermediate estuarine situation comparable with Pritchard's (1952) definition of a positive coastal plain estuary, in which river runoff and precipitation exceed evaporation. Salinities ranged from $4^{\circ}/_{oo}$ at the mouth of San Antonio-Guadalupe River to $27^{\circ}/_{oo}$ at Aransas Pass, and reflected high rainfall, but not flood conditions, in the drainage basin. Collier and Hedgpeth (1950) established a similar set of isohalines in Aransas Bay for March, 1937 (Fig. 4), indicating similar climatic conditions. Examination of 30 years salinity records for these bays shows the positive estuarine situation to be the prevalent one for the Rockport bay system.

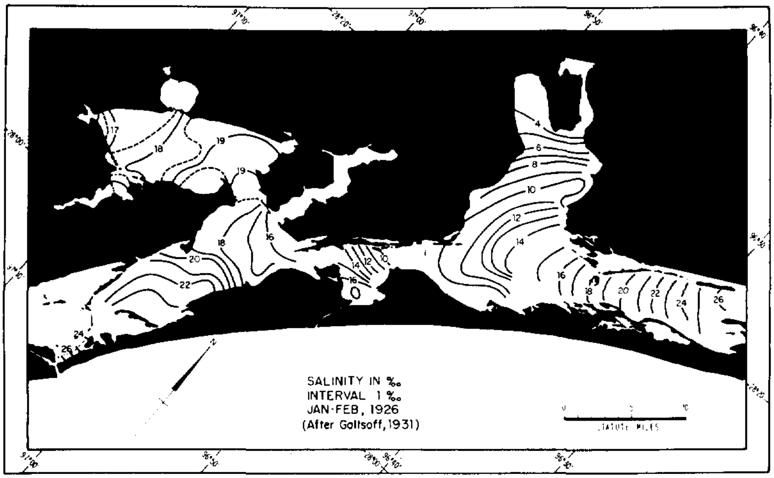

FIG. 3.—Surface isohalines during period of "average" rainfall. Contour interval $1^{\circ}/_{oo}$. Dashed line interval $0.5^{\circ}/_{oo}$.

Extreme flood conditions have been recorded several times, the most severe by Collier and Hedgpeth on July 14, 1936, when salinities ranged between 3 and $5^{\circ}/_{oo}$ throughout Aransas Bay, and San Antonio and Copano bays were virtually fresh. Similar conditions also occurred in May, 1938, June, 1941, October, 1946,

---

[4] This point has been disputed by Ladd, Hedgpeth, and Post (1957, pp. 603–04), but it should be pointed out that the present study includes four times the number of stations, occupied over a considerably longer period than that discussed by Ladd.

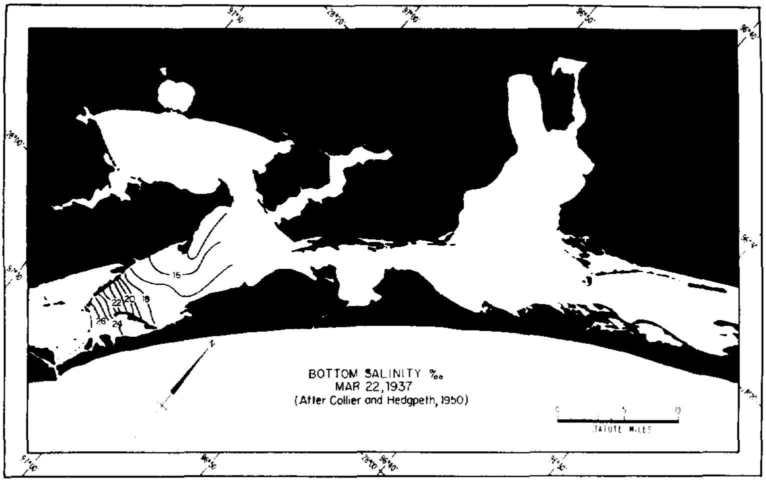

FIG. 4.—Bottom isohalines during period of "average" rainfall, stressing reduced salinities in vicinity of Aransas Pass. Contour interval 1°/00.

and in June, 1957 (Fig. 5). A particularly great destruction of fauna requiring high salinity for optimum living conditions was observed during the June, 1957, flood. This was to be expected, as bay salinities preceding the flood were approximately 40°/00, whereas salinities preceding the earlier floods were much lower. Since high-salinity faunas had not become so firmly established in the upper bays prior to earlier floods, mass mortalities of marine invertebrates were not of the magnitude of that which occurred in 1957.

The distribution of salinity in the Rockport bays during drought conditions

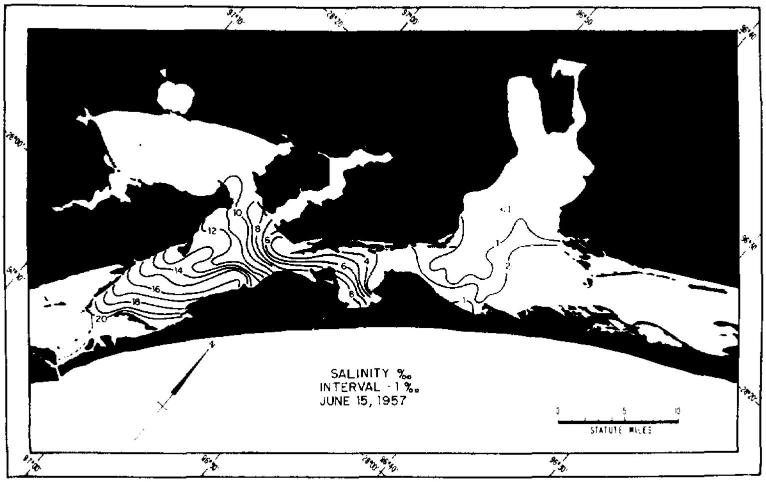

FIG. 5.—Surface isohalines immediately after major flood in drainage basin.

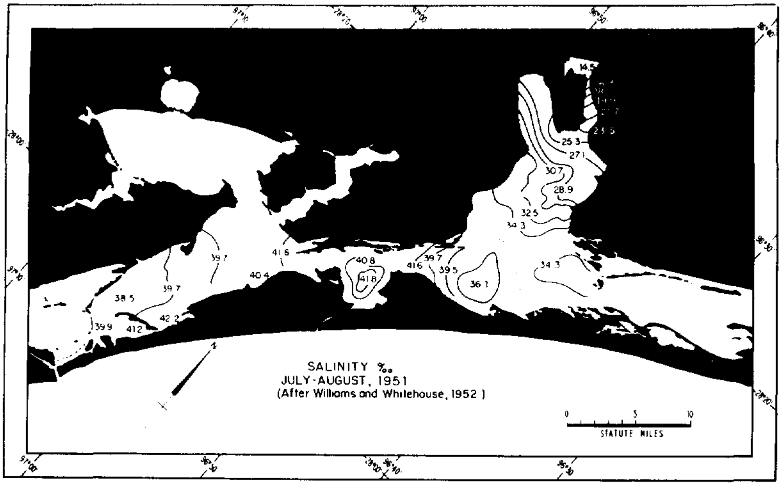

FIG. 6.—Surface isohalines during severe drought period.

has been discussed by Phleger (1956) and Parker (1955). The salinity patterns existing in the early stages of the recent Texas drought (Williams and Whitehouse, 1952) show a uniform salinity distribution in Aransas Bay of about 40°/oo, but a considerable spread of values from 14 to 42°/oo in San Antonio Bay (Fig. 6). Salinity values obtained by Phleger and Lankford in November, 1954, at a later stage of the drought (Fig. 7) show a spread of values from 24°/oo at the river's mouth to 36.8°/oo in Mesquite Bay, with a difference of only 2°/oo from the cen-

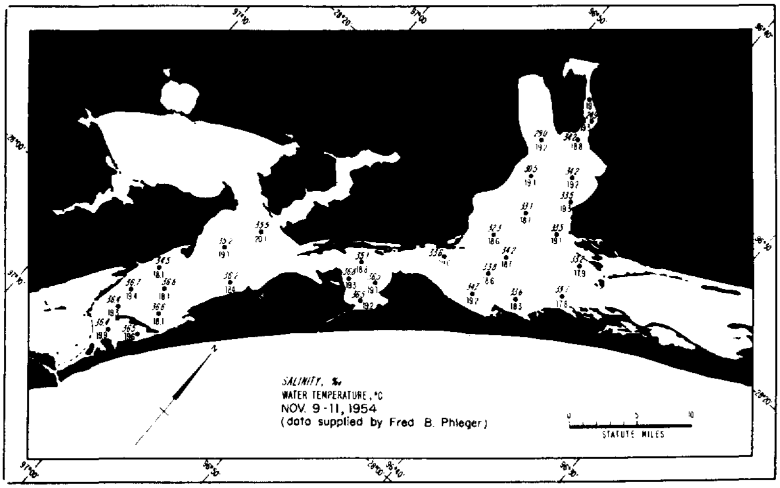

FIG. 7.—Distribution salinity and temperature during drought, showing virtually an isohaline condition throughout. (After Phleger and Lankford)

TABLE I. RANGE OF PHYSICAL CHARACTERISTICS, ROCKPORT AND LAGUNA MADRE

Environment	*Physical Factor*	*Rockport Area*	*Laguna Madre*
Marshes and Shores	Depth	0 to 1 ft.	Shore to 6 in.
	Salinity	0 to $7^{\circ}/_{oo}$	36 to $60^{\circ}/_{oo}$
	Water temp.	0 to 37°C.	5 to 40°C.
	Bottom sediments	Sand	Sand
	Currents	—	—
	Morphology*	IX	IX
River Influence, Low Salinity	Depth	1 to 4 ft.	Absent
	Salinity	1 to $30^{\circ}/_{oo}$	
	Water temp.	1 to 34°C.	
	Bottom sediment	Clayey silt, silty clay	
	Currents	Weak	
	Morphology	IV and VI	
Enclosed Bays Low to Variable Salinity	Depth	1 to 6 ft.	Absent
	Salinity	3 to $40^{\circ}/_{oo}$	
	Water temp.	10 to 34°C.	
	Bottom sediment	Silty clay, sand-silt-clay	
	Currents	Weak	
	Morphology	II	
Low-Salinity Living Reefs	Depth	1 to 3 ft.	Absent
	Salinity	3 to $40^{\circ}/_{oo}$	
	Water temp.	10 to 34°C.	
	Bottom sediment	Shell	
	Currents	Weak	
	Morphology	VIII	
High-Salinity Living Reefs	Depth	1 to 15 ft.	Absent
	Salinity	5 to $41^{\circ}/_{oo}$	
	Water temp.	4 to 34°C.	
	Bottom sediment	Shell, sandy shell	
	Currents	Weak to strong	
	Morphology	VII and VIII	
Open High-Salinity Bay and Sound Centers	Depth	5 to 12 ft.	3 to 5 ft.
	Salinity	5 to $41^{\circ}/_{oo}$	23 to $42^{\circ}/_{oo}$
	Water temp.	4 to 34°C.	9 to 33°C.
	Bottom sediment	Silty clay	Sand, silty sand, clayey sand
	Currents	Weak	Weak
	Morphology	III (modified)	V
Open High-Salinity Bay and Sound Margins	Depth	1 to 5 ft.	1 to 3 ft.
	Salinity	3 to $42^{\circ}/_{oo}$	23 to $69^{\circ}/_{oo}$
	Water temp.	3 to 36°C.	9 to 36°C.
	Bottom sediment	Sand, sand-silt-clay	Sand, silty sand
	Currents	Weak to strong	Weak
	Morphology	III	V

* Morphologic types from Price, 1947.

I. Long narrow enclosed lagoon, length 3 to 4 times width.
II. Enclosed basins of oval shape, most shorelines curving.
III. Enclosed segment of coastal lagoons.
IV. Embayment of drowned valleys.
V. Segment separated by bars and spits.
VI. Unfilled part of alluvial plain.
VII. Narrow deep channels.
VIII. Submerged bars, usually aligned perpendicular to the circulation.
IX. Narrow fringing marsh and shoreline, not inundated.

Types VII, VIII, and IX originated by the writer. Sediment types from Shepard, 1954.

TABLE 1 (*Continued*

Environment	*Physical Factor*	*Rockport Area*	*Laguna Madre*
Inlets, Inlet Influence	Depth	5 to 22 ft.	3 to 30 ft.
	Salinity	11 to 36°/$_{oo}$	30 to 40°/$_{oo}$
	Water temp.	10 to 34°C.	9 to 30°C.
	Bottom sediment	Sand, shelly sand	Sand
	Currents	Strong	Strong
	Morphology	VII	VII
Enclosed Hypersaline Bays	Depth	Absent	1 to 5 ft.
	Salinity		23 to 80°/$_{oo}$
	Water temp.		9 to 36° C.
	Bottom sediment		Sand, shelly sand
	Currents		Weak
	Morphology		I
Open, Shallow Hypersaline Bays	Depth	1 to 2 ft.	1 to 4 ft.
	Salinity	20 to 42°/$_{oo}$	23 to 80°/$_{oo}$
	Water temp.	3 to 36° C.	9 to 36° C.
	Bottom sediment	Clayey sand	Sand, shelly sand
	Currents	Weak	Weak
	Morphology	V	I
Relatively Deep Hypersaline Bays	Depth	Absent	1 to 8 ft.
	Salinity		2 to 102°/$_{oo}$
	Water temp.		9 to 30° C.
	Bottom sediment		Clay
	Currents		Weak
	Morphology		IV

ter of San Antonio Bay to the Gulf of Mexico (similar to Pritchard's "neutral estuary"). Although a few surveys taken during this prolonged drought indicated occasional tongues of low-salinity water in lower San Antonio Bay, the rest of the bay system was isohaline at normal sea water values or above. It can be seen, therefore, that drought conditions in Texas bays convert the bays from the normal positive estuarine condition to Pritchard's inverse estuarine condition in which evaporation exceeds river runoff and precipitation. Salinity ranges for each of the Rockport bay environments are tabulated in Table I, which gives the range of physical variables for the bay areas covered in this study.

Temperature.—The distributional patterns of water temperature and salinity in the Rockport bays show close similarity; i.e., changes in water temperatures from the inlet to the river mouth correspond with similar changes in salinity from inlet to river mouth. Temperature distributional patterns have been discussed in detail by Collier and Hedgpeth (1950) and more recently by Phleger (1956) and Parker (1955). An example of areal distribution of water temperature in the Rockport area throughout 2 years of sampling can be found in Phleger (1956, pp. 98–99). In summer, lower temperatures and lower salinities are found in the deeper parts of the bays, whereas higher water temperatures occur simultaneously with hypersalinities in the very shallow parts of the bays. This is a result of excessively high summer air temperatures and consequent evaporation. In winter, when air temperatures may drop below freezing, and ice occasionally forms at the edges of the lower-salinity bays, the higher water temperatures are found in the deeper parts of the bays, generally associated with the tidal movement of warmer Gulf water into the bays. The water temperature differences from one end of the bay system to the other are small (Fig. 7), and day-to-night differences in one place may be greater than those between inlet and river.

Only the long period and seasonal fluctuations of air temperature and resultant differences in water temperature are of value in assessing the effect of temperature on the distribution of invertebrates in the bays. In the past 60 years there have been periods of severe winters with prolonged freezes and lower winter temperatures, alternating with periods of at least 6 years with no freezing air temperatures and warmer winters. These sudden freezes when ice was observed around the edges of Copano and St. Charles bays (the last of which was observed in January, 1951) have had considerable effect upon the composition of faunal assemblages in the Rockport area (Gunter and Hildebrand, 1951). Temperature ranges for the Rockport bay environments are given in Table I.

Sediments.—Maps of the distribution of sediment units have been prepared or published for the bays of the Rockport area and the Laguna Madre. Most of the sediment maps used in this study have a sediment textural nomenclature developed by A.P.I. Project 51 and published by Shepard (1954). This system is based entirely on proportions of sand, silt, and clay as represented in the triangular diagram (Fig. 8). The sediment distribution map for the Rockport area (Fig. 8) was originally published in Shepard and Moore (1955). The Rockport bay sediments consist of silty clays in the deep central parts of the bays, grading into a mixed zone of sandy clay, clayey sand, or sand-silt-clay at intermediate depths, and a narrow zone of bordering sands in the shallowest depths where there is considerable wave action. This general arrangement of sediments from fine in the center to coarse materials at the bay margins is locally complicated by variations in source, topography, placement of large oyster reefs, and water circulation, resulting in somewhat different arrangement of sediments such as shown in lower San Antonio and Mesquite bays (Fig. 8). The sediment types most representative of the Rockport bay biological environments are also given in Table I.

Currents.—A brief discussion of currents and wind velocity data obtained by this Project may be found in Shepard and Moore (1955, pp. 1481–93). A hypothetical circulation of the bays in the Rockport area can be postulated from a composite of the distribution of salinity values at different times of high and low river discharge, wind direction, and tides (Fig. 9). A suggestion of possible circulation patterns in Aransas Bay was also offered by Collier and Hedgpeth (1950, p. 151). These patterns were deduced from the isohalines and isotherms at various stages of the tide, although no current measurements were made at that time. Velocities of slightly more than 1.2 knots were obtained in Aransas Pass by A.P.I. Project 51 personnel, when winds were blowing either north or south at more than 8 knots.

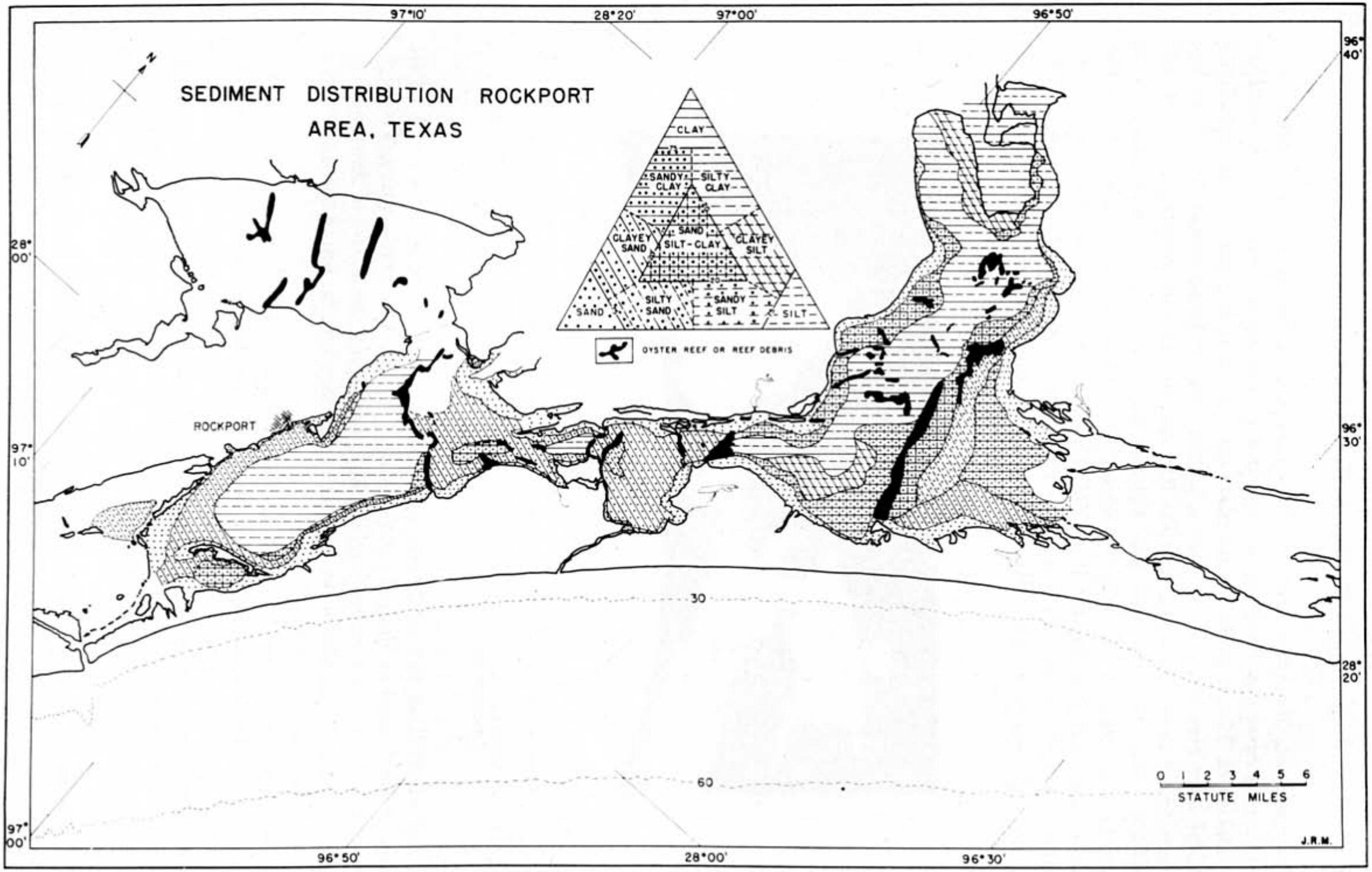

FIG. 8.—Sediment distribution, Rockport area, based on percentages of sand-silt-clay. (After Shepard and Moore, 1955)

Measurements of current velocity at the entrance to Copano Bay in Aransas Bay indicated a current moving out of Copano Bay in response to a northeast wind, at a velocity of .17–.37 knot. Currents strong enough to lay channel markers horizontal were also observed in the "land cut" of the Intracoastal Waterway between San Antonio Bay and Aransas Bay concurrent with prolonged "northers" and high river discharge into San Antonio Bay. The direction was always from San Antonio Bay to the deeper Aransas Bay. This current is indicated by the isopleths for Aransas Bay for June, 1957 (Fig. 5), showing a plume of low-salinity water flowing from the entrance of the Intracoastal Waterway into Aransas Bay. Strong currents were also observed in Lydia Ann Channel during periods of strong winds from the north and south. These currents emanating from Lydia Ann Channel, tend to dissipate as the water empties into Aransas Bay. The high-salinity or Gulf water moves into the bay, first along the shores of Aransas Bay, and then into the middle of the bay, as can be seen by examining the isohalines of Aransas Bay in Figures 3–7.

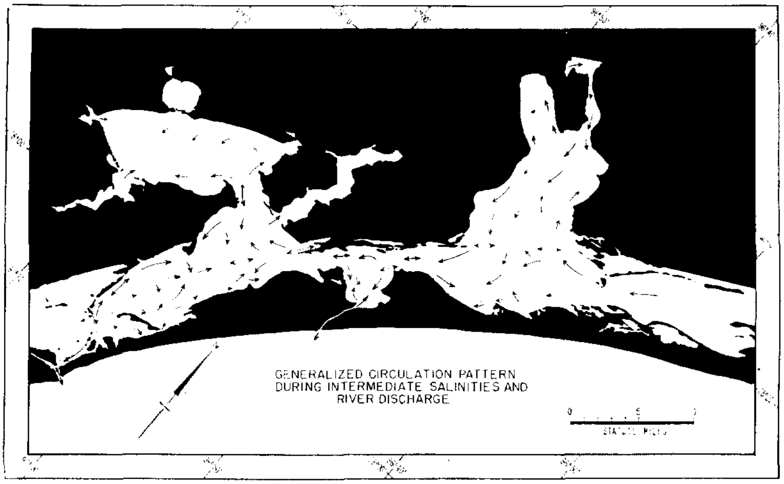

FIG. 9.—Generalized circulation. Direction of arrows dependent on stage of tide and wind direction. Length of arrows indicates comparative current strength.

This semi-permanent circulation of Gulf water along the shores, rather than in the bay center is borne out by the presence of predominantly Gulf invertebrates at the bay margins, and their absence in the center or upper reaches of Aransas Bay throughout most of the period of observation. Along with wave action, this type of circulation is probably instrumental in depositing the coarser sediments into narrow bands paralleling the shorelines of both St. Joseph Island and the Live Oak Peninsula.

Since many of the characteristic species composing the assemblages cited in this paper have pelagic or free-living larval stages, it can be seen that the movement of water is extremely important in determining the assemblage of deposition. An excellent discussion concerning the factors influencing larval settlement and the composition of benthic communities can be found in Thorson (1958, pp. 479–89). As the larvae are transported in almost the same manner as sediment grains, it is no wonder there is such a close correlation between sediment types and faunal distribution. Papers have been written by European biologists on the transportation of larval mollusks by currents, and the close correlation between current strength and direction, sediment types, and the size and composition of benthic populations (Kreger, 1940; Baggerman, 1953; and Verwey, 1952). It is also significant that the circulation of bay waters is in part a reflection of the physiography or shape of the bays. Under some conditions water movement actually creates some of the topographic features such as sand bars and channels. Because the water circulation, shoreline, and bottom topography are so closely interrelated, it can be seen that there is good reason for certain macrofaunas appearing to be indicators of sedimentary environments and marine topography.

According to Hedgpeth (personal communication) the movement of water is strongest along the north shore, which is characterized by a much wider band of coarse sediments (Fig. 8). The comparative current strengths for each of the biological environments in the Rockport area are given in Table I.

MACRO-INVERTEBRATE ASSEMBLAGES

Since most bay or lagoon deposits contain far more dead shell material than living fauna, it was felt that both the living and dead assemblages should be discussed, and then be combined into the assemblage of deposition. It is also necessary to discuss the living assemblages in relation to the climate and hydrography existing at the time of sampling, and thus be in a better position to explain the presence of shell remains of forms not living at the time of sampling. In the Rockport area, this means separating the living assemblages found during wet periods and low salinity, from those found during droughts and high salinity. This task was not too difficult since extensive faunal lists have been compiled in this region from 1892 to the present time. Lists of the organisms collected during the past 60 years and their collectors may be found in Parker (1955).

ASSEMBLAGES OF ROCKPORT REGION

Although the environmental boundaries in the Rockport bays tend to fluctuate considerably over the years, the assemblages characterizing these environments are distinct. The information used to establish these faunal assemblages was obtained from 400 biological stations taken during this study (Figs. 10a and 10b) and 71 stations taken as part of Ladd's (1951) study (Fig. 11). In the present study, a broad environmental concept is presented which may have an application to ancient sedimentary environments where the paleontologist has only a few widely spaced samples for analysis. Within the larger bay environments, smaller "sub-facies" are also demonstrated which should be of some use to the biologist or geologist studying Recent sediments, or to the paleontologists using large num-

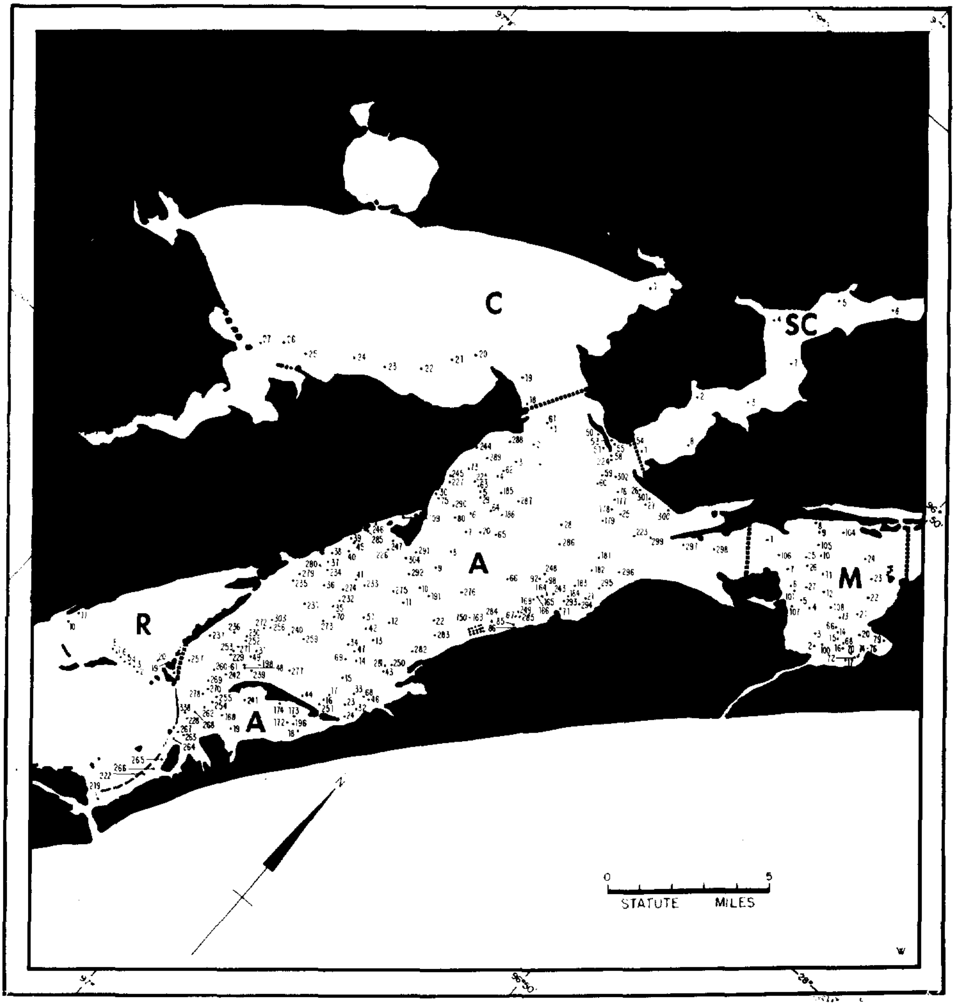

FIG. 10a.—Location of biological samples, Aransas Bay and vicinity (1951–57). Stations within area bounded by dashed lines take prefix of block letter.

bers of closely spaced samples. The major biological assemblages of the Rockport bays and associated minor assemblages (Figs. 12a and 12b) are discussed. Because the boundaries of these environments and associated assemblages change considerably with large-scale climatic changes, it was necessary to construct two environmental or facies maps. One (Fig. 12a) shows the areal extent of the environments during prolonged low salinity, and the other (Fig. 12b) shows the same environmental coverage during prolonged high salinity. The salinity connotations in the environmental titles, describe the environment, and do not infer that salinity is the only controlling factor. The distribution of the dead shell in these

FIG. 10b.—Location of biological samples, San Antonio Bay and vicinity (1951–57). All stations on this chart prefixed by S, except E-8 in Espiritu Santo Bay.

bays is an indication of the extent of low-salinity influence during periods not sampled during this study.

I. *River-influenced, low-salinity assemblage.*—The part of the Rockport bay system characterized by the low-salinity or river-influenced fauna is small in comparison with that in the Mississippi Delta region (Parker, 1956) and in some of the large bays and sounds on the north and east. Only a small part of San Antonio Bay and perhaps parts of Copano Bay are continually freshened by the rather small rivers which empty into these bays. As can be seen in Figures 12a and 12b, the boundary of this environment fluctuates considerably with the

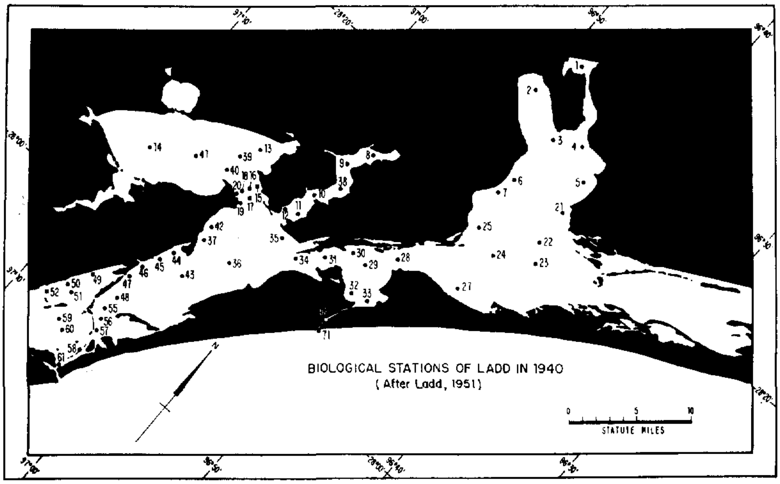

FIG. 11.—Location of biological samples taken by Ladd in 1940.

changing hydrography. At the time of Ladd's (1951) study when salinities throughout the Rockport bays were considerably below normal Gulf salinity of 36°/oo, this environment (called the "bay head facies" by Ladd) included Mission Bay (part of Copano Bay), parts of St. Charles Bay and half of San Antonio Bay. During the recent drought, this assemblage was eliminated completely from Copano Bay and St. Charles Bay, as well as from a large part of San Antonio Bay. From the faunal distribution in the past and present time, it can be postulated that salinity is one of the more important factors influencing the assem-

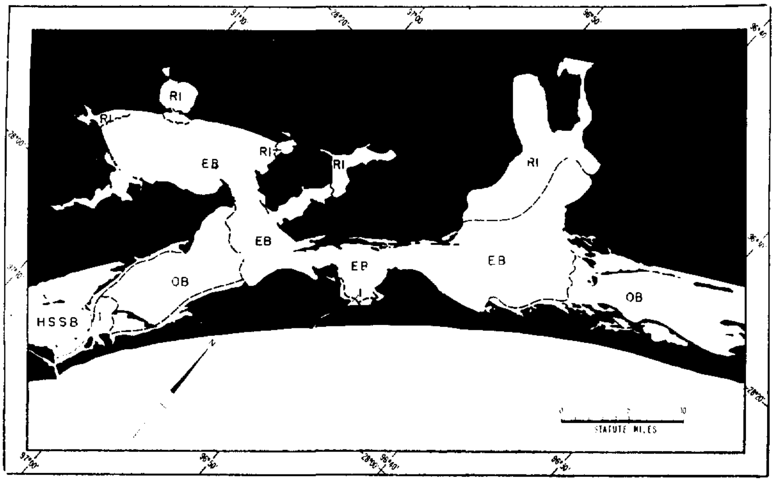

FIG. 12a.—Boundaries of macro-invertebrate assemblages during period of high rainfall. HSSB—high-salinity shallow bay; I—inlet; OB—open bay; EB—enclosed bay; RI—river-influenced, low salinity.

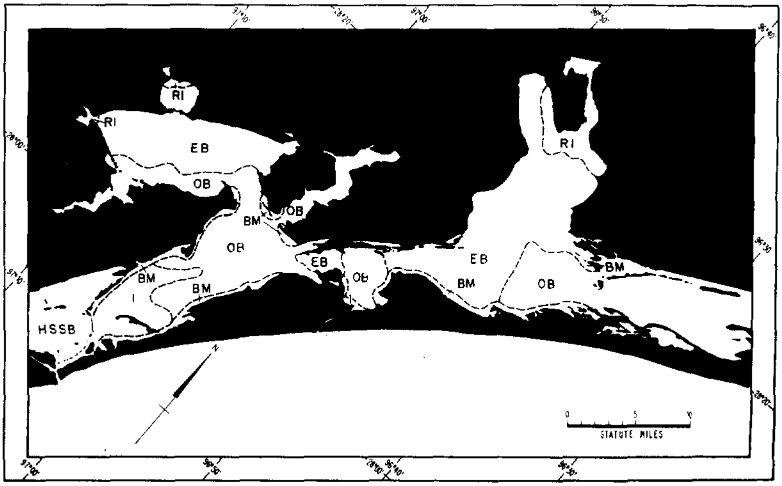

FIG. 12b.—Boundaries of macro-invertebrate assemblages during droughts and high salinity. HSSB—hypersaline shallow bay; I—inlet; BM—bay margin; OB—open bay center; EB—enclosed bay; RI—river-influenced.

blages in this environment, although river-borne nutrients and high turbidity and associated fine sediments may also be important. Circulation is also important in determining the distribution of the low-salinity fauna. Most of the river water flows along the western shore of San Antonio Bay, and likewise the majority of the living representatives of low-salinity species are also found along this shore, being conspicuously absent from the opposite shore. The physical factors characteristic of this environment are given in Table I.

The low-salinity environment is a difficult one for the survival of true marine animals, and only five species of invertebrates are known to thrive there, characterizing low-salinity areas along most of the northern Gulf coast. The boundaries of this environment, based on an average of the ranges of the indicator species and environmental factors are shown in Figure 13a, demonstrated by the distribution of the pelecypod, *Rangia cuneata* and Figure 13b, by the distribution of the pelecypod, *Macoma mitchelli*. From the distribution of dead shell of both of these species, it can be seen that low-salinity conditions must have been far more widespread in the past than during the period the area was sampled by Ladd and the writer. The presence of these forms mixed with an enclosed-bay assemblage in slightly older deposits suggests that low and intermediate salinities alternated with considerable frequency. The other two invertebrate species typical of this environment are the gastropod, *Littoridina sphinctostoma*, and the river shrimp, *Macrobrachium ohione* (reported by Hedgpeth, 1949). The pelecypod, *Mulinia lateralis*, is also found in river-influenced areas, but is by no means characteristic of this environment. The Rockport river-influenced fauna are tabulated in Table II in the Appendix, which lists all of the invertebrates by environment. Representative specimens of these species are figured on Plate I.

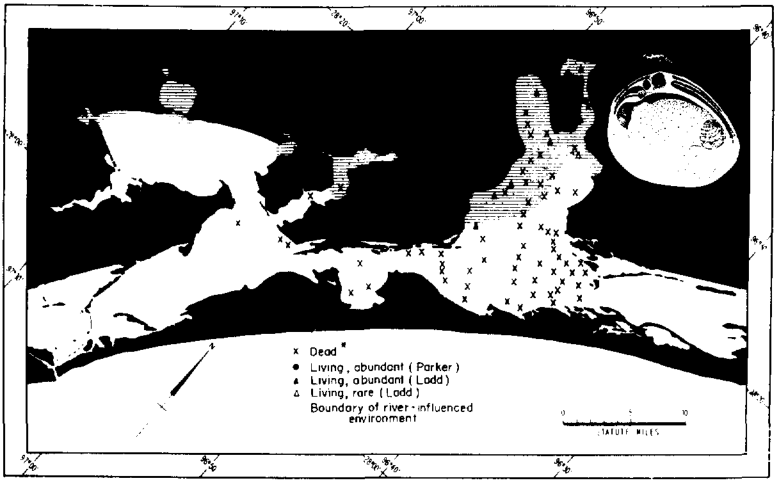

FIG. 13a.—Distribution of pelecypod, *Rangia cuneata*, most abundant during times of low salinity and high rainfall.

II. *Enclosed bays of variable low to intermediate salinities, characterized by oyster reefs.*—The enclosed-bay environment corresponds roughly with Ladd's (1951) "reef and inter-reef facies" during times of low salinity, but it is more difficult to define when the bays are essentially isohaline. This environment characterizes the major parts of the Rockport bays; although the faunal composition may change considerably with long-period changes in salinity and temperature. Its boundaries include all of the major oyster reefs, since these biological units re-

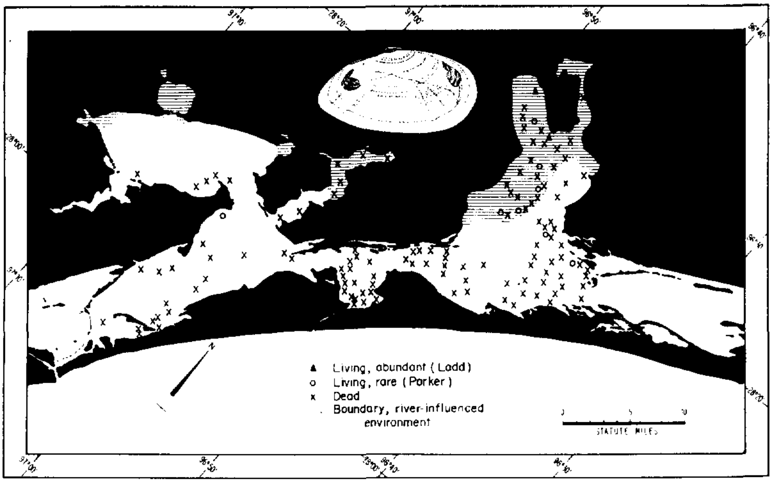

FIG. 13b.—Distribution of pelecypod, *Macoma mitchelli*, most abundant during times of low salinity and high rainfall.

main intact and soon become repopulated after periods of adverse salinity conditions. The oyster reefs also act as natural barriers to the circulation, thus serving to isolate this environment from the high-salinity parts of the bays, as well as the river-influenced areas. Exclusive of the oyster-reef assemblage, which is a sub-assemblage and is discussed separately, only seven species of invertebrates can be considered characteristic (in terms of abundance) of the level-bottoms between the oyster reefs. However, a number of species from the high-salinity waters may migrate into the "inter-reef" area at times of high salinity. The superimposed distribution of two of the more characteristic invertebrates, Figure 14a, the pelecypod, *Mulinia lateralis*, and Figure 14b, the brittle star, *Amphiodia limbata*, illustrate the extent of the enclosed-bay environment. Apparently *Mulinia* is less dependent on gross salinity changes, as the distribution of living and dead specimens during both Ladd's and the present survey show excellent agreement. *Mulinia* is also common in the other environments, but its presence elsewhere is not significant, as there are many more abundant species and individuals in the other environments. No comparison of the distribution of *Amphiodia* at different salinity periods was possible, as it was not cited dead or alive by Ladd. The fauna typical of the enclosed bay areas of variable salinity is as follows.

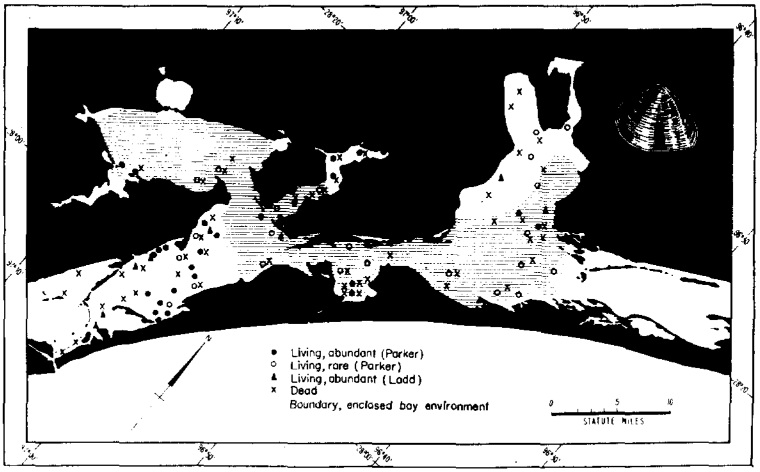

FIG. 14a.—Distribution of pelecypod, *Mulinia lateralis*, most abundant during times of low to variable salinity.

GASTROPODS
Retusa canaliculata (Say, 1827)

PELECYPODS
Ensis minor Dall, 1899
Mulinia lateralis (Say, 1822)
Nuculana acuta (Conrad, 1834)
Nuculana concentrica (Say, 1824)
Tagelus plebeius (Solander, 1786)

ECHINODERMS
Amphiodia limbata (Grube)

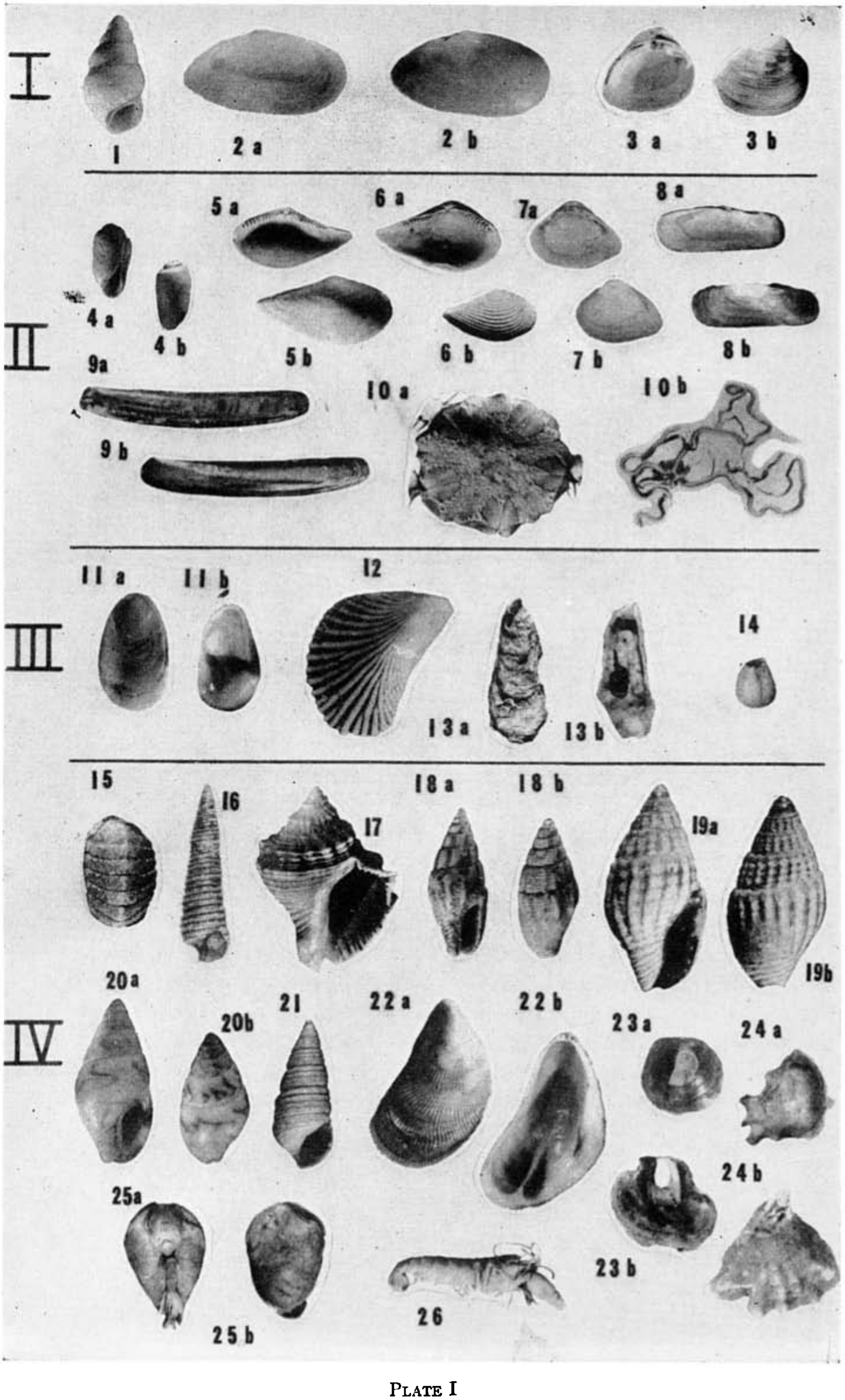
I
1
2 a
2 b
3 a
3 b
II
5 a
6 a
7a
8 a
4 a
4 b
5 b
6 b
7 b
8 b
9a
9 b
10 a
10 b
III
11 a
11 b
12
13 a
13 b
14
15
16
17
18 a
18 b
19a
19b
20a
21
22 a
22 b
23 a
24 a
IV
20b
24 b
25a
23 b
26
25 b

PLATE I

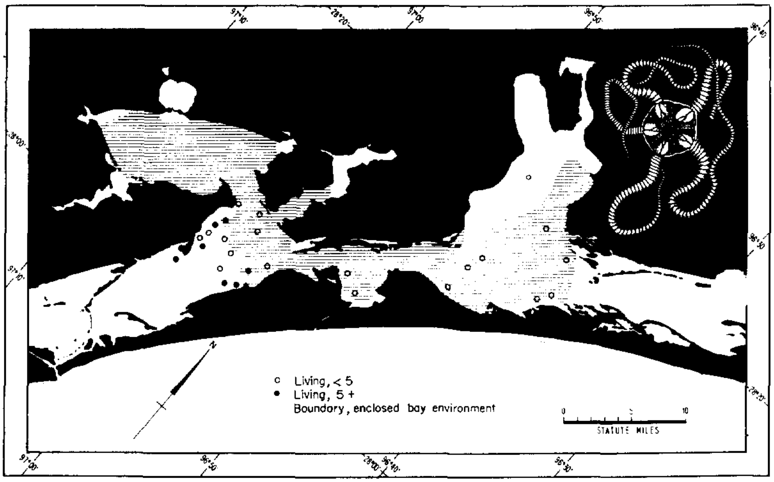

FIG. 14b.—Distribution of brittle star, *Amphiodia limbata*, taken only during period of high salinity. Although occurrences are shown in Aransas Bay, as outside the environmental boundary, most are within the physiographic boundary of the enclosed part of that bay.

←

PLATE I

I. RIVER-INFLUENCED, LOW-SALINITY ASSEMBLAGE

1. *Littoridina sphinctostoma*, size—3×2 mm., aperture.
2. *Macoma mitchelli*, size 21×12 mm., a. interior, b. exterior.
3. *Rangia cuneata*, size 42×39 mm., a. interior, b. exterior.

II. ENCLOSED BAYS, VARIABLE LOW TO INTERMEDIATE SALINITIES

4. *Retusa canaliculata*, size—6×3 mm., a. aperture, b. back.
5. *Nuculana concentrica*, size—11×6 mm., a. interior, b. exterior.
6. *Nuculana acuta*, size—6×4 mm., a. interior, b. exterior.
7. *Mulinia lateralis*, size—10×7 mm., a. interior, b. exterior.
8. *Tagelus plebeius*, size—42×16 mm., a. interior, b. exterior.
9. *Ensis minor*, size—54×10 mm., a. interior, b. exterior.
10. *Amphiodia limbata*, disc diameter—6 mm., a. disc, b. ventral side.

III. LOW-SALINITY OYSTER REEF

11. *Crepidula plana*, size—22×12 mm., a. back, b. interior (aperture).
12. *Brachidontes recurvus*, size—16×11 mm., exterior.
13. *Crassostrea virginica*, size—170×70 mm., a. exterior, b. interior.
14. *Balanus eburneus*, size—6×5 mm. side view.

IV. HIGH-SALINITY SHELL REEF

15. *Ischnochiton pappilosa*, size—3×2 mm., exterior.
16. *Seila adamsi*, size—6×1 mm., aperture.
17. *Thais haemastoma floridana*, size—47×29 mm., aperture.
18. *Anachis avara semiplicata*, size—11×5 mm., a. aperture, b. back.
19. *Anachis obesa*, size—4×2 mm., a. aperture, b. back.
20. *Mitrella lunata*, size—4×2 mm., a. aperture, b. back.
21. *Odostomia impressa*, size—3×1 mm., aperture.
22. *Brachidontes exustus*, size—17×9 mm., a. exterior, b. interior.
23. *Amonia simplex*, size—21×20 mm., a. interior (top value, b. interior, attached valve).
24. *Ostrea equestris*, size—19×14 mm., a. interior, b. exterior.
25. *Diplothyra smithi*, size—6×4 mm., a. dorsal, b. side.
26. *Crangon heterochelis*, size—37 mm., side view.

The physical factors characterizing this environment in the Rockport area are given in Table I, and all of the invertebrate species taken in this environment are given in Table II in the Appendix.

Low-salinity oyster reef.—Although this assemblage is part of the enclosed-bay environment, it is the dominant group of organisms, and contributes most of the shell material in the inter-reef deposits. *Crassostrea virginica*, the bay oyster, forms the greater part of the reef, while the other invertebrates attach to the surface of the oysters, either competing for food or feeding on the oysters themselves. In the northern Gulf of Mexico, the bay oyster flourishes and builds its reefs in shallow water, many of them perpendicular to the prevailing currents under what appear to be ideal conditions: a firm bottom, salinities ranging from about 12 to 25°/₀₀ (which will exclude most of the fouling organisms), and temperatures cool enough in winter to permit cessation of reproductive activities, so that they may devote their energies to growth. The Rockport area does not provide these "ideal" conditions for oyster growth at the present time, but there is considerable evidence that this has not always been the case. Most of the modern reefs extend in depth to at least 14 feet below the surface of the sediment (Norris, 1953), and subsurface borings in San Antonio Bay indicated reefs dating about 9,000 years old, as deep as 80 feet below the surface (Shepard and Moore, 1955, pp. 1555–59). Marine Sonoprobe records in Corpus Christi Bay a few miles south of Rockport, also show buried reefs presumed to be oysters, with thicknesses of 60–80 feet (McClure, Nelson, and Huckabay, 1958). At present, the Rockport oyster reefs are primarily composed of dead shell with very few live oysters attached. The faunal composition of the oyster reefs during times of reduced salinity is simple, and usually stabilized for long periods of time in such areas as western Louisiana and east Texas.

It should also be noted that the shape of *Crassostrea* is generally diagnostic of certain environmental conditions as noted by Gunter (1938). On hard bottom and uncrowded beds, the shells are thick, curved to the right, and almost as wide as long. When growing on soft or rapidly silting bottom, in shallower water and crowded conditions, shells are generally very long, straight, and thin. *Crassostrea virginica* living in higher than normal salinities exhibits very thin, crenulated and highly colored lips (Parker, 1955).

The invertebrate species found on the Rockport reefs during stable low salinities are as follows.

GASTROPODS

Crepidula plana Say, 1822

PELECYPODS

Brachidontes recurvus (Rafinesque, 1820)

Crassostrea virginica (Gmelin, 1791)

CRUSTACEANS

Balanus eburneus Gould, 1841

Balanus amphitrite niveus Darwin, 1854

Other invertebrates become part of the oyster-reef assemblage whenever salinities rise to more than 25 °/₀₀ for any extended period (Puffer and Emerson, 1953), and may eventually become so abundant as to retard the activities of the dominant *Crassostrea virginica*. At stable high salinities, the gulf oyster, *Ostrea equestris*, may completely replace the bay oyster, but because of its small size may never form large reefs. In June, 1957, there was an opportunity to observe the effect of suddenly reduced salinities upon *Ostrea equestris*. During the recent drought *Ostrea equestris* became the dominant oyster on the reefs in the Rockport area, but when salinities dropped to a low of 1–5°/₀₀, all of the *O. equestris* died in Aransas Bay proper, Mesquite Bay, and San Antonio Bay. The organisms cited in the paper by Puffer and Emerson (1953) are those typical of an oyster or shell reef living in high salinities near an inlet or in an open sound, and are listed here with additional species taken by this writer.

GASTROPODS

Anachis avara semiplicata (Stearns, 1873)
Anachis obesa (C. B. Adams, 1845)
Mitrella lunata (Say, 1826)
Odostomia impressa (Say, 1821)
Seila adamsi (H. C. Lea, 1846)
Thais haemastoma floridana (Conrad, 1837)

CHITONS

Ischnochiton papillosa (C. B. Adams, 1845)

PELECYPODS

Anomia simplex d'Orbigny, 1842
Brachidontes exustus (Linné, 1758)
Diplothyra smithi (Tryon, 1862)
Ostrea equestris Say, 1834

BRYOZOA

Bugula, species
Membranipora, species

CRUSTACEANS

Crangon heterochelis (Say)
Menippe mercenaria (Say)

Figure 15 shows the distribution of both kinds of oyster reefs in the Rockport region. The characteristic physical factors are given in Table I, and representative specimens of most of the species characteristic of enclosed bays and

FIG. 15.—Distribution of low-salinity reefs in Rockport area, illustrated by long, narrow "coon" oysters, *Crassostrea virginica*. High salinity reefs are typified by *Ostrea equestris*, the small round oyster, with crenulated margin and teeth on inside of margin.

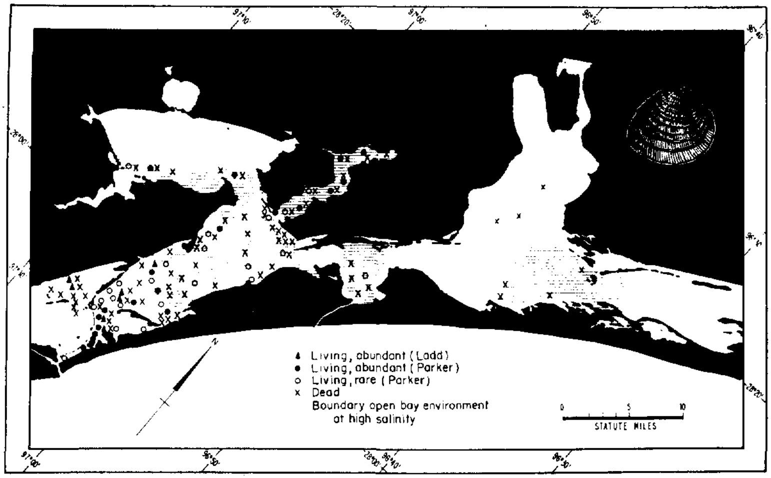

FIG. 16a.—Distribution of pelecypod, *Chione cancellata*. Most abundant during times of high salinity, when it is found throughout lower bays and inlets.

reefs are figured on Plate I. All of the organisms found in the enclosed bay assemblages are given in Table II in the Appendix.

III. *Open high-salinity bays and sounds*.—The areal boundaries of the high-salinity bay assemblage correspond roughly to Ladd's "polyhaline facies" boundary in Aransas Bay. This assemblage also occupies a part of lower San Antonio Bay during times of extended high salinity. Many more species and numbers of individuals inhabit high-salinity bays during extended periods of lower and unstable salinities. Figures 16a and 16b illustrate the extent of the high-salinity bay

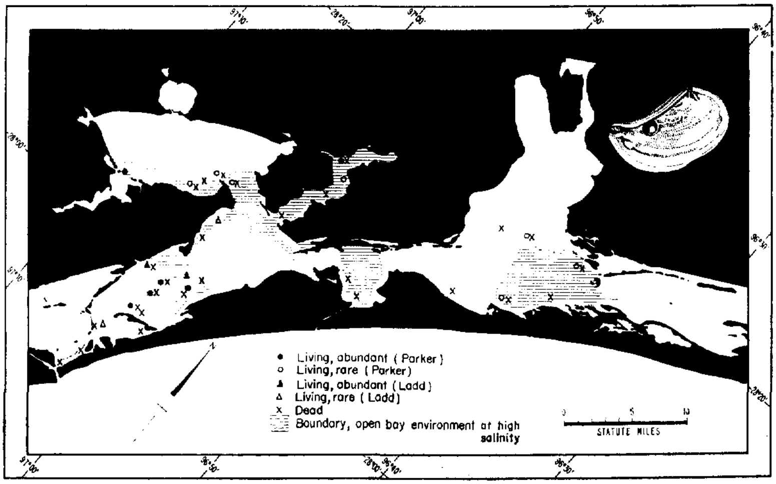

FIG. 16b.—Distribution of pelecypod, *Pandora trilineata*, most abundant at times of high salinity.

environment in the Rockport area at times of extended high salinity, indicated by the superimposed distribution of two of the more characteristic invertebrates, the pelecypods, *Chione cancellata* and *Pandora trilineata*. The change in distribution of high-salinity organisms from a period of low salinity (Ladd) to the period covered by the present study is evident from Figures 16a and 16b. During Ladd's study both *Pandora* and *Chione* were confined to the inlet end of Aransas Bay, but by 1957 both occurred throughout Aransas, Copano, St. Charles, Mesquite, and lower San Antonio bays. From Ladd's study it was also deduced that the present invasion of these organisms into other parts of the bay system is unique, since Ladd found no dead shell of these species in the other bays.

In older deposits the presence of these forms in a thick section would indicate rather permanent open bay or sound conditions of near normal marine salinities. Their presence as either a thin layer or sparsely mixed with an enclosed-bay fauna, would indicate a brief change in salinity characteristics due either to a short-term change in climate (such as the recent drought), or a temporary enlargement of the inlets by storms.

Of the 34 invertebrate species taken alive in the high-salinity region, 17 species were abundant but not everywhere confined to the bays, and 8 species were confined to this environment. Although many invertebrate species are found in the open high-salinity bays and sounds, this environment may be the most difficult to identify in older deposits on the basis of the macrofauna, because the majority of forms are also found in the shallow shelf waters of the Gulf of Mexico. The high-salinity bays, therefore, are similar to the upper sound environment of the Mississippi Delta region (Parker, 1956). There is also considerable contamination of invertebrate species from the inter-reef and oyster-reef assemblages during times of extended low salinity, as can be seen by examining the distribution maps of the dead shell of characteristic species of the other environments. There are 8 reliable indicators for high-salinity bays under all conditions. These species are seldom found in the other bay environments (except inlets), and are rare on the continental shelf. The 8 species are here listed.

GASTROPODS

Nassarius acutus (Say, 1822)

PELECYPODS

Chione cancellata (Linné, 1767)
Diplodonta punctata (Say, 1822)
Macoma constricta (Bruguiere, 1792)
Pandora trilineata Say, 1822
Semele proficua (Pulteney, 1799)
Tagelus divisus (Spengler, 1794)
Trachycardium muricatum (Linné, 1758)

High-salinity bay centers.—The high-salinity bay environment can be subdivided into two facies or sub-environments on the basis of differing faunal assemblages and physical factors: bay centers and bay margins. Because the bay centers are deeper, they contain finer sediments and are characterized by more stable salinities and temperatures than the shallower bay margins. Living individuals are relatively scarce in the bay centers because of the predominance of fine clayey sediments. It is noted, however, that most of the mollusk species living in these fine sediments are deposit feeders, well adapted for obtaining organic matter for food in an environment which would be detrimental to most filter feeders. The faunal composition of the Rockport Bay centers is similar to that of the "lower Breton Sound and pro-delta slope" environment of the Mississippi Delta (Parker, 1956, p. 321), and both areas have similar ranges of environmental factors. The invertebrates most common to high-salinity bay centers are listed.

GASTROPODS

Nassarius acutus (Say, 1822)

Retusa canaliculata (Say, 1827)

PELECYPODS

Abra aequalis (Say, 1822)
Anadara campechiensis (Gmelin, 1790)
Anadara transversa (Say, 1822)
Corbula contracta Say, 1822
Diplodonta punctata (Say, 1822)

Mulinia lateralis (Say, 1822)
Nuculana acuta (Conrad, 1834)
Nuculana concentrica (Say, 1824)
Pandora trilineata Say, 1822
Periploma fragile (Totten, 1835)

CEPHALOPODS

Lolliguncula brevis (de Blainville, 1823)

All of the invertebrate species taken in the bay centers are listed in Table II (Appendix).

High-salinity bay margins.—The bay margins are characterized by sandy sediments, ranging from sand-silt-clay to almost pure fine sand, a direct contrast to the fine clayey sediments of the bay centers (Table I and Fig. 8). The action of both wave movement perpendicular to the shore and the general parallel movement of high-salinity water along the shores (Figs. 8 and 9) produce narrow bands of coarse-grained sediments parallel with the shore. As it is probable that the larvae of the high-salinity gulf invertebrates located in and close to the inlets are also transported close to and parallel with the shore, the circulation may be a primary factor in determining the composition of the bay margin fauna. Evidence to support this premise is offered in the high percentage of species common to both the Gulf and inlets found along the bay margins. Another factor which may influence the composition of the bay margin assemblage is the availability of land-derived organic matter from runoff.

The loosely compacted sediments characterizing the bay margins may also be "ideal" for the penetration just below the surface sediments by the large filter-feeding pelecypods (*Mercenaria* and *Cyrtopleura*) characteristic of this assemblage. Apparently, the fine silty clays of the bay centers will not support these large clams, and inhibit the suspension-feeding mechanisms of these species; whereas the fine, very well sorted sands adjacent to the shore are too dense for penetration.

The extent of this assemblage in the Rockport area, and the distributions of the two species which best characterize the environment, the pelecypods, *Mercenaria mercenaria campechiensis* and *Tagelus divisus*, are shown in Figures 17a and 17b. Seventeen of the species of invertebrates considered most indicative of

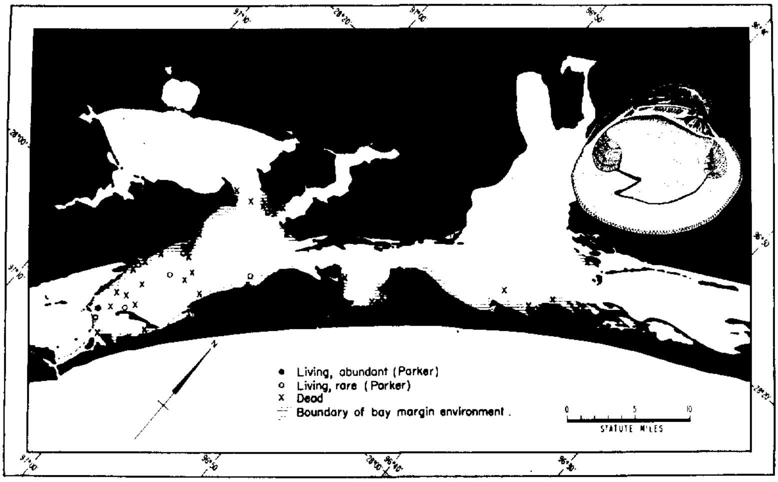

FIG. 17a.—Distribution of pelecypod, *Mercenaria mercenaria campechiensis*, one of large heavy forms typical of high-salinity bay margins.

this environment are here listed and all of the species taken are given in the Appendix. Most of the named species of high-salinity bay environments are illustrated on Plate II.

GASTROPODS

Nassarius vibex (Say, 1822)	*Vermicularia fargoi* (Olsson, 1951)

PELECYPODS

Aequipecten irradians amplicostatus (Dall, 1898)	*Cyclinella tenuis* (Récluz, 1854)
Chione cancellata (Linné, 1767)	*Cyrtopleura costata* (Linné, 1758)

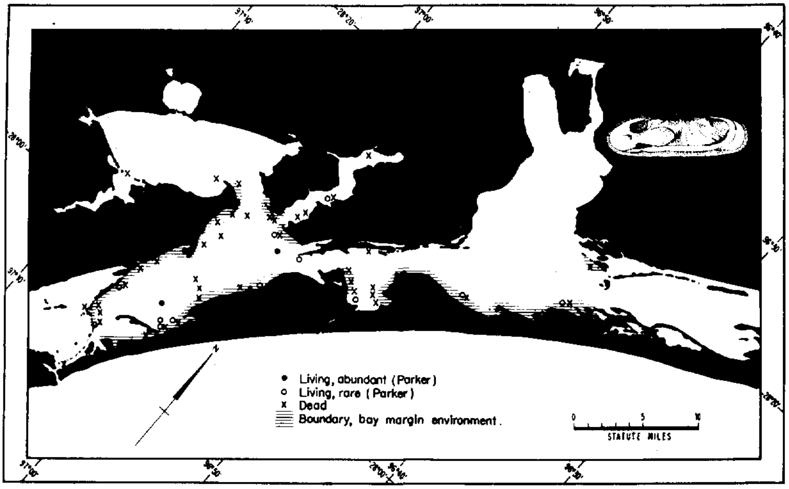

FIG. 17b.—Distribution of pelecypod, *Tagelus divisus*, indicative of bay margins during high-salinity regimes.

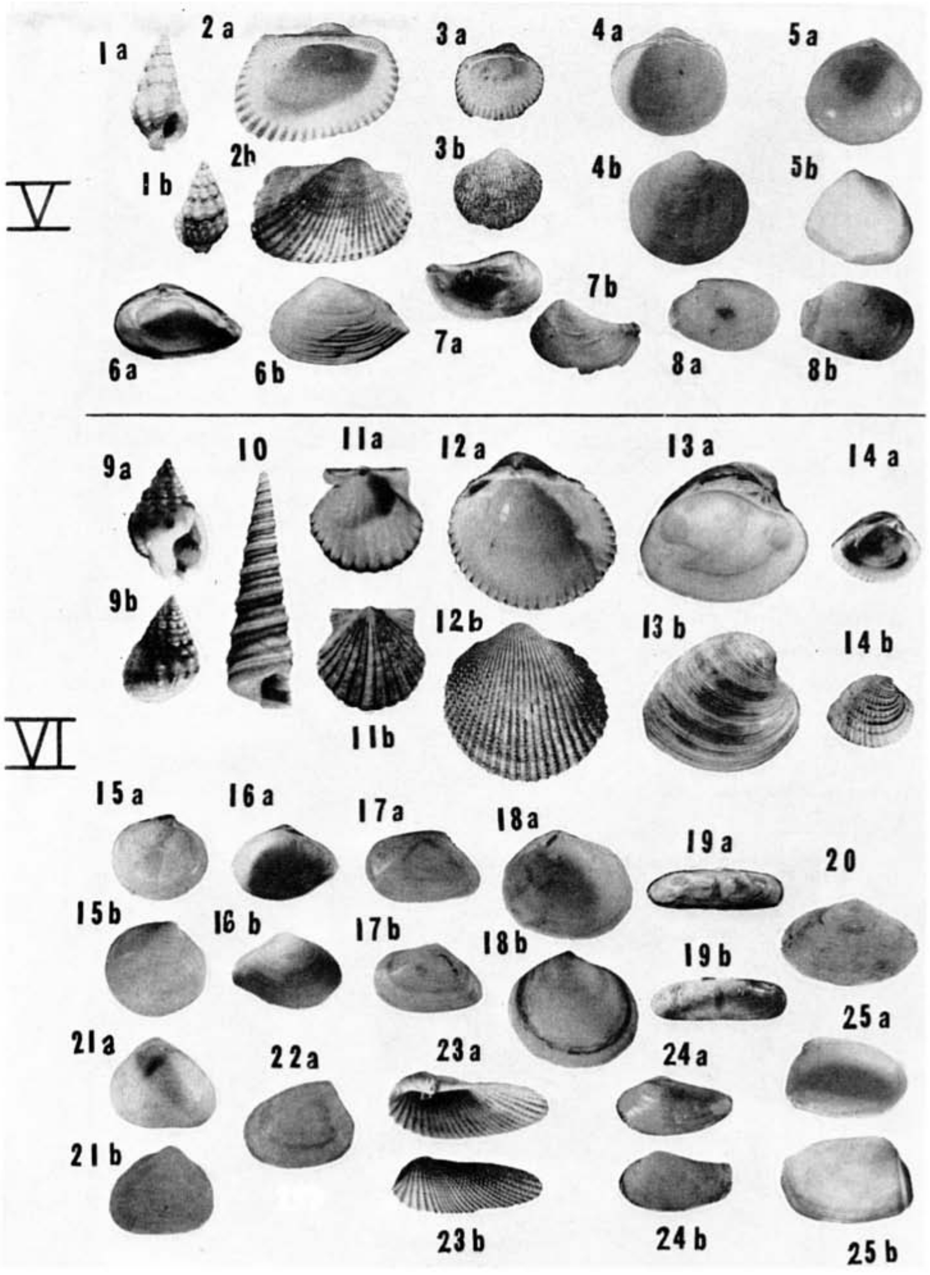
V
1a
1b
2a
2b
3a
3b
4a
4b
5a
5b
6a
6b
7a
7b
8a
8b
VI
9a
9b
10
11a
11b
12a
12b
13a
13b
14a
14b
15a
15b
16a
16b
17a
17b
18a
18b
19a
19b
20
21a
21b
22a
23a
23b
24a
24b
25a
25b

PLATE II

Ervillia concentrica (Gould, 1862)
Lyonsia floridana hyalina (Conrad, 1846)
Mercenaria mercenaria campechiensis (Dall, 1902)
Macoma brevifrons (Say, 1834)
Macoma constricta (Brugiere, 1792)
Mactra fragilis Gmelin, 1790
Mysella planulata (Stimpson, 1857)
Periploma inequale (C. B. Adams, 1842)
Tagelus divisus (Spengler, 1794)
Trachycardium muricatum (Linné, 1758)

ECHINODERMS
Thyone mexicana Deichmann, 1946

IV. *Inlets and inlet influence.*—The assemblage characterizing the inlet environment always occupies Aransas Pass and most of Lydia Ann Channel, even during the times of very reduced salinity in the Aransas Bay system. However, during times of drought and high salinity this assemblage invades Aransas Bay along the margins for a considerable distance, and follows the Intracoastal Waterway channel out into the bay (Fig. 18). The presence of a great many suspension-feeding inlet species adapted for holding fast to the bottom and requiring a constantly renewed source of plankton indicates that strong currents characteristic of this environment are important in determining the character of the assemblage. The Rockport inlet area also contains more species than any of the other bay environments. There is a mixture of species restricted to bays, shallow-shelf species, and certain forms indigenous to inlets. The inlets are the deepest part of the bay region (because of current scour), with depths of 16–22 feet as compared with the greatest depth of 12 feet in Aransas Bay. The greater depths and steady influx of Gulf water apparently minimize the short-term fluctuations of

←«««

PLATE II

V. OPEN HIGH-SALINITY BAYS AND SOUNDS CENTERS

1. *Nassarius acutus*, size—11×4 mm., a. aperture, b. back.
2. *Anadara transversa*, size—15×10 mm., a. interior, b. exterior.
3. *Anadara campechiensis*, size—38×30 mm., a. interior, b. exterior.
4. *Diplodonta punctata*, size—12×11 mm , a. interior, b. exterior.
5. *Abra aequalis*, size—12×10 mm., a. interior, b. exterior.
6. *Corbula contracta*, size—7×5 mm., a. interior, b. exterior.
7. *Pandora trilineata*, size—20×11 mm., a. interior, b. exterior.
8. *Periploma fragile*, size—12×8 mm., a. interior, b. exterior.

VI. OPEN HIGH-SALINITY BAYS AND SOUNDS MARGINS

9. *Nassarius vibex*, size—12×8 mm., a. aperture, b. back.
10. *Vermicularia fargoi*, size—26×7 mm., aperture.
11. *Aequipecten irradians amplicostatus*, size—32×31 mm., a. interior, b. exterior.
12. *Trachycardium muricatum*, size—44×42 mm., a. interior, b. exterior.
13. *Mercenaria mercenaria campechiensis*, size—102×94 mm., a. interior, b. exterior.
14. *Chione cancellata*, size—26×22 mm., a. interior, b. exterior.
15. *Cyclinella tenuis*, size—15×15 mm., a. interior, b. exterior.
16. *Macoma constricta*, size—59×41 mm., a. interior, b. exterior.
17. *Macoma brevifrons*, size—12×7 mm., a. interior, b. exterior.
18. *Semele proficua*, size—13×11 mm., a. interior, b. exterior.
19. *Tagelus divisus*, size—29×9 mm., a. interior, b. exterior.
20. *Mactra fragilis*, size—35×22 mm., exterior.
21. *Mysella planulata*, size—4×3 mm., a. interior, b. exterior.
22. *Ervillia concentrica*, size—3×2 mm., interior.
23. *Cyrtopleura costata*, size—98×39 mm., a. interior, b. exterior.
24. *Lyonsia floridana hyalina*, size—12×5 mm., a. interior, b. exterior.
25. *Periploma inequale*, size—17×11 mm., a. interior, b. exterior.

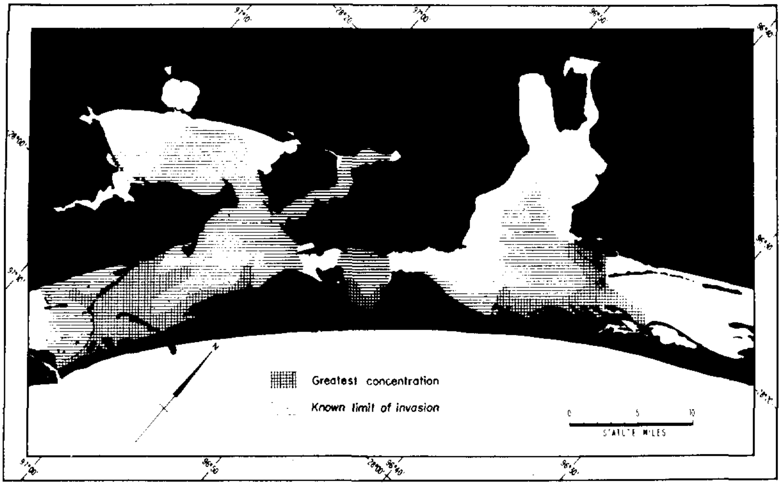

FIG. 18.—Limit of encroachment of high-salinity shallow shelf invertebrates into Rockport bays during period of extended high salinity.

air temperature and salinity, providing a more uniform marine environment. The range of physical factors characterizing this environment is given in Table I, and the complete list of animals taken in the inlets is given in Table II (Appendix).

The areal extent of the inlet environment is shown in Figures 19a and 19b, utilizing the distributions of the scaphopod, *Dentalium texasianum* and the solitary coral, *Astrangia astreiformis*. Although both of these invertebrates were taken alive only in the inlets or in the inlet-influenced regions, the distribution of dead individuals was quite different. *Astrangia* was completely confined to the lower end of Aransas Bay, living or dead, whereas *Dentalium*, although taken alive only in the inlet areas, was taken dead throughout Aransas Bay and San Antonio Bay. The fauna which can be considered indigenous to the inlets is here listed, and most of the species are illustrated on Plate III.

GASTROPODS

Anachis avara similis (Ravenel, 1861)
Cantharus tinctus (Conrad, 1846)
Epitonium angulatum (Say, 1830)
Epitonium humphreysi (Kiener, 1838)
Sinum perspectivum (Say, 1831)
Turbonilla interrupta Totten, 1835

SCAPHOPODS

Dentalium texasianum Philippi, 1849

PELECYPODS

Atrina seminuda (Lamarck, 1819)
Crassinella lunulata (Conrad, 1834)
Lucina amiantus (Dall, 1901)
Lucina crenella (Dall, 1901)
Tellidora cristata (Récluz, 1842)

CHITONS

Chaetopleura apiculata Say, 1830

ECHINODERMS

Arbacia punctulata (Lamarck, 1816)
Hemipholas elongata (Say, 1825)
Ophiolepis elegans Lütken, 1859
Ophiothrix angulatus (Say, 1825)

CORALS

Astrangia astreiformis Milne-Edwards and Haime, 1849

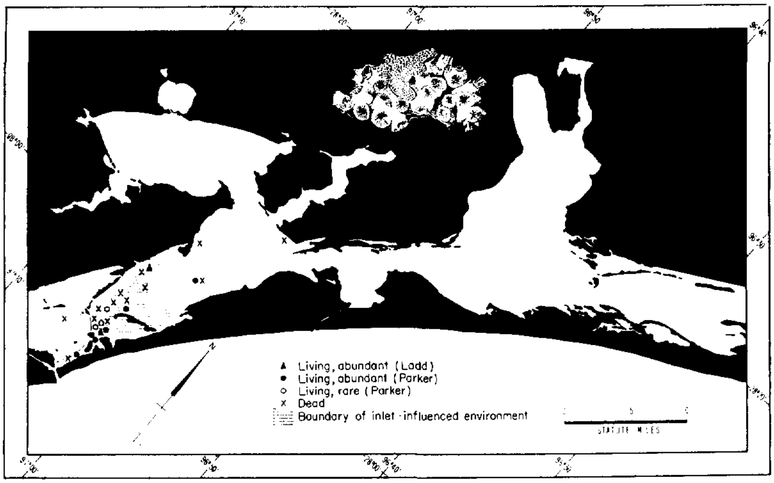

FIG. 19a. Distribution of solitary coral, *Astrangia astreiformis*, indicative of inlet conditions or deep channels at high salinity.

CRUSTACEANS
Dromidia antillensis Stimpson, 1858
Heterocrypta granulata (Gibbes, 1849)

The following invertebrates which are abundant in the inlets, may also be found in large open marine sounds and the nearshore open Gulf of Mexico to depths of at least 30 feet; most of which are illustrated on Plate IV.

GASTROPODS
Busycon contrarium (Conrad, 1840)
Cantharus cancellarius (Conrad, 1846)
Crepidula fornicata (Linné, 1758)
Cyclostremiscus trilix (Bush, 1885)

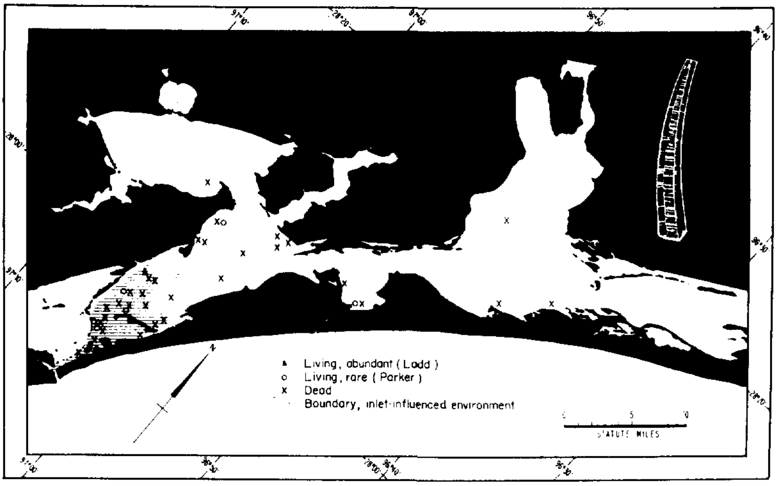

FIG. 19b.—Distribution of scaphopod, *Dentalium texasianum*, characteristic of high-salinity channels or inlets.

Diodora cayenensis (Lamarck, 1822)
Neosimnia uniplicata (Sowerby, 1848)
Oliva sayana Ravenel, 1834
Olivella mutica (Say, 1822)
Natica pusilla Say, 1822
Polinices duplicatus (Say, 1822)
Pyramidella crenulata Holmes, 1859
Seila adamsi (H. C. Lea, 1846)
Thais haemastoma haysae Clench, 1927
Turbonilla incisa Bush, 1899

PELECYPODS

Corbula swiftiana C. B. Adams, 1852
Chione cancellata (Linné, 1767)
Eontia ponderosa (Say, 1822)
Macoma tenta (Say, 1834)
Petricola pholadiformis Lamarck, 1818
Tellina alternata Say, 1822
Tellina versicolor De Kay, 1843

COELENTERATES

Leptogorgia setacea (Pallas, 1766)
Renilla mülleri Kölliker

ECHINODERMS

Luidia alternata (Say, 1825)
Luidia clathrata (Say, 1825)
Mellita quinquiesperforata (Leske)

CRUSTACEANS

Hepatus epheliticus (Linné)
Libinia emarginata Leach
Ovalipes guadalupensis (Saussure)
Petrolisthes armatus (Gibbes)
Portunus gibbesi (Stimpson)
Portunus spinimanus Latreille
Portunus ventralis (Milne-Edwards)

The inlet environment may be difficult to recognize in older deposits, because of the large number of species common to both the nearshore shelf and bays. There are also many motile forms, such as gastropods, echinoderms, and crustaceans. This environment may be recognized in older deposits by the mixture of assemblages, many motile forms and the presence of the few indigenous attaching species.

Shallow, grassy, hypersaline lagoons and bays.—This environment is associated with the inlets which furnish a source of high-salinity water. The best example can be observed in Redfish Bay, and similar examples exist near the former Corpus Christi Pass at the northern end of the Laguna Madre, the shallow grassy bays near the entrance to the Gulf at Brazos Santiago Pass, and the shallow bay areas in Espiritu Santo Bay near Pass Cavallo (Fig. 1). The shallowness of these areas may be related to the influx of sand and other coarse materia

---

PLATE III

VII. INLET INFLUENCE (RESTRICTIVE)

1. ***Chaetopleura apiculata***, size—10×7 mm., exterior.
2. ***Epitonium humphryesi***, size—11×5 mm., aperture.
3. ***Epitonium angulatum***, size—13×6 mm., aperture.
4. ***Sinum perspectivum***, size—31×31 mm., a. aperture, b. top.
5. ***Anachis avara similis***, size—8×3 mm., a. aperture, b. back.
6. ***Turbonilla interrupta***, size—5×1 mm., aperture.
7. ***Dentalium texasianum***, size—20 mm., side view.
8. ***Atrina seminuda***, size—188×108 mm., a. interior, b. exterior.
9. ***Crassinella lunulata***, size—8×7 mm., a. interior, b. exterior.
10. ***Lucina amiantus***, size—6×6 mm., a. interior, b. exterior.
11. ***Lucina multilineata***, size—5×5 mm., a. interior, b. exterior.
12. ***Tellidora cristata***, size—15×13 mm., a. interior, b. exterior.
13. ***Astrangia astreiformis***, size—25 mm., clump.
14. ***Ophiolepis elegans***, size—disc—20 mm., arms, 55 m., a. disc, b. dorsal, c. ventral
15. ***Hemipholis elongata***, size—disc—7 mm., a disc, b. dorsal, c. ventral.
16. ***Heterocrypta granulata***, size—15×10 mm., a. dorsal, b. ventral.

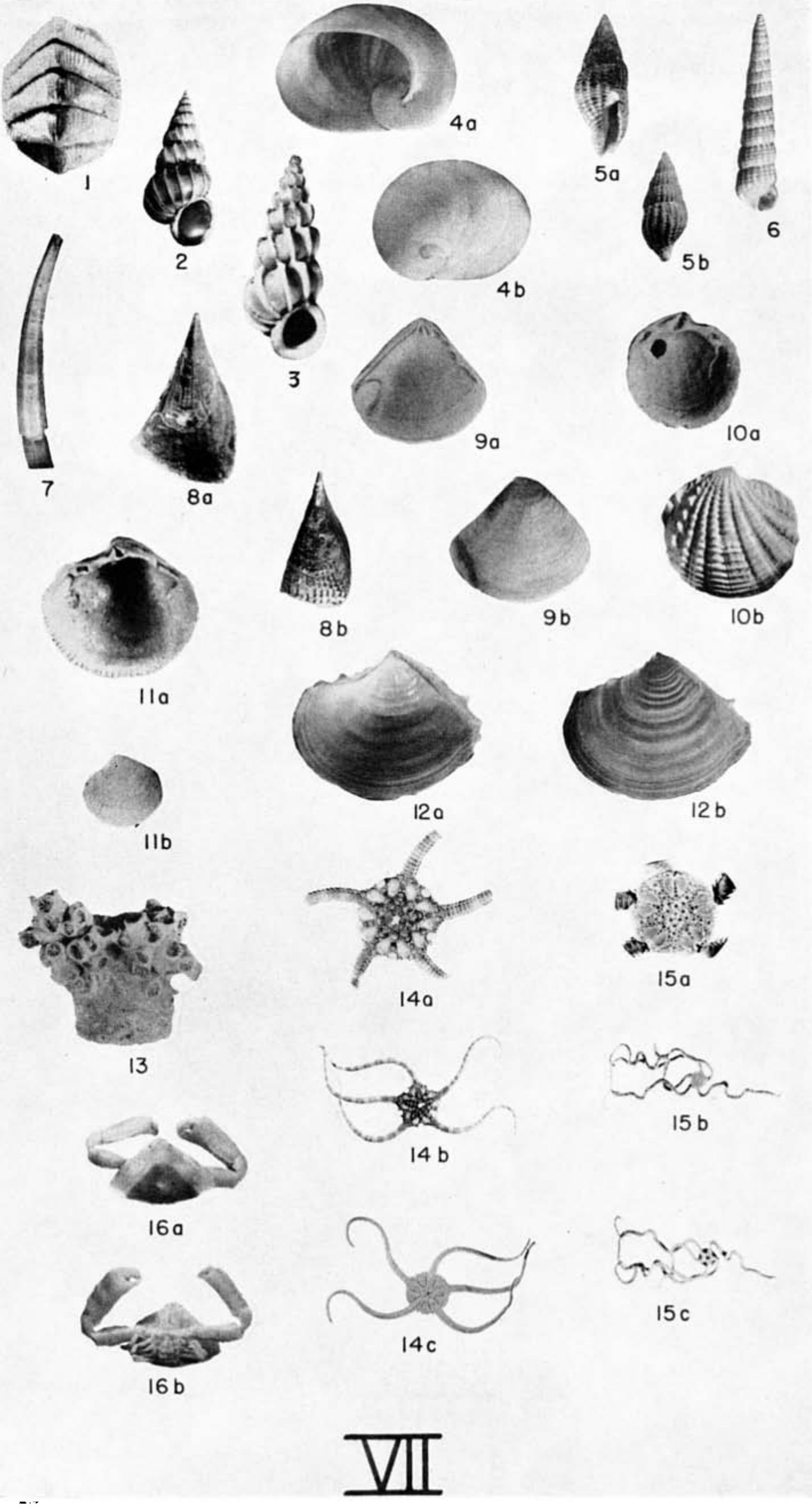
1
2
3
4a
4b
5a
5b
6
7
8a
8b
9a
9b
10a
10b
11a
11b
12a
12b
13
14a
14b
14c
15a
15b
15c
16a
16b
VII

Plate III