An. Inst. Biol. Univ. Nal. Autón. México 43, Ser. Cienc. del Mar y Limnol. (1): 1-20, 5 figs., 2 tablas (1972)

ECOLOGY AND DEVELOPMENT OF TWO COASTAL LAGOONS IN NORTHWEST MEXICO

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ABSTRACT

Long and narow inlet-channels into Morancarit and Huizache-Caimanero Lagoon result in development of only inner lagoon water masses reflected by inner lagoon and marsh assemblages of foraminifera.

Occurrence of an inner lagoon assemblage of foraminifera in Yavaros Lagoon, a small lagoon with free access to the open-ocean, is due to drainage from an agricultural area.

Huizache-Caimanero Lagoon is filled with water during the rainy season. At this time most of the estuarine water enters from the Caimanero inlet-channel and most of the outflow of runoff water is through the Huizache inlet-channel. This flow is reflected by the occurrence of one open ocean species of Foraminifera near the Caimanero inlet-channel, an inner lagoon assemblage in the Caimanero basin and no Foraminifera in the Huizache basin.

Experimental flooding of Etchoropo Lagoon with estuarine and irrigation water resulted in very large standing stocks of Foraminifera, where none had previously existed, within three months after flooding and rapid turnover of the population. The Yavaros area lagoons developed on the delta of the Mayo River and source of sediment for the lagoon barrier is from the west. The Etchoropo and Moroncarit basins are almost full of sediment; the Yavaros basin is rapidly filling with sediment brought in by the drains from the irrigated area.

The Huizache-Caimanero Lagoon is essentially filled with sediment. The inner lagon barrier was formed by sediments from the north when the Presidio River was farther south and the Baluarte River was farther north than now. Channels traversing this inner barrier record a flood and relocation of the river effluents. The outer barrier was deposited by sediment derived from the Baluarte River recording a change in direction of net sediment transport. A recent shift in positions of the Presidio and Baluarte Rivers is believed to have resulted from an intense flood. These events correlate with those described previously in adjacent Nayarit State by other authors.

RESUMEN

Las características de los largos y delgados canales que comunican a la Laguna Huizache-Caimanero con el mar a través de los estuarios respectivamente de los ríos Presidio y Baluarte, sólo permiten el desarrollo de masas de agua de laguna interior, según indican los conjuntos de foraminíferos encontrados, que son característicos de lagunas interiores y marismas.

La presencia de un conjunto de foraminíferos indicativo de laguna interior en la Laguna de Yavaros, una pequeña laguna con acceso libre al océano abierto, es debida al drenaje de una zona agrícola.

La Laguna de Huizache-Caimanero se llena de agua durante la época de lluvias. En ese momento, la mayor parte de las aguas estuarinas entran por el canal que

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comunica a Caimanero con el estuario del río Baluarte y la mayor parte del flujo de salida de agua es a través del canal que comunica a Huizache con el estuario del río Presidio. Este flujo se refleja en la presencia de una especie de foraminíferos de mar abierto en la porción sur de Caimanero, cerca del Estero de Agua Dulce, un conjunto característico de laguna interior en Caimanero y ausencia de foraminíferos en Huizache.

La inundación experimental de la Cuenca de Etchoropo con agua estuarina y de irrigación originó poblaciones muy grandes de foraminíferos en un período de 3 meses después de la inundación y un rápido cambio en la población en sitios donde anteriormente no existía nada.

El área de la Laguna de Yavaros es parte del desarrollo complejo deltáico del río Mayo y la fuente de sedimentos para la formación de la barrera arenosa es desde el occidente. Las cuencas de Etchoropo y Moroncárit están prácticamente llenas de sedimentos; la cuenca de Yavaros se está rellenando rápidamente con sedimentos descargados por los drenes del área de irrigación.

La Laguna Huizache-Caimanero está esencialmente llena de sedimentos. La barrera arenosa interior fue formada por sedimentos procedentes del norte cuando el río Presidio estaba mucho más al sur y el río Baluarte estaba notablemente más al norte que en la actualidad. Los canales que atraviesan esta barrera interior muestran una inundación y reubicación de las afluentes del río. La barrera exterior fue depositada por sedimentos derivados del río Baluarte registrando un cambio en la dirección del transporte neto de sedimentos. Se nota un cambio reciente en la porción de los ríos Presidio y Baluarte, posiblemente como resultado de una intensa inundación. Esos eventos se correlacionan con los descritos previamente en Nayarit por otros autores.

INTRODUCTION

Two areas of Mexican coastal lagoons have been studied to evaluate their potential as national resources, particularly shrimp fisheries. One area in southern Sonora contains Yavaros and associated lagoons and the other is the Huizache-Caimanero Lagoon in southern Sinaloa (Fig. 1). Members of the Universidad Nacional Autónoma de México have investigated sediment distribution, some chemical interactions, ecology of some of the organisms and biological productivity in these areas. The purpose of the present study is to interpret the assemblages of foraminifera as indicators of the different lagoonal environments, and to discuss some aspects of the probable development of the lagoons. The interpretations are based on preliminary collections and studies. We believe, however, that we have made progress in understanding some lagoonal environments not previously reported. It is hoped that our results will serve as a stimulus to more detailed studies in these and other areas.

YAVAROS LAGOON AREA

DESCRIPTION OF THE AREA

The Yavaros Lagoon area is located on the Gulf of California, in the southern part of coastal Sonora, from 26°50'W Lat and 109°25'W Long to 109°50'W Long (Figs. 1, 2). It is a part of a coastal plain and delta complex formed by the Mayo River, and the present river forms the western boundary. Inland from the lagoon there is a large agricultural area which is at an elevation of about 2 m above Yavaros Lagoon and slopes gently upward inland. Water from the Mayo

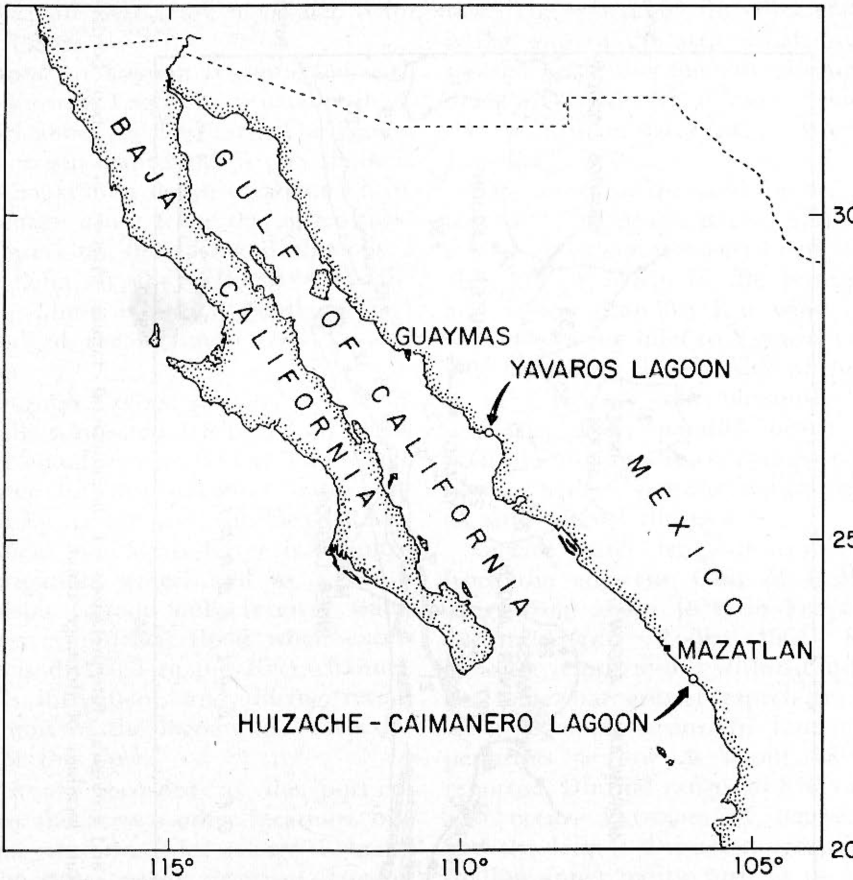

Figure 1. Locations of areas.

River is used for irrigation, and the agricultural area is drained of excess water through the series of drainage canals which flow into the lagoons.

The climate of this region is semi-arid, with a rainfall of approximately 300-400 mm/year mostly during summer months. Mean monthly temperatures range from a maximum of about 30°C in July and August to a minimum of about 15°C during December-February. Evaporation rate is approximately ten times the annual precipitation. Prevailing winds in summer are southeasterly and during the rest of the year are northwesterly. There are infrequent storms of gale force.

The Yavaros area consists of three "lagoons" which have different geographic names but are a part of the same lagoon system (Fig. 2). Yavaros Lagoon, the largest of the lagoons, is irregular in shape, is 4-8 Km wide and extends along the coast for about 12 Km. The inlet has a maximum depth of 10 m and there is a well-developed lagoonal channel system which has been filled with sediment in the inner reaches of the three embayments within the lagoon. Drainage canals from the agricultural area enter the lagoon at four locations

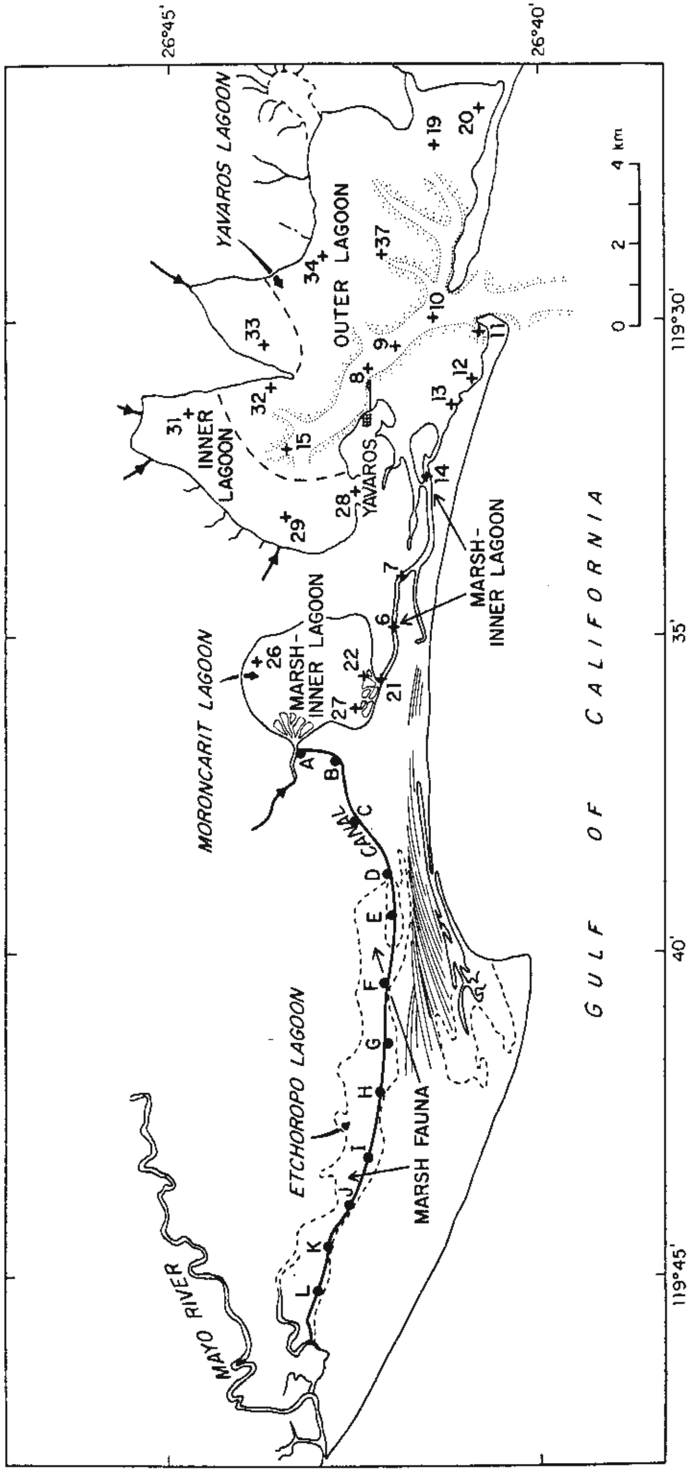

Figure 2. Yavaros Lagoon area, with locations of samples and ecological interpretations of foraminiferal faunas. Arrows at lagoon borders indicate locations of drainage canal.

where small deltas are associated with the effluents.

Moroncarit Lagoon is connected with lower Yavaros Lagon by a narrow inlet-channel about 10 Km long. The lagoon floor is basin-shaped and is very shallow, with a maximum depth of about 1.5 m. A drainage canal from the agricultural area enters on the east and there is a small delta at the effluent into the lagoon. There is also a small delta at the end of the channel from Yavaros Lagoon.

Etchoropo Lagoon consists of a series of small, connected basins at an elevation of about -0.5 to -0.8 m. The source of water for this irregular basin was previously runoff from the Mayo River. At present the Mayo River is dammed for irrigation water, and as a result Etchoropo Lagoon only receives water at times cf unusual flood when excess runoff is diverted to the river channel. This is infrequent, and during recent years most of the lagoon has been dry most of the time.

Tides are recorded at the port of Yavaros and at two other locations, one of them near the inlet (Barra Lobera) and the other inside Yavaros Lagoon (Pecio El Carmen). The range of most tides varies approximately from. 0.5 to 1.0 m, and the averagy range of spring tides is about 1.3 m with occasional spring tidal ranges as great at 1.7 m. The delay of the tide from the inlet to the port is 30 minutes and from the inlet to the inner lagon the delay is 60 minutes.

The sediments of Yavaros Lagoon are dominantly fine sand, except on the inner borders where somewhat finer material occurs. Fine-grained sediment characterizes Moroncarit Lagoon and the area surrounding the estuary leading into the lagoon. Presence of silts and clays at these locations is partly a result of deposition at the end of the tidal excursion where current velocities are low. The source of the silts and clays is the soils of the area which are transported into the lagoons through the drainage canals, as is most evident in the pattern of sediment in Moroncarit Lagoon.

The source of the sand for the lagoon barrier is the Mayo River. The barrier is 3.5 Km wide at its eastern end, narrows abruptly to 1 Km in the central part and is less than 0.5 Km wide on the west side of the inlet to Yavaros Lagoon. The barrier on the east side of this inlet is very narrow and obviously "sand--starved". Low, parallel beach ridges occur locally in the central part of the barrier with a pattern indicating drift of sand toward the east.

Surface water temperatures reported from the adjacent Gulf of California range from about 18°C in Febraury to 30° in August (Roden, 1964). Ranges of water temperatures within the lagoon are somewhat greater especially in the inner lagoonal basins. In January temperatures as low as about 13°C are reported. Diurnal ranges of 8°C or more also occur. Extremes of temperatures and the largest diurnal ranges occur in shallow inner basins such as in Moroncarit Lagoon (Arenas, 1970).

Salinity of the adjacent offshore Gulf of California surface water is about 35 to 35.4‰ (Roden, 1964). The salinity of the Gulf water entering the lagoons is modified by evaporation in the partially enclosed basins and by drainage of essentially fresh water from the irrigation area; these factors result in marked salinity variations within the lagoons. This also affects the nearshore water immediately adjacent, as reflected in salinity variations of 23‰ to 38‰ reported by Arenas (1970) from the inlet to Yavaros Lagoon. This must reflect considerable variation in the volume of fresh water draining into the lagoon from the irrigated area, as well as seasonal range in evaporation rate.

Some salinity records within the lagoon are higher than those at the inlet; this occurs in inner reaches where there are no drainage effluents, such as in the southeast arm of the lagoon. Salinities in Moroncarit Lagoon, on the other hand, are lower than Gulf water. This is a result of the flow of fresh water drainage into the small shallow basin. It also is due to the slow rate of supply of water from Yavaros Lagoon through the long and narrow channel connecting with Yavaros Lagoon.

Currents within the lower part of the main lagoonal channel have been recorded with velocities as high as 60 cm/sec during a tide range of about 1 m.

ECOLOGY OF FORAMINIFERA IN YAVAROS AND MORONCARIT LAGOONS

Foraminiferal populations at all stations in Yavaros Lagoon contain few species and are dominated by *Ammonia beccarii* and *Elphidum* cf. *E. translucens,* typical lagoon forms. Approximately six nearshore open-ocean species are very rare at the stations in the lower lagoon, and together with the two dominant species form a lower lagoon fauna. A fauna interpreted as representing an inner lagoon one occurs at stations in the northerly embayments of the lagoon (Fig. 2). Faunas in Moroncarit channel are an inner bay assemblage; in Moroncarit Lagoon the faunas are inner lagoon ones also containing living specimens of *Miliammina fusca,* a marsh form.

The inner lagoon assemblage in Yavaros Lagoon indicates the presence of an ecologically distinctive water mass in the inner reaches of the bay. This water mass is formed by runoff from the irrigation drainage canals, since the inner lagoon assemblage occurs only in places affected by drainage such as in the northwest arm of Yavaros Lagoon. The ecology of the foraminifera in Moroncarit Lagoon is a mixture of inner lagoon and marsh; this appears to reflect the slow exchange of water with Yavaros Lagoon through the long and narrow Moroncarit Channel and the runoff from the drainage canal. The marsh which borders this channel also influences the environment in the lagoon.

Unusually large standing stocks of foraminifera (living specimens/ 10 ml wet surface sediment) were collected at the following locations: 1) stations 20, 34 and 37 in the southeast arm of the lagoon, 2) station 22 at the effluent of Moroncarit Channel into Moroncarit Lagoon, and 3) station 13 near the effluent of Moroncarit Channel into Yavaros Lagoon. Unusually small standing stock were collected at two stations near the border of Moroncarit Lagoon, at two stations near the border of Yavaros Lagoon and at stations in Moroncarit Channel.

The presence of high standing stocks in the southeast arm of Yavaros Lagoon probably is related to the higher than normal salinity which occurs some of the time in that part of the lagoon. High standing stock of foraminifera are reported from Laguna Madre, Texas (Phleger, 1960), Ojo de Liebre, and Guerrero Negro Lagoons, Baja California (Phleger and Ewing, 1962); these lagoons are hypersaline. The high organic production, indicated by large standing stocks, is a result of constant re-supply of sea water containing nutrients and trace materials necessary for plant growth.

The large standing stocks near the effluents at each end of the Moroncarit Channel may be attributed to the mixing of runoff water from the irrigation drainage channel with sea water from lower Yavaros Lagoon. Unusually large standing stocks of foraminifera are reported offshore from Main Pass in the Mississippi Delta (Lankford, 1959) and

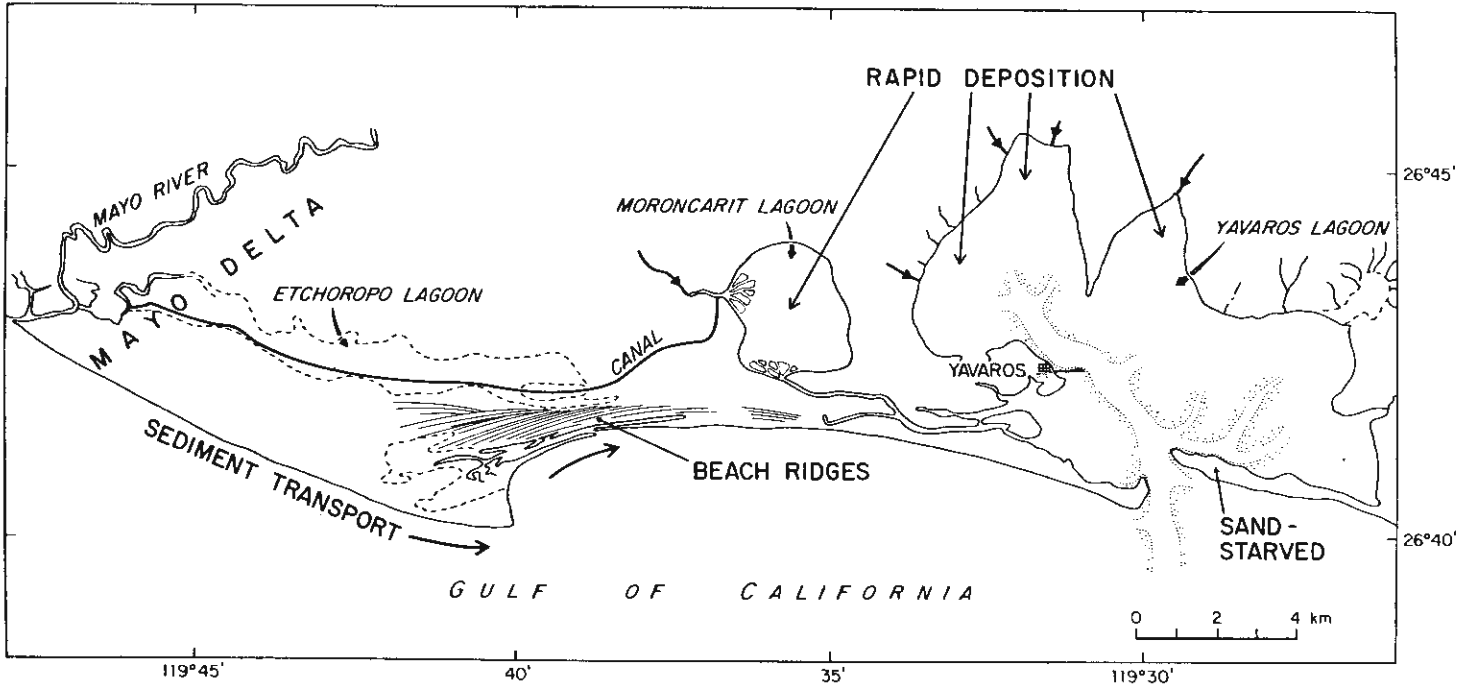

Figure 3. Yavaros Lagoon area, showing direction of nearshore transport and areas of rapid deposition in the lagoons asociated drainage canals.

near the mouth of the Guadalupe River in San Antonio Bay, Texas (Phleger and Lankford, 1957). These large populations have been attributed to trace materials introduced by the rivers. Both nutrients and trace materials are introduced from the fertilized agricultural areas through the channel which flows into Moroncarit Lagoon. This water mixes with sea water introduced into Moroncarit Lagoon during the flood current and the ebb current causes further mixing in lower Yavaros Lagoon.

EXPERIMENTAL FLOODING OF ETCHOROPO LAGOON

Etchoropo Lagoon was filled with water by engineers of Secretaría de Recursos Hidráulicos by means of a canal traversing the lagoon from east to west. Marine or estuarine water was introduced from the estuary of the Mayo River on the west and irrigation water was introduced at the eastern end of the canal. This experimental flooding was done to determine whether the lagoon basin could be established as a commercial shrimp fishery.

The first flooding was in April, 1970. Members of the UNAM monitored the salinity and temperature and estimated shrimp and fish populations at frequent intervals for a few months. The average depth of water in the basin away from the canal was approximately 50-100 cm. The water temperatures are higher than the Gulf of California surface temperatures due to rapid solar heating of the shallow water.

The salinities in Etchoropo Lagoon are a function of the salinity and rate of water flowing from the Mayo River estuary, the rate of fresh flow irrigation water, the high evaporation rate, and the solution of residual salt which was in the sediment before flooding. The salinity of the water entering from the Mayo estuary on the west usually approximates that of Gulf water, but has ranged from about to 38‰. The water at this end of the canal enters through a gate which opens during flood current and closes during the ebb current. Salinities measured at the eastern end of the canal range from 5 to 8‰. The water in the middle part of the lagoon is hypersaline with maximum observed salinities ranging from 40 to 60 ‰. Short period variations in salinity are reported to be large (Carranza, 1970).

Populations of shrimp and mullet are reported by Carranza (1970) to be very large in the flooded Etchoropo Lagoon. This indicates a rapid migration of these forms into the area from the Gulf. Dry sediments from several locations within Etchoropo Lagoon were examined for tests of foraminifera before flooding; only two specimens were found at one location. Samples of 10 ml of surface sediment were collected on July 7, 1970, after flooding, for analyses of the foraminifera. The locations of these stations and the salinity of the water are on Figure 2. All samples contained living foraminifera and at some stations very large standing stocks were present (Table 1).

The assemblage of foraminifera is a marsh and inner lagoon one composed of five species. *Miliammina fusca*, a marsh species is restricted to the western part of the lagoon where it apparently was introduced from the Mayo River estuary. In the eastern half of the lagoon there are only 1 or 2 species/sample, whereas in the western half there are 2 to 5 species/ sample. The number of living foraminifera per sample is very much greater in the western half than in the eastern half. The number of empty tests in all samples is considerably less than the number of living specimens, indicating that they are derived from turnover of the population after flooding of the lagoon. Most of

		YAVAROS																MORONCARIT							ETCHOROPO											
SAMPLE NO.		8	9	10	11	12	13	15	19	20	28	29	31	32	33	34	37	6	7	14	21	22	26	27	A	B	C	D	E	F	G	H	I	J	K	L
TOTAL LIVING		36	75	104	5	40	420	144	136	424	102	76	5	135	18	385	610	4	20	26	110	690	3	10	1	15	32	7	9	17	229	208	690	164	54	136
TOTAL DEAD		184	115	576	20	24	280	516	728	1800	36	48	2	1770	31	685	1520	88	36	6	740	130	6	7	0	0	32	1	0	4	33	8	320	76	22	16
Ammonia beccarii	L	78	26	77		40	67	41	71	55	100	80	60	55	100	58	47		40	42	36	45	100	27			50	30			7	90	62	63		56
	D	60	66	68	50		63	75	53	54	18	54	70	54	62	57	52	61	91		81	31	50	14			100				3	38	23	21		25
Ammotium salsum	L		7																	58	9	4			100	100					1	7	25	5	100	15
	D					100	4				82				6			4	40	100		3									46	12	28	59	100	
Buccella sp.	L								3				20			4	2																			
	D	4	7						4	1			50	1		7	4																			
Bulimina marginata	L																																			
	D																1																			
Buliminella elegantissima	L		7																																	
	D																																			
Bolivina acutula	L									2		5				1																				
	D																																			
B. vaughani	L							5								3																				
	D	2																																		
Discarbis sp.	L		13					9																												
	D		4					1	5					1																						
Elphidium incertum	L			23			7	5	18	13				16		13	3																			
	D	2	4	15			7	1	5	22		8		15		11	8																			
E. cf. translucens	L	11	20		100	40	26	20	3	28		15		26		13	16	100			46	50		80			50					1	1	20		3
	D	22	22				18	16	7	20		6		27	6	12	16	27	9		12	61	50	86				100				12	25	10		25
Miliammina fusca	L																		20		9	1											9	12		26
	D																																12	10		50
Milialids	L																5											70	100	100	92	2	3			
	D																1				5	3								100	51	38	12			
Nanianella basispinata	L		20														3																			
	D		4				4										1	4																		
Q. spp.	L	11						20	5	2				3		8	24																			
	D	10		14	50		4	7	26	3				2		13	16	4																		
Trochammina sp.	L																																			
	D																1																			
Reaphax nanus	L																																			
	D														26																					

Table 1. Foraminifera in samples from the Yavaros Lagoon area in percents of living (L) and dead (D) populations.

these empty tests were at stations G-K in the western half of the lagoon, a result of the relatively large standing stocks and presumably fast population turnover in that area. A small miliolid occurred at the hypersaline stations, D-I, and was very abundant at station G, where there was a salinity of 54‰ at the time of collection. This miliolid is similar to the one reported from the hypersaline marsh in the brine pans at Ojo de Liebre Lagoon in Baja California (Phleger, 1967).

The distribution of living foraminifera clearly indicates migration from the Mayo estuary after flooding and dispersal throughout the lagoon within 3 months. The colonization by large populations, however, has occurred about halfway in the lagoon.

During the seven months of observed flooding (April-November, 1970) there was no provision for exchange of water out of the lagoon. If the flooding with sea water, and fresh water is continued at the original rate with no provision for outflow, it is probable that the lagoon will eventually become strongly hypersaline. This may result in a complete floral and faunal change due to "brine pan" conditions such as those at Ojo de Liebre, Baja California (Phleger and Ewing, 1962).

HISTORY OF DEVELOPMENT

It is suggested that the sand barrier forming the present lagoon system began at some lower stand of sea level. This may have been during a slowdown in the post-glacial rise of sea level at about 10 m approximately 6,000 to 7,000 years B.P. (Curray, 1961; Phleger, 1967). As sea level rose the barrier probably built upwards reaching approximately its present level about 2,500 years B.P. Abundant sand in the nearshore zone to form the barrier was supplied by the sediments of the delta of the Mayo River. It appears that the present Yavaros Lagoon basin was made by three stream channels on the delta which were incised at some time during lower than present sea level. The evidence for this is the shape of the lagoon and the escarpment around the inner borders which has been cut 2-3 m into the old deltaic deposits.

The Etchoropo basin filled rapidly with sediment transported into it by the Mayo River which is nearby and considerable progradation of the shoreline has occurred seaward from the Etchoropo basin. Some of the inner reaches of Yavaros Lagoon and Moroncarit Lagoon are at present being rapidly filled with sediment transported into them from the canals which drain the irrigation area.

HUIZACHE-CAIMANERO LAGOON

DESCRIPTION OF THE AREA

Huizache-Caimanero Lagoon is in coastal southern Sinaloa, extending approximately from 22°40'N Lat to 23°07'N Lat and 106°00'W Long to 106°16'W Long (Figs. 1,4). The climate of the area is tropical with summer rain. The average rainfall is about 800 mm with 80% of the rain during July-September and 12% during the months of June and October. Mean monthly temperatures range from a low of 19°C in January to 28° during July-September. The vegetation has been described as a semi-deciduous tropical forest.

The lagoon is bounded on the northwest by the Presidio River and on the south by the Baluarte River, and is as-

		APRIL, 1969								SEPTEMBER, 1969																		
STATION NO.		A	B	C	D	E	F	G	H	7	21	24	23	25	29	33	36	39	42	46	50	54	69	62	64	67	71	74
TOTAL LIVING		52	9	0	360	100	2	48	5	4	73	64	30	10	180	13	129	2	64	116	5	428	60	104	85	198	20	192
TOTAL DEAD		42	20	5	34	5	8	156	7	48	90	64	15	8	362	11	109	43	434	544	46	1544	562	404	1310	452	60	300
Ammobaculites exiguus	L	2	22					7																				
	D	2	5				25																					
Ammonia beccarii	L				94	97								60	3	15	10		70	95	20	53	43		12	7		
	D									2				25			11		77	82	10	88	57	5	35	14		
Ammotium salsum	L	2	67		6	3		93	100	100	96			20	20	15	30	100	5	3	80	1	40	100	6	90		
	D	2	90	100	100	100		100	100	98	97			50	55	91	12	98	4	13	90	2	34	95	24	79	100	3
Ammoastuta inepta	L	27																										
	D	12																										
Arenoparrella mexicana	L	35					100																					
	D	62					75																					
Elphidium incertum	L														74	70	60					1						
	D													24	37	9	77	2				1			1			
Haplophragmoides sp.	L	6																										
	D	17					25																					
Miliammina fusca	L	28													1													
	D	5	11												7											1		
Palmerinella sp.	L										4	100	100		2				25	2		45	13		82	3	100	100
	D										3	100	100		1				19	2		9	5		39	6		96
Quinqueloculina sp.	L																						4					
	D																			3			4		1			
Trochammina inflata	L																											
	D		5																									
T. sp.	L																											
	D													25														

Table 2. Foraminifera in samples from the Huizache-Caimanero Lagoon in percents of living (L) and dead (D) populations.

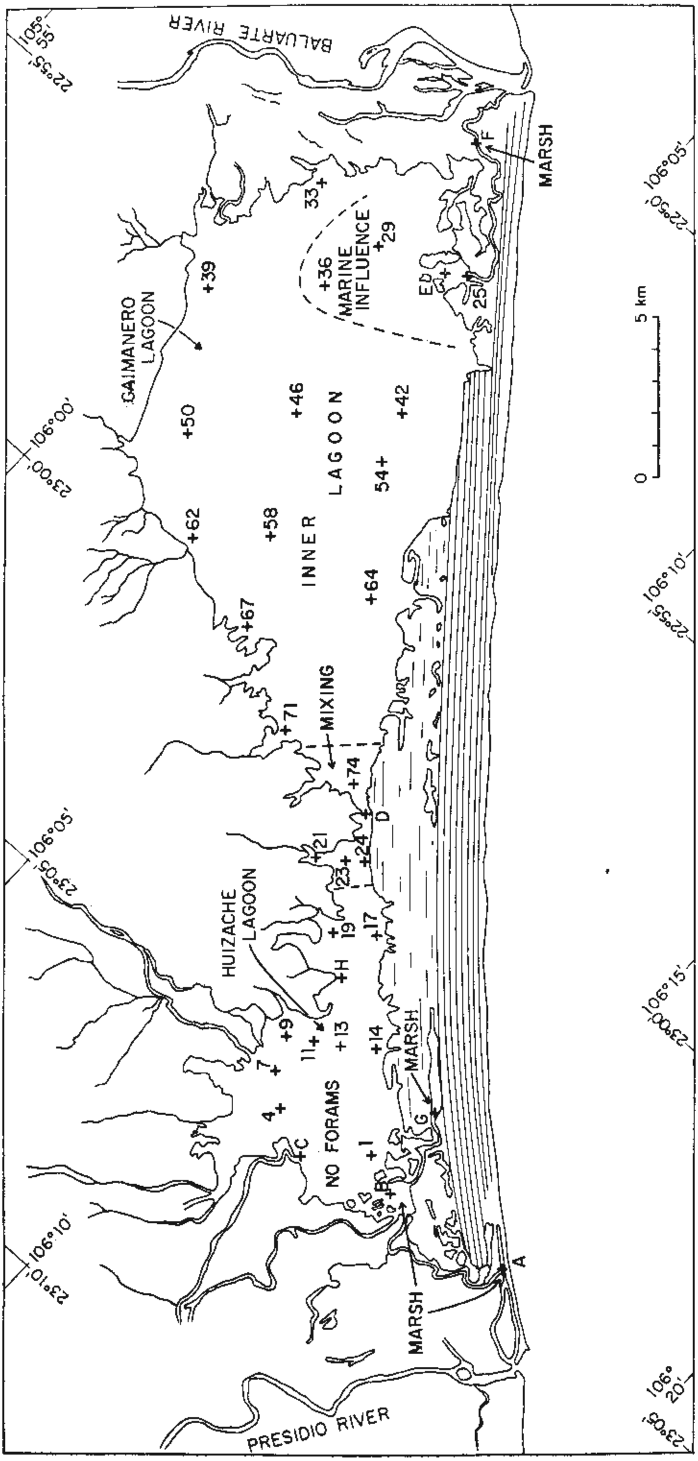

Figure 4. Huizache-Caimanero Lagoon, with locations of samples and ecological interpretations of foraminiferal faunas.

sociated with the delta complexes of the two rivers. These rivers have relatively small drainage basins which extend part way up the western flank of the Sierra Madre Occidental. Several small streams flow into the lagoon which are active only during the rainy season. The coastal plain is narrow (10-25 Km) and low hills are adjacent to the lagoon area.

The lagoon consists of two basins. The northwestern basin, called Huizache, is about 12 x 5 Km; the southeastern basin, called Caimanero Lagoon, is 10 x 20 Km, and they are connected by an opening about 250 m wide. The lagoon basins are flat and very shallow and there is no natural channel system. Most of the lagon is fillied with water only during the rainy season when the maximum depth in the Huizache basin is 60-80 cm, and in the Caimanero basin is about 120 cm. The Caimanero basin and one small basin in the Huizache area are partly filled with water during the dry season. There are two inlets, one at each end of the lagoon which connect with the estuaries of the Presidio and Baluarte Rivers. Both of these inlets are narrow, meandering, 8-10 Km in length and are bordered by mangroves.

The lagoon barrier is 1.5-3.5 Km wide and extends about 35 Km between the two river mouths. There are three distinctive morphologies which occur in different parts of the barrier. An inner section bounding most of the Huizache basin and a part of the Caimanero basin has obscure beach ridges and an irregular shape on its inner edge. There are several indentations extending from the lagoon side which appear to have been overflow channels at an early stage of development of the barrier. An outer section consists of several clearly developed parallel beach ridges of sand. In the southeastern 8 Km, near the Baluarte River, this section is narrow and contains only 2 or 3 ridges. The third type of barrier morphology occurs near the rivers and appears to be river delta deposits.

Most of the sediments in the lagoon basins are silty clay with some large patches of clayey sand in the Caimanero basin. The sediments of the barrier are primarily sand, with some silt and clay especially in the depressions between the sand ridges.

The water temperatures in the shallow lagoon basins closely follow air temperatures. The maximum temperature of about 36°C occurs from June to September, and a minimum temperature of 15°C was observed in February. Salinities vary, depending upon amount of runoff, supply of sea water and evaporation. Values range from 1‰ to about 60‰ in the constriction between the two basins. In the southeastern part of Caimanero basin observed salinities range from 7‰ to 40‰. It appears that a significant amount of salt in the water is derived from residual salt left in the sediment when the lagoon is mostly empty of water during the dry season. In September 1969 when the lagoon was flooded, salinities ranged from less than 1‰ to 14‰, with the lower salinities of 0.3-2.6‰ in Huizache basin and the higher salinities in Caimanero basin. The low salinities in the Huizache basin clearly indicate that most of the runoff flows into that basin during the rainy season.

ECOLOGY OF FORAMINIFERA

The assemblage of foraminifera within the lagoon consists primarily of *Ammotium salsum, Ammonia beccarii* and *Palmerinella* sp. This fauna is characteristic of inner lagoons which may have brackish water at certain times, and often a marked seasonal range in salinity (Parker *et al,* 1953; Bermudez, 1934), In addition, *Elphidium incertum* is abundant at 2 stations in the southeastern end of the Caimanero basin near the effluent of the inlet.

There were no foraminifera in most of the samples collected from the Huizache basin. An exception is at station 7 where four very fragile living *Ammotium salsum* were found. These foraminifera are interpreted as specimens which survived the dry season in a remnant pool of water. Also, the three stations near the narrows between the basins contain foraminifera in an area where some water is present during the dry season. The population at these stations and at one station on the Caimanero side of the narrows is dominated by *Palmerilla* sp. The absence of foraminifera in most of the Huizache basin appears to reflect the very low salinities during the rainy season and suggests that foraminifera do not tolerate the conditions which obtain there. The dominance of *Palmerinella* near the narrows may be an indication of the limit of tolerance of salinity or other conditions of the lagoon fauna.

The presence of moderate numbers of living foraminifera at all stations in the Caimanero basin probably results in large part from their survival in the water which persists in this basin during the dry season. When the extent of the water in the basin increased during the rainy season, they dispersed throughout the area because the salinities and other factors were within their range of reproduction and survival. The presence of large numbers of *Elphidium incertum,* a nearshore form (Phleger, 1964), at stations in Caimanero basin near the inlet suggests that an appreciable amount of sea water has been introduced from the estuary of the Baluarte River.

A few samples were collected in April 1969 near the end of the dry season from very shallow pools in the lagoon and from the inlets. The living fauna in samples from pool in the lagoon contained *Ammotium salsum* and *Ammonia beccarii.* The fauna in samples from the inlets was a typical marsh assemblage, containing *Ammotium salsum, Arenoparrella mexicana, Haplophragmoides* sp., *Miliammina fusca,* and *Ammoastuta inepta.*

The evidence from the distributions of foraminifera and salinities suggests: (1) most of the sea water enters this lagoon through the inlet from the estuary of the Baluarte River and into the Caimanero basin; (2) most of the fresh runoff water enters the lagoon during the rainy season into the Huizache basin; (3) most of the mixing of sea water and fresh water occurs in the area of the narrows between the two basins; (4) the stocks of most foraminifera in the lagoon survive in pools which exist during the dry season; (5) the assemblage of foraminifera is an inner lagoon one due to the long narrow inlets having the ecology of a marsh which serve as barriers to invasion of nearshore open-ocean species into most of the lagoon.

HISTORY OF DEVELOPMENT

The oldest part of the lagoon barrier is the inner section which has modified beach ridges and an inner edge indented with what appear to be old overflow channel. The sediment source for this part of the barrier was from the Presidio River and the net longshore drift was to the south. The Presidio River mouth and inlet to the lagoon was approximately 8 Km to the southeast of its present position (Fig. 5). There is no indication of the location of the southeastern inlet, but it was probably several kilometers to the northwest of the present mouth of the Baluarte River. This part of the present barrier is probably the same age as stage III of the barrier south of the Baluarte River described by Curray *et al* (1969).

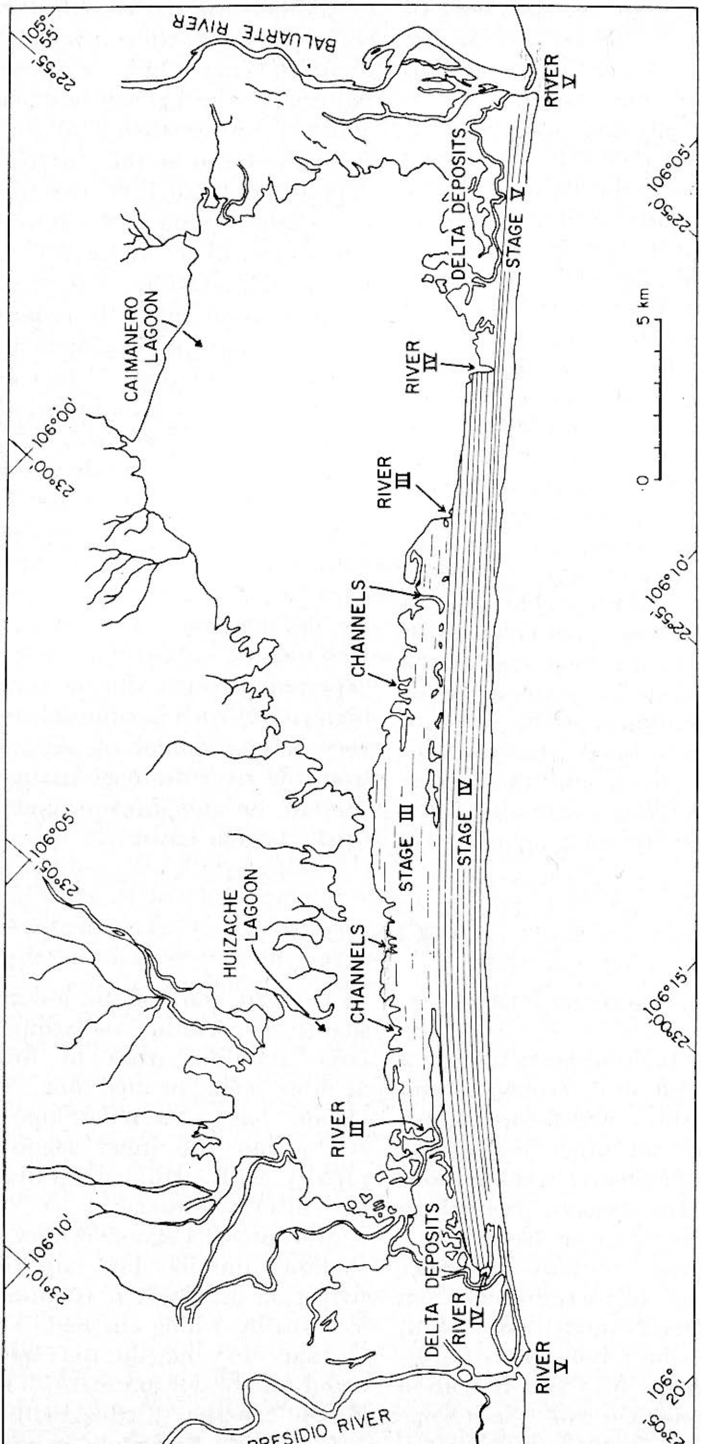

Figure 5. Huizache-Caimanero Lagoon, showing different stages of development of the lagoon barrier and probable locations of river mouth at these stages.

The next stage in development of the barrier was the deposition of the seaward parallel beach ridges which appear to be the same as stage IV of Curray *et al* (1969) and are presumed to date from about 1500 B.P. The source of this sediment was the Baluarte River and there was thus a net longshore sediment transport to the north. At the beginning of stage IV, the mouth of the Baluarte River was about 8-9 Km northwest of its present position and the mouth fo the Presidio River appears to have shifted about 5 Km to the northwest from its former position.

The shift in direction of net sediment transport indicates a marked climatic change, as suggested by Curray *et al* (1969). There is evidence of at least one intense flood after the deposition of the stage III sediments. This is seen in the old overflow channels which trend at angles to the long axis of the barrier and appear to extend across the sediments deposited at this stage. A flood may have caused the shift in position of the rivers, and the lagoon basin may have been essentially filled with sediment at this time.

Another apparently abrupt shift of both rivers to their present positions occurred later. This is shown by the pattern of the barrier beach ridges for about 8 Km northwest of the Baluarte River, and also by the pattern of deltaic deposits and adjacent beach ridges on the southeast side of the Presidio River. The most likely cause for an abrupt shift of the positions of the river mouths is an unusual flood. It is possible that this last stage in development is to be correlated with stage V of Curray *et al* (1969). At the beginning of their stage V the Rio Grande de Santiago also changed position and they estimate this date at about 500 years B.P.

The lagon is now essentially filled with sediment, and it is possible that most of the filling occurred early in its development. Deposition of large amounts of sediment in the basins is expected to occur during times of very high runoff such as unusual storms when very large volumes of soil are eroded from the river drainage basins and transported by the streams and deposited in the lagoon basins.

DISCUSSION

DISTINCTIVE LAGOON FEATURES

Each lagoonal basin appears to have a combination of physical, ecological and sedimentary features which distinguish it from most or all other lagoons. A summary of the distinctive combinations of features of the lagoons studied in northwest Mexico is given below.

Yavaros Lagoon contains an inner lagoon assemblage of foraminifera even though it is relatively small (8 x 12 Km) and has a wide, short inlet. This results from the drainage of fresh irrigation water into the lagoon and the formation of low salinity in the inner lagoon. In contrast, part of the lower lagoon is slightly hypersaline and supports a very large standing stock of foraminifera, at least some of the time. The lower lagoon has a well-developed channel system but the inner lagon is filling rapidly with sediment transported by agricultural drainage.

Moroncarit Lagoon is very small and shallow, and has low salinities due to irrigation drainage. It is connected with Yavaros by a long channel. The ecology is that of a marsh and inner lagoon based on the foraminifera. The basin is almost completely filled with sediment.

Etchoropo Lagoon is a very shallow

basin connected with the estuary of the Mayo River. In the past it was filled with water only during floods of the river. Almost no foraminifera inhabited the lagoon when it was full, suggesting that the water during river floods was essentially fresh. The river is now dammed and there is almost no natural flow into the basin. Artificial flooding has introduced almost undiluted sea water from the Mayo estuary on the west and fresh irrigation water on the eastern end. There is no outflow. The water was hypersaline except near the fresh water inflow. Standing stocks of shrimp, mullet and foraminifera were large three months after flooding. The ecology is that of a marsh.

The Huizache-Caimanero Lagoons consists of two shallow basins which differ ecologically and dynamically, and are connected by a narrow opening. Each basin has a very long and narrow inlet-channel to the estuary of a river. The Caimanero basin contains some hypersaline water during the dry season and apparently much or all of the sea water reaching both basins flows in through the Caimanero inlet-channel from the open-ocean. During the rainy season the water is brackish (about 10-15‰ in September 1969). The standing stock of foraminifera is an inner lagoon assemblage, and is similar in size to that in many other lagoons.

The Huizache basin contains water only in a few small areas during the dry season, and at that time there does not appear to be any significant inflow of water into the basin from the open-ocean through the inlet-channel. During the rainy season the basin is full of water having salinities generally less than 2‰; there appears to be mixing with the Caimanero water but no significant inflow of sea water through the Huizache inlet-channel. There are essentially no living foraminifera during the rainy season. During the dry season a sparse marsh assemblage of living foraminifera was found in residual pools.

ECOLOGICAL GENERALIZATIONS

Certain aspects of the ecology, sediment deposition and development of water characteristics in these coastal lagoons are important because of probable general applications. These may be useful as guides in investigating other coastal lagoons.

The size of the standing stock of organisms is an indication of the amount of organic production, with a relatively large standing stock indicating relatively high organic production. Foraminifera are abundant and ubiquitous in marine environments, and the relative sizes of their standing stocks are considered to be a reliable indication of relative amounts of total organic production. This has proved to be true where independent measurements have been made of standing stocks of foraminifera and rates of organic carbon fixation in the same area (Lankford, 1959; Thomas and Simmons, 1960).

Large standing stocks of foraminifera were found at the stations in Etchoropo Lagoon where the water was hypersaline when the samples were collected. Large living populations also were present in the southeastern part of Yavaros Lagoon where somewhat hypersaline conditions are reported some of the time. Large living populations in hypersaline lagoonal areas are reported from Laguna Madre, Texas (Phleger, 1960), Laguna Madre, Tamaulipas, (Ayala-Castañares and Segura, 1968) and Ojo de Liebre Lagoon, Baja California (Phleger and Ewing, 1962; Phleger, 1967). Our present samples are additional confirmation that hypersaline lagoonal areas are characterized by high organic production rates. This is a result of frequent or constant resupply of sea water containing nutrients to replace that lost by evaporation.

The samples for foraminifera from Etchoropo Lagoon were collected approximately three months after the experimental flooding of that area. The basin contained no water before flooding, and a total of only two tests of foraminifera were discovered in numerous samples collected before water was introduced. There were abundant living foraminifera from the western end where sea water was introduced to about halfway within the basin, and living specimens were present in smaller numbers at the other stations as well. This is evidence that the dispersal and occupation by benthic foraminifera was very rapid. The presence of empty tests in the sediment where almost none were previously present indicates that reproduction had occured at most stations.

An "inner lagoon" assemblage of foraminifera is characterized by species which appear to be indigenous to lagoons. The "outer lagon" fauna, on the other hand, contains nearhsore open-ocean species in addition to lagoon forms. The inner lagoon fauna occurs where open-ocean water is modified, usually in the inner reaches of a lagoon where exchange rates with the open-ocean are slow due to distance from the inlet. Living conditions are modified by the inner water becoming hyposaline where there is runoff into the lagoon and becoming hypersaline where no runoff occurs. The development of a distinctive inner lagoon water mass and fauna also appears to be a function of size of the lagoons, being best developed in large lagons and not being present in some small ones.

Moroncarit and Huizache-Caimanero Lagoons contain only an inner lagoon (and marsh) assemblage of foraminifera and no outer lagoon fauna is present. This is due to the presence of very long (8-10 Km) and narrow (10-20 m) inlet-channels which are the only access routes for nearshore marine water. These inlet-channels have fringing marsh and the environment within the channels appears to be that of a marsh, based on the foraminifera. This provides an effective barrier to invasion of most nearshore benthic foraminifera.

An additional barrier in these areas is the abundant runoff of fresh water into the basins. In the Huizache basin the abundant runoff into the basin during the rainy season appears to form a hydraulic barrier which prevents sea water from entering the basin. This is based on the very low salinities when the basin is full of water and on the absence of benthic foraminifera at most stations.

ORIGIN OF MULTIPLE BEACH RIDGES

There has been considerable recent discussion of the possible mechanisms of origin of sandy lagoon barriers (i.e., Shepard, 1960; Hoyt, 1967; Curray, Emmel and Crampton, 1969; Phleger, 1969). An early hyphotesis was that the lagoon barriers have formed by emergence of longshore submerged bars (De Beaumont, 1945; Johnson, 1919), and this is still considered by many to be the most probable explanation. Another explanation is that a lagoon barrier is built of sand from the surf zone piled by waves on a beach and with relative rise of sealevel the beach builds upwards by the same process (Phleger and Ewing, 1962; Hoyt, 1967), forming a lagoon on the landward side. If there is an abundant supply of sand the lagoon barrier will prograde seaward, and it may increase in height due to formation of dunes and/or formation of storm berms. The importance of longshore drift of sand is recognized by proponents of both hypotheses.

Many barriers are characterized by having multiple beach ridges, such as those at Huizache-Caimanero Lagoons in southern Sinaloa and fronting a part of Etchoropo Lagoon in Sonora. The possible significance of these multiple ridges has received little attention. In Nayarit, between the Baluarte and Santiago Rivers, Curray *et al* (1969) have suggested that the multiple ridges were formed as submerged longshore bars. In the Ojo de Liebre Lagoon area of Baja California the four beach ridges on the lagoon barrier are interpreted as berms formed during unusual storms (Phleger, 1965).

Many lagoon barriers do not have clearly defined multiple beach ridges, although such features are very common in other areas. They are always present, in our experience, where the barriers have prograded seaward for an appreciable distance and generally are not present where the barrier is narrow. It appears that multiple beach ridges occur only where there is an abundant supply of sand on a relatively stable coast. The source of sediment is both the relict sediment of the nearshore turbulent zone and also the sands being supplied to the nearshore zone by rivers. Multiple ridge barriers are very often associated with deltaic coasts, such as in both the present areas.

The association of multiple beach ridges and an abundant source of supply of sand is clearly shown in the Yavaros Lagoon area. They occur only in the western part of the barrier closely associated with the delta of the Mayo River, and it is obvious that the source of sand for their formation is in the delta. It is also apparent that their formation is a result of the combination of wave action and the longshore drift of sand. The barrier is relatively wide in this western area. It becomes very narrow toward the east, indicating a low supply of sand, and there are no multiple beach ridges.

It seems likely that as least three general processes may have contributed to the formation of multiple beach ridges, that different process may be dominant in different areas, and that a combination of them may operate in many places.

1. Beach ridges can develop by a combination of longshore drift and wave action extending a spit from an abundant source of sand.

2. We have not observed any clearly defined nearshore submerged bars fronting lagoon coasts in Mexico during extensive examination of them from low flying airplanes. It is posible, nevertheless, that such bars do develop with unusual wave conditions, such as during storms, or at places where they have not been observed.

3. It appears that the ridges can be formed on barriers as berms during unusual storms. Deposition of wind blown sand has increased the height of beach ridges above sea level in some places.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to the following persons and institutions for their valuable cooperation in this study: F. Mendoza Von Borstel, Director General de Grande Irrigación y Control de Ríos, Secretaría de Recursos Hidráulicos; A. Cortés, Coordinador de los Planes Piloto "Escuinapa y Yavaros", Secretaría de Recursos Hidráulicos; A. Ortega, Instituto de Biología, UNAM for his assistance collecting the samples; M. Gutiérrez and V. M. Malpica, Instituto de Geología, UNAM for their cooperation in part of the field work.

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