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THE MISSISSIPPI MARINE FISHERY

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INTRODUCTION

Mississippi's marine fisheries play a vital role in the economy of the state's coastal counties. This is not a recent circumstance - early colonists in this area also derived their livelihood by fishing and farming. Even before the colonists came, the Biloxi and Pascagoula Indians supported themselves in part by harvesting the locally abundant fish and shellfish. Then, as now, Mississippi's marine fishery is part of and is directly affected by what happens in the total world fishery.

Marine fisheries world wide yield more abundant harvests now than they did in the early days, not because of an increase in abundance of fishery resources, but primarily because of increased efforts.

WORLD FISHERIES

World landings in 1978, the most recent year for which data are available, were a record 72.4 million metric tons (2.205lb/MT)[a], almost 2 percent greater than the 1977 total of 71.2 million metric tons. Japan was the leading fishing nation with 15 percent of the total world landings; the USSR was second with 12 percent; China was third with 6 percent; and the U. S. was fourth with 5 percent of the total world fishery landings.

[a]All statistical data used in the preparation of the paper were taken from U.S. Department of Commerce, National Marine Fisheries Service, Statistical Digests Nos. 63-70, and current Fisheries Statistics Nos. 6721, 6921, 7190, 7456, and 7724. The 1979 landings data was supplied by Mr. Hermes Hague, Pascagoula, MS NMFS Laboratory.

U. S. FISHERIES

U. S. Landings for 1979 amounted to approximately 2.52 million metric tons (6.3 billion pounds) valued at $2.2 billion, up 4 percent in quantity and 20 percent in value compared with 1978, the previous record year. The U. S. marine recreational catch for this same time period was estimated to be 1.6 billion pounds of marine finsish, or about the same as the average amount of edible finfish landed by the commercial fishery in recent years.

GULF FISHERIES

Mississippi

The total commercial landings in the Gulf of Mexico in 1979 amounted to 2,128,903 pounds or 965,489 metric tons valued at $530,145,000. These landings account for about 34 percent of the total U. S. production of all marine fishery resources landed, but only account for 24 percent of the total value. The State of Mississippi landed 283,632,000 pounds, which was valued at $33,342,000 (Table 1). Mississippi ranked second in total volume of fishery products landed in the Gulf and fifth in value. The Port of Pascagoula - Moss Point, Mississippi ranked third in the nation and first in Mississippi in total volume of fishery products landed. A total of 209,888,000 pounds or 74 percent of all fishery products landed in Mississippi are landed in the Port of Pascagoula - Moss Point. These large landings are composed primarily of menhaden and industrial bottomfish. Mississippi has the highest volume of fishery products landed per mile of coast line of all the Gulf States. This amounts to 49,893,295 million pounds per mile of coast line.

Table 1. Volume and value of fishery products landed in the Gulf - 1979.

State	Volume	Value
Alabama	33,269,000	49,981,000
Florida	99,030,000	88,114,000
Louisiana	1,529,081,000	198,508,000
Mississippi	382,632,000	33,342,000
Texas	84,891,000	160,200,000
	2,128,903,000	530,145,000

GULF RECREATIONAL FISHERIES

Mississippi

The total recreational catch in the Gulf in 1979 was estimated to be 22,155,000 pounds. Gulf recreational fishermen spent an estimated $268,455,510 in catching these fish. The 1979 recreational harvest in Mississippi in 1979 amounted to 2,300,500 pounds and it was estimated that Mississippi recreational fishermen spent $8,774,400 in making that catch.

VOLUME AND VALUE

10-Year Mississippi Average

The data presented to date has dealt exclusively with 1979 because that is the most recent data set available from the National Marine Fisheries Service, the federal agency which collects, compiles and distributes this information. It is most interesting to analyze this data over long periods of time so that trends can be identified. The laboratory maintains a 10-year average. These figures are up-dated once each year and are published in *Marine Briefs,* a monthly publication of the Gulf Coast Research Laboratory.

You can see from Table 2 that the yearly landings in Mississippi have ranged from 188,642,000 in 1973 to 333,761,000 pounds in 1979 over the 10-year period 1970-1979. Menhaden account for 93.2 percent of the volume of all fishery resources landed in Mississippi. If the industrial ground fish data were included in the landings data, the industrial fish catch (menhaden, pet food) would account for an even larger percentage of the total landings. All other finfish (red fish, mullet, croaker, speckled trout, etc.) account for only 2.2 percent of Mississippi's total landings.

Menhaden account for 97.9 percent of the volume of all finfish landed in Mississippi while the Other finfish account for only 2.3 percent of all finfish landed (Table 3). Finfish account for 96 percent of all fishery products landed in Mississippi and the remaining 4 percent is composed of shellfish. Shrimp account for 74.7 percent of the volume of shellfish while oysters and crabs account for 8.8 and 15.7 percent respectively of all shellfish landed.

Finfish account for 56.3 percent of the value of the fishery products landed while shellfish account for 43.7 percent of the total value. The two most valuable fisheries in Mississippi are menhaden and shrimp which account for 45.9 percent and 38.8 percent respectively of the total value of all fishery resources landed (Table 4).

Table 2. Volume of Mississippi landings, 1970 to 1979 (thousands of pounds).

	Finfish[1]			Shellfish					
	Mehaden	Other*	Total	Shrimp (Heads On)	Oysters	Crabs	Other	Total	State Total
1970	205,980	4,654	210,634	9,604	548	2,027	212	12,391	223,025
1971	308,351	4,734	313,085	9,589	1,215	1,259	373	12,436	325,521
1972	178,273	4,837	183,110	7,951	1,220	1,362	191	10,724	193,834
1973	177,856	4,657	182,513	3,681	612	1,815	21	6,129	188,642
1974	215,674	5,119	220,793	5,316	277	1,667	–	7,260	228,053
1975	212,071	4,372	216,443	4,044	1,081	1,137	–	6,262	222,705
1976	180,152	11,386	191,539	7,551	1,561	1,335	–	10,403	201,942
1977	228,962	3,956	232,918	10,539	1,386	1,919	4	13,847	246,765
1978	298,992	4,657	303,649	8,286	682	1,942	2	10,912	314,561
1979	318,259	5,456	323,715	8,459	272	1,313	2	10,046	333,761

[1]Due to confidentiality laws, industrial (pet food) landings data are not included.
*Includes Spotted and White Sea Trout, Flounder, Red Drum, Red Snapper, Etc.
**Includes Spiny Lobster and Squid.

Table 3. Dockside value of Mississippi landings, 1970 to 1979 (thousands of dollars).

	Finfish[1]			Shellfish					
	Menhaden	Other*	Total	Shrimp (Heads On)	Oysters	Crabs	Other**	Total	State Total
1970	3,888	1,393	5,281	3,810	238	193	110	4,360	9,641
1971	4,823	1,181	6,004	4,261	473	126	336	5,297	11,301
1972	29,15	1,273	4,188	4,966	581	169	191	5,907	10,095
1973	8,789	1,427	10,216	3,698	366	231	21	4,316	14,532
1974	8,743	1,396	10,139	3,020	159	227	–	3,406	13,545
1975	6,067	1,460	7,527	3,825	534	177	–	4,536	12,063
1976	6,839	1,913	8,752	8,418	1,015	268	–	9,701	18,453
1977	10,298	1,405	14,321	10,079	1,156	413	1	11,709	26,030
1978	13,502	1,505	15,007	9,297	735	423	1	10,455	25,462
1979	13,013	1,837	14,850	15,382	256	316	1	15,953	30,803

[1]Due to confidentiality law, Industrial (Pet food) landing data are not included.
*Includes Spotted and White Sea Trout, Flounder, Red Drum, Red Snapper, etc.
**Includes Spiny Lobster and Squid.

Table 4. Ten-year average, 1970 to 1979 (percent volume and dockside value).

		Percent To Finfish			Percent Of Total	
		Volume	Value		Volume	Value
Finfish:	Menhaden	97.9	81.9		93.2	45.9
	Other	2.3	18.1		2.2	10.4
	Total Finfish	100.0	100.0	Subtotal	96.0	56.3
		Percent Of Shellfish			Percent Of Total	
Shellfish	Shrimp	74.7	88.2		3.0	38.8
	Oysters	8.8	7.2		0.3	3.2
	Crabs	15.7	3.3		0.6	1.4
	Other	0.8	1.3		0.1	0.3
	Total Shellfish	100.0	100.0	Subtotal	4.0	43.7
				Total	**100.0%**	**100.0%**

Source: U. S. Department of Commerce, National Marine Fisheries Service, Statistical Digest Nos. 63-67, and current Fisheries Statistics Nos. 6721, 6921, 7190, 7456, and 7724, Hermes Hague, Pascagoula NMFS, Supplied 1979 Landing Data.

FUTURE OF MISSISSIPPI FISHERIES

Introduction

In general, I see no great increase in Mississippi's marine fishery landings. I think that there will be a holding action in most fisheries in that we will all be striving to maintain our fisheries near their present levels through sound management and maintenance and where possible, improvement of our environment.

Oysters

Oyster production in Mississippi has drastically declined over the past several years. There have been several reasons for this decline, the most notable of which, all the frequent floods throughout the 1970s and two disasterous hurricanes in the last 12 years.

The state, with the help of federal funds, has underway a rehabilitation program for our oyster resources in Mississippi. By planting shell, both oyster and clam, in established oyster growing areas to improve and expand the reef bottom, and in planting new areas to increase overall oyster growing area in the state, and with no significant natural disaster in the next 18 months, oyster production should increase. By relaying seed oysters from closed areas to the newly replanted areas, these new areas should come on line very quickly. A good example of the potential of this type program is the "White House" relay reef and the newly planted area to the west of the relay reef. The new area was planted with clam shells in June 1980. A good spat set was noted almost immediately and by January 1981, a significant population of oysters was in evidence. These oysters should be ready to harvest in the fall of 1981. If this type of public program is continued with the cooperation of all the oyster industry, then oysters will once again be a viable crop in Mississippi, although it will never hold the prominence that it once held.

A second aspect in the rehabilitation of the oyster industry, is the change in the laws which regulated the leasing of state owned water bottoms to private individuals for growing oysters. Although there have been interesting innovations in relaying and recovering oysters, I do not yet see any significant impact on increased production of oysters as a result of this program.

Shrimp

The shrimp landings in Mississippi have exhibited a steady decline since the record catch of 10,539,000 pounds in 1977 to approximately 5,923,000 pounds in 1980. During the period 1971 through 1980, landings in Mississippi have ranged from the all time high of 10,539,000 pounds in 1977 to a low of 3,681,000 shrimp landed in 1973. Coupled with this decline has been a astronomical increase in the cost of fuel and supply costs increases have made shrimping a marginal business at best.

The prediction as of this writing is that there will be a good to excellent shrimp harvest in 1981 in terms of the pounds landed. The high cost of fuel and other supplies coupled with a reduced demand will again make shrimping a marginal business. As of December 1980, there were 70,535,000 pounds of shrimp in cold storage across the country. This included 30,167,000 pounds of raw, headless, 4,763,000 pounds of breaded, 18,384,000 pounds of peeled, and 17,221,000 pounds of unclassified shrimp. Generally these are large size shrimp which command high prices, therefore, in 1981 the shrimp most in demand will be the smaller lower priced shrimp. Therefore, I would not look for the high prices seen in 1979. The general public quits buying shrimp when the price goes out of sight. In the past, institutional sales have taken up the slack and will continue to do so, but not to the degree needed to hold up the price at 1979 level.

Imports will continue to be a problem particularly from Mexico. I do not look for the federal government to impose a tariff on imported shrimp.

Edible Finfish

This category includes most of the species that are taken by both recreational and commercial fishermen and is the group around which much controversy revolves here in Mississippi and along the Gulf coast. Included here are the speckled trout, white trout, flounder, red fish, red snapper, etc. The total catch per year over the last 10 years has ranged from a low of 3,956,000 pounds in 1977 to a high of 11,386,000 pounds in 1976. Yearly fluctuations within each group are great each year, but the overall average has remained fairly stable over the years. Increases in mullet landings are expected to increase in the near future.

Crabs

Projected Gulf landings for hard bule crabs in 1980 indicate a production of 40 million pounds with an ex-vessel value of $8.7 million. While production in Louisiana remains the most influential factor in the Gulf region, Texas landings have steadily increased and are estimated to approach 10 million pounds in 1980. The fishery in Mississippi has remained relatively stable with average yearly landings of 1,570,833 pounds for the 10-year period from 1970-1979. Yearly landings during this period varied from a high of 2,027,430 pounds in 1970 to a low of 1,136,600 pounds in 1975. Landings approaching 2,000,000 pounds were recorded in 1977 and 1978.

Prediction of year class strength, based on the abundance of juveniles in the estuary, is complicated by the protracted spawning of blue crabs and the migratory nature of the fishery in Mississippi. Because blue crabs spawn from early spring through late fall, post-recruitment individuals are found on estuarine nursery grounds throughout the year. The year-round presence of these newly recruited juveniles does not easily allow for identification of distinct year classes upon which predictive capabilities can be developed. In the fishery itself, rises in the CPUE and landings generally follow the arrival of crabs in Mississippi Sound from adjacent waters. Peaks are associated with the fall-winter arrival of mature females from Lakes Pontchartrain and Borgne and the summer arrival of mature females from the Gulf. The overwintering area and the initial point of origin for this latter group of crabs has not been established and it is probable that these crabs represent stocks from neighboring states. Because adult blue crab populations are not restricted by state boundaries and move freely through the waters of the north central Gulf, a regional approach to solving the problems associated with the estuarine monitoring of juveniles must be implemented in order to develop predictive capabilities.

Menhaden

As pointed out earlier, menhaden are our most valuable finfish in Mississippi both in volume of pounds caught and in value.

Annually the Gulf produces about 65 percent of the U. S. landings of menhaden. Mississippi annually produced approximately 20 percent of the Gulf catch. Most of the fish meal produced from menhaden is consumed in Mississippi. It is used as a protein source in both catfish and poultry feeds.

The menhaden fleet has remained relatively stable in the Gulf over the past several years. Predictions are for another good year in the Gulf in 1981 for menhaden.

Industrial Bottomfish

There are no data available on the landings of the industrial bottomfish fishery because there are only two plants operating in Mississippi and federal confidentiality laws prohibit the publication of that information.

FISHERY MANAGEMENT

In 1976, the U.S. Congress passed Public Law 94-265 entitled, "Fishery Conservation and Management Act." This Act established the 200-mile fishery zone off the U.S. Coast and established Regional Fishery Management councils in all regions of the country to manage the fishery resources in what is known as the Fishery Conservation Zone (FCZ). The FCZ is the area from the states territorial seas out 200 miles. The state territorial sea is the area from the shore outward to three miles. A third category, inland waters, are those waters within a state's boundaries.

The Management Councils (in the Gulf-Gulf of Mexico Fishery Management Council) are charged with managing the FCZ, the states are charged with managing the territorial seas and their internal waters. There is also a provision in the Law which allows the Management Council to preempt the state's authority in territorial seas if they find that the states are managing their resources contrary to that of the Council. In Mississippi, this would mean that the Gulf Council could manage our fishery resources up to the mainland beaches if they deemed it necessary. Therefore, two things in my opinion need to take place in Mississippi. The first is to continue the flexible management system we now have in Mississippi waters and second, to establish through the courts, the Mississippi southern boundry as a line across the barrier island passes. This would allow Mississippi Sound to be reclassified as internal waters thus allowing the state to manage the fishery resources in response to local needs.

CONCLUSION

The Mississippi Marine fishery industry, both recreational and commercial, is a vital portion of the economy of the three coastal counties and of the State of Mississippi. Currently, it is a healthy industry with one major exception - the shrimp industry. The overall catch in 1981 should be good and the prices good, but operating costs will continue to be high.

MARSHES OF MISSISSIPPI SOUND: STATE OF THE KNOWLEDGE

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INTRODUCTION

Marsh ecosystems of Mississippi Sound provide both unique habitats and a relatively limited resource to the states of Alabama and Mississippi. Originally located along all protected shorelines of the mainland and the leeward shores of the barrier islands, their areal coverage and, thus, functional value have been reduced as pressures to utilize coastal lands have increased. Marshes serve many functions vital to man and coastal ecosystems. Of primary importance is their role in providing a rich and abundant food source to estuarine and coastal food chains (Cruz, 1973). Marshes serve as a protected, nutrient rich, living space for young and juveniles of many animals, and breeding and spawning areas for others. A positive correlation between commercial yields of penaeid shrimp per unit area of intertidal marsh and latitude has been demonstrated for 27 worldwide locations (Turner 1977). Densely vegetated, relatively flat, expanses of marshes are quite successful in sediment binding and erosion control and serve to help dampen the energies and water volumes of storm surges. Additionally, marshes play important roles in water quality and quantity, removing nutrients and toxic materials from the water and regulating flows (Banus et al. 1974; Pomeroy et al. 1966).

Although the quantitative evaluation of each of these functions is difficult to assess, their importance is, nevertheless, without question. To assure continued performance of these and other roles, marshes must be protected from destruction and deterioration by wise management. The effects of each potential activity on marsh tracts must be understood. In the event that natural conditions must be allowed to deteriorate, plans must exist to ameliorate the situation or restore previous functions to the system.

GENERAL DESCRIPTION AND DISTRIBUTION

The marshes characteristic of Mississippi Sound and the north central coast of the Gulf of Mexico are primarily irregularly flooded marshes, built on deltaic plain sediments deposited by a number of fairly large coalescing river systems. The Gulf Coast marshes in general lack any relief features with most areas lying only slightly above mean Gulf level (Chabreck 1972).

The occurrence, areal coverage and community composition of marshlands depends upon several environmental parameters including tidal range, shoreline elevation, sediment sources, topography and salinity of flooding waters. For example, major areas of the Mississippi Sound marshes are characterized by the patchy distribution of several mixed species of vascular vegetation due to localized variations in soil and/or water regimes. Banks of tidal bayous and creeks are usually vegetated with the halophytic *Spartina alterniflora* rather than the dominant, but less salt tolerant, *J. roemerianus*. Human alterations of marshlands, such as dredging, filling, and drainage have significantly affected the distribution and size of coastal wetlands.

Within Mississippi marshes are found in four estuarine systems - the Pearl River, St. Louis Bay, Biloxi Bay and the Pascagoula River, as well as on the larger barrier islands - Horn and Petit Bois. Most of the marshes are now confined to the interior shorelines of each of these estuaries and their tributaries, with the only significant marshes remaining, on the northern sound shores, at the mouth of the Pascagoula River and around Point aux Chenes Bay on the Alabama line (Figure 1). The larger estimate of Eleuerius (1973) includes the barrier islands. Greater acreage is found in Jackson (34,000 acres) and Hancock counties (22,000 acres) with only 8,000 acres located in Harrison county (Wicker, 1980).

Protection provided by nearshore Dauphin Island, ample sediment replenishment from Mobile Bay and minimal shoreline activity have resulted in Alabama in a continuous band of marshes along the northern shore of Mississippi Sound. Though Crance (1971) has defined the entirity of the Sound as an estuary in Alabama, Heron Bay, Fowl River Bay, Portersville Bay, and Grand Bay exhibit some degree of physical separation from each other, but have relatively unrestricted interaction with Mississippi Sound. Approximately 12,184 acres (4,933 hectares) of tidal marsh are located along their shores (Table 1). An additional 1,077 acres (436 hectares) of marshland borders Mississippi Sound on Dauphin Island, for an Alabama total of 13,261 acres (5,369 hectares) (Figure 1).

Within the two states there are approximately 76,761 acres (31,077 hectares) of marshes.

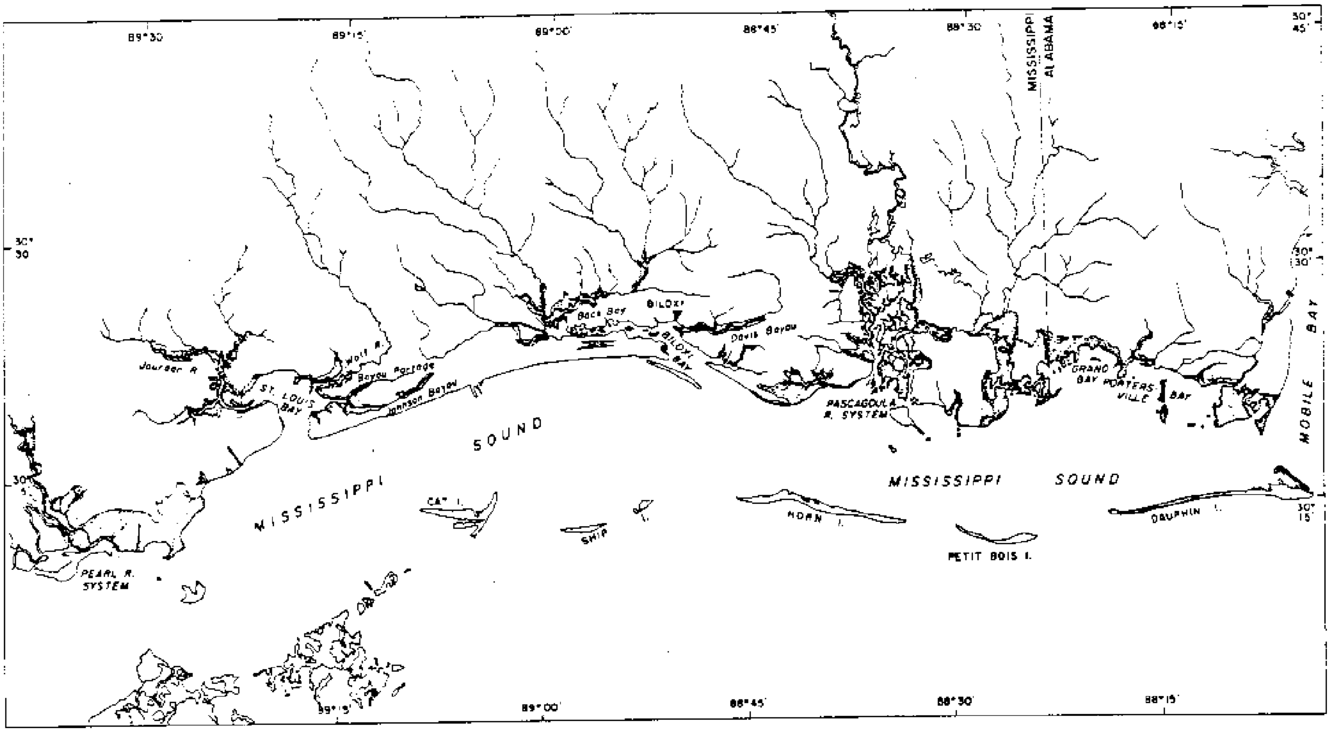

Figure 1. The marshes of Mississippi and Alabama.

Table 1. Marsh acreage of Mississippi Sound, as estimated by various authors.

Source	Location	Area Acres (Hectares)
1. Eleuterius 1973	Mississippi Mainland	61,398 (24,858)
	Mississippi Barrier Islands	2,126 (861)
	TOTAL	66,108 (26,764)
2. Wicker 1980	Jackson County, MS	34,000 (13,765)
	Hancock County, MS	22,000 (8,907)
	Harrison County, MS	8,000 (3,239)
	TOTAL	63,500 (25,709)
3. Stout & Lelong 1981	Fowl R. Bay/Heron Bay, AL	7,949 (3,218)
	Portersville Bay, AL	1,554 (629)
	Isle aux Herbes, AL	693 (281)
	Grand Bay, AL	1,988 (805)
	Dauphin Island, AL	1,077 (436)
	TOTAL	13,261 (5,369)

STRUCTURAL ASPECTS

Soil

The marsh soil grades from generally sandy (e.g., in the Barrier Island marshes) to silty with a thin surface layer of muck. Texture analysis done by Humphrey (1979) on muddy inshore marsh substrate revealed the following components: 24-28% sand, 40-48% silt, and 24-36% clay. Soil organic content ranged from 5 to 13%. pH values were about 5.3-5.9 in areas dominated by *S. cynosuroides* and 6.2 in *Juncus* marshes (Hackney and de la Cruz, 1978; and Faulkner and Cruz In Press). Free-soil water salinity ranged from 2.5 to 16.8ppt (Hackney and de la Cruz 1978) and may get to about 20ppt during prolonged dry periods.

The chemical composition of surface and subsurface sediments of a *Juncus* and a *Spartina cynosuroides* marsh is summarized in Tables 2 and 3. Both types of marshes showed similar orders of relative abundance of nutrient elements (N > Mg > Ca > K > Mn > P > Zn) in surface and subsurface soils.

Flora

Vascular Macrophytes. Four marsh types, as described in Table 4, are found in Mississippi Sound and its tributaries. Most marsh communities of the Sound are of the saline type with brackish, intermediate and freshwater marshes located primarily along the tributary streams. The marsh types represent a salinity continuum from marine waters through combined tidal and riverine influence to completely river water flooding the marshes. Along this continuum from salt to fresh is an increase in species diversity within the marshes and reduced species dominance.

Table 2. Chemical composition of surface (0-2 cm) and subsurface (2-10 cm) sediments of a *Juncus* dominated marsh community. Values are means of 5-6 replicates expressed in $\mu g\ g^{-1} \pm$ standard deviation; numbers in parentheses are per cent coefficient of variation.

Parameter	Surface (0-2 cm)	Subsurface (2-10 cm)
P	23.0 ± 4.0 (17.4)	27.0 ± 4.0 (14.8)
K	409.0 ± 18.0 (4.4)	418.0 ± 41.0 (12.2)
Ca	1277.0 ± 208.0 (16.3)	847.0 ± 226.0 (26.7)
Mg	1959.0 ± 212.0 (10.8)	1515.0 ± 246.0 (16.2)
Mn	145.0 ± 35.0 (24.1)	48.0 ± 33.0 (68.8)
Zn	8.6 ± 0.5 (6.0)	6.2 ± 1.7 (26.9)
N	5400.0 ± 770.0 (14.3)	2580.0 ± 690.0 (26.7)

Table 3. Chemical composition of surface (0-2 cm) and subsurface (2-10 cm) sediments of a *Spartina* dominated marsh community. Values are the mean of 5-6 replicates expressed in $\mu g\ g^{-1} \pm$ standard deviation; numbers in parentheses are the percent coefficient of variation.

Parameter	Surface (0-2 cm)	Subsurface (2-10 cm)
P	26.0 ± 3.0 (11.5)	23.0 ± 2.0 (8.7)
K	446.0 ± 23.0 (5.2)	385.0 ± 16.0 (4.2)
Ca	925.0 ± 71.0 (7.7)	672.0 ± 0.0 (0.0)
Mg	1708.0 ± 67.0 (3.9)	1364.0 ± 31.0 (2.3)
Mn	92.4 ± 37.3 (40.2)	61.6 ± 37.0 (59.7)
Zn	5.5 ± 1.7 (30.9)	5.5 ± 0.3 (5.4)
N	4740.0 ± 370.0 (7.8)	3610.0 ± 790.0 (21.9)

Of all species found, *Juncus roemerianus* is the most widespread being highly euryhaline (Eleuterius 1978). This single plant dominates approximately 72% and 76% of Mississippi Sound marshes in Alabama and Mississippi, respectively (Table 5). Only four other species, *Spartina alterniflora*, *S. patens*, *Distichlis spicata* and *Scirpus olneyi*, are found to dominate significant acreage of marshes on the Sound. Eleuterius and McDaniel (1978) identified 173 species which occur in the marshes of Mississippi; as many as 40 species occur in one locality (Hackney and de la Cruz In Press$_b$).

Benthic Algae. Sage and Sullivan (1978) describe a single nearly homogeneous community of blue-green algae throughout the coastal marshes of Mississippi. This community, including 25 species, is restricted to open areas within the otherwise dense overstory of spermatophytes. *Schizothrix calcicola* is found to dominate all marshes with two co-dominant species (Table 6).

Diatoms have been shown to exhibit a continuous benthic marsh cover, with or without spermatophyte cover, and to have slight variations in community composition related to spermatophyte community types (Sullivan 1978). Of 119 taxa identified, *Navicula tripunctata* is the most abundant species (Table 6). The greatest number of species (89) are found in stands of *Distichlis spicata* and the lowest species numbers (79) in *Juncus roemerianus*. Only 7 species are restricted to a single spermatophyte type.

Multicellular algae that inhabit the Mississippi Sound marshes are poorly known. Pecora (1978) described two species of *Vaucheria* (Xanthophyceae) from just one collection from a marsh in St. Louis Bay. One species, *Vaucheria adela*, was only known from the type specimen before Pecora's report. Such are usually found along the banks of creeks or in areas disturbed by fires. At times *Spyrogira spp.* attain great importance in the small tidal creeks and other slow moving aquatic situations. During one wet period in 1979 a green alga, *Chaetomorpha linum* became very abundant, literally covering a 10 x 30 m area that had been cleared the previous winter. The presence of other algal genera, *Mougeotia*, *Lyngbya*, *Merismopedia* and even a member of the red algae, *Compsopogon coerulens* (T. Dale Bishop, Personal Communication) attest to the need for more reserach on this aspect of the brackish marsh flora. We can only speculate on the trophic importance of such algae. Likewise, no data area available on the productivity or trophic role of diatoms or blue-green algae.

Table 4. Characteristic dominant plants of marsh types represented in Mississippi Sound. Compiled from Stout (1981), Sapp, et al. (1976), and Eleuterius (1972, 1973).

Marsh Type	Scientific Name	Common Name	Comments
Saline Marsh	*Juncus roemerianus*	Black Needlerush	1. Low diversity
	Spartina alterniflora	Smooth Cordgrass	2. Great homogeneity of stands
	S. patens	Saltmeadow Cordgrass	
	S. cynosuroides	Giant Cordgrass	
	Distichlis spicata	Salt Grass	
	Salicornia spp.	Saltworts	
	Scirpus olneyi	Three-square	
	S. robustus	Leafy Sedge	
Brackish Marsh	*Juncus roemerianus*		
	Spartina alterniflora		1. Greatly diminished
	S. cynosuroides		2. Greater abundance
	S. patens		3. Greater abundance
	Limonium caroliniana	Sea Lavender	4. *D. spicata* and *Salicornia* spp. *absent.*
	Scirpus olneyi		
	Sagittaria latifolia	Arrow Leaf	
Intermediate Marsh (Brackish II of Stout, 1981)	*Juncus roemerianus*		1. Absence of *S. alterniflora, S. patens, S. cynosuroides, Scirpus olneyi* and *S. robustus*
	Phragmites australis	Roseau Cane	
	Cladium jamaicense	Saw Grass	
	Scirpus validus	Bullwhip	
	Iris virginica	Blue Flag	2. Increased diversity
Fresh Marsh	*Phragmites australis*		1. Absence of *J. roemerianus*
	Sagittaria lancifolia		2. Greater diversity
	Eleocharis sp.	Spike Rush	3. Great heterogeneity of stands
	Scirpus validus		
	Zizania aquatica	Wild Rice	
	Typha sp.	Cattails	
	Alternanthera philoxeroides	Alligator Weed	

Table 5. Contribution of dominant plant species to marshlands of Mississippi Sound.

Location	Species	Percentage Dominance	Area Covered	Source
Alabama	*Juncus roemerianus*	71.5	9,489 (3,842)*	Sapp et al. 1976
	Spartina alterniflora	13.0	1,725 (698)	
	S. patens	4.5	593 (240)	
	Distichlis spicata	6.6	876 (355)	
Mississippi	*Juncus roemerianus*	96.0	61,398 (24,858)	Eleuterius 1972
	Spartina alterniflora	3.0	2,028 (821)	
	S. patens	0.7	460 (186)	
	Scirpus olneyi	0.1	96 (39)	

*Acres (hectares)

Table 6. Dominant algal species of Mississippi Sound marshes.

Group	No. of Taxa	Dominant Species	Source
Blue-green	25 species	*Schizothrix calcicola* *Anacystis montana* *Anacystis aeruginosa*	Sage & Sullivan 1978
Diatoms	119 species	*Navicula tripunctata* *Nitzschia pseudoamphioxys* *Navicula salinicola*	Sullivan 1978

Fauna

Insects. The insect populations of a *Juncus* dominated marsh have been studied by Parsons (1978). Two hundred sixty five species representing 72 families and 9 orders were collected using standard sweepnet techniques. Only 4 Diptera, 1 Hymenoptera, and 1 Hemiptera were collected consistently throughout the year. Two seasonal peaks in insect diversity were found, one in May and the other in September (Parsons 1978). The spring peak coincided with the time when there were large quantities of fresh, new vegetation. The second peak occurred when the senescence of most marsh vegetation began.

Three species of conocephaline grasshoppers (Tettigoniidae) were the major insect herbivores grazing on the leaves of *J. roemerianus*. They ingested 104.6 kj m^{-2} of the above ground production of *Juncus*. Practically all the grazing occurred in the summer and was localized on the distal portions of the *Juncus* leaves. Following the grazing season, the distal portion of the leaves die and may fall to the marsh floor representing the early addition of 245.7 kj m^{-2} yr^{-1} of *Juncus* material to the heterotrophic food chain (Parsons and de la Cruz 1980).

Macrofauna. Humphrey (1979) in a 12-month study of 5 experimental stations along a 264 m transect across a marsh island in Mississippi found that the macrofauna inhabiting the marsh was dominated by mollusks, arthropods, and nematodes. Densities of organisms were generally higher and exhibited a bimodal pattern of abundance in the more flooded marsh zones. The infauna was most abundant in January and July. This seasonal pattern became less obvious in areas of the marsh where flooding did not regularly occur (Humphrey 1979). These areas are subject to long periods of desiccation, thus normal recruitment patterns are obscured. Diversity values were highest at the most flooded station; lower and more variable diversity characterized the less flooded areas. The dominant macrofaunal component of the marsh soil was the Carolina marsh clam, *Polymesoda caroliniana* (Duobinis-Gray and Hackney, In press). This clam was found throughout the marsh, in regularly flooded as well as poorly flooded areas in Mississippi. The largest population was found in an area flooded 12% of the time, 136 individuals per square meter, and in an area flooded only 3.2% of the time, 126 clams per square meter. Smaller populations numbering only 68 clams per square meter were found in a permanently flooded area. Only juvenile clams and no adults were collected from the less flooded areas. The high average density was due to large numbers of juveniles which would take advantage of wet periods and then die after the marsh remained dry for a long period of time. Juvenile clams that settled in the more flooded areas of the marsh were prey of several abundant decapods such as the blue crab, *Callinectes sapidus*. Clams larger than 15 mm were able to withstand decapod predation and long periods of desiccation. The average abundance of clams on the study marsh was 100 per square meter.

In Alabama, Ivester (1978) found oligochaete worms dominating the macrofaunal communities of *Spartina alterniflora, Juncus roemerianus* and *Distichlis spicata*, although their percentage contribution varies between communities. Other abundant forms comprised significant differences in community composition, particularly bivalve and snail species. Overall diversity and abundance were low compared to other marine habitats. The fauna represented only a few highly specialized forms (Ivester 1978).

Meiofauna. Composition of meiofaunal communities have been examined within stands of *Spartina alterniflora* and *Juncus roemerianus* in Alabama (Harp 1980). Nematodes dominated both communities, though there were differences in species composition and dominance between communities (Table 7).

The meiobenthic community in the Mississippi marsh did not show the same pattern of density and diversity as the macrofauna, and all areas of the marsh (poorly flooded and well flooded) had a high degree of similarity with respect to meiofauna. Lowest densities occurred during winter, with higher densities occurring in the spring and the summer. The most abundant components of the meiofaunal community were nematodes, harpacticoid copepods, and foraminifera (Humphrey 1979).

Ichthyofauna. The marsh community is closely associated with the aquatic community in the small tidal creeks that drain the marsh. Most of the organisms inhabiting the marsh have aquatic larvae and during periods of high water, many of the aquatic species move onto the marsh in search of food, or to avoid predation. Hackney (1977) collected 30 species of fish and six decapod crustaceans from a small tidal creek in a *Juncus* marsh in Mississippi (Table 8). The number of organisms in the creek was highest in late spring and in early winter. Animal biomass, however, was relatively constant except during winter when it was at its lowest. There was, generally, a large month-to-month fluctuation of the biomass component. The patterns of fluctuation seemed poor until the resident species were separated from the non-resident animals. Resident species are defined as organisms that spend all or most of their life cycle in and near the marsh, e.g., *Palaemonetes pugio* (grass shrimp), *Fundulus grandis* (gulf killifish), *F. confluentus* (marsh killifish), and *Lucania parva* (rainwater killifish). Non-resident species which dominated the marsh during the summer are those which exhibit a life-cycle with juvenile stages requiring the marsh environment and adults living in the marine waters offshore. Such species include the penaeid shrimps, members of the sciaenid fishes, and *Brevoortia patronus* (gulf menhaden). Another group of fish occurring in these brackish marshes is the sunfish family (Centrarchidae) which was the dominant ichthyopredator during the summer months (Hackney and de la Cruz 1981). For example, the largemouth bass, *Micropterus salmoides* fed voraciously on large numbers of the marsh fiddler crab, *Uca longisignalis*. The diversity of the aquatic community is further enhanced by the presence of typically marine, but euryhaline species such as the goby family (Gobiidae), the jack (Carangidae), and needlefish (Belonidae).

Table 7. Dominant meiofauna and macrofauna of *Juncus roemerianus*, *Spartina alterniflora*, and *Distichlis spicata* marshes on Mississippi Sound.

Marsh Type	Meiofauna[1]	Macro-Fauna[2]
Spartina alterniflora	*Microarthridion littorale* *Enhydrosoma propinquum*	Oligochaeta (80%) *Nereis succinea* *Littorina irrorata* *Neritina reclivata* *Geukensia demissa* *Uca sp.*
Juncus roemerianus	*Nanopus palustris* *Schizopera sp.*	Oligochaeta (54%) *Nereis succinea* Unident. Capitellidae *Melampus bidentata* *Polymesoda caroliniana* *Uca sp.*
Distichlis spicata		Oligochaeta (53%) *Neretina reclivata* *Melampus bidentata* *Uca* sp. *Orchestia grillus* Unident. Capitellidae

[1] From Harp 1980.
[2] From Ivester 1978.

Table 8. Fishes collected in a tidal creek draining a marsh in St. Louis Bay, Mississippi. Fish considered freshwater fish are followed by an (F), brackish fish by (B), and marine fish by (M). (From Hackney and de la Cruz, 1981).

Lepisosteus oculatus (f)	spotted gar	*Lepomis macrochirus* (F)	bluegill sunfish
Anguilla rostrata (F, B, M)	american eel	*L. microlophus* (F)	redear sunfish
Brevoortia patronus (B, M)	gulf menhaden	*Micropterus salmoides* (F)	largemouth bass
Anchoa mitchilli (B)	bay anchovy	*Oligoplites saurus* (M)	leatherjacket
Synodus foetens (M)	inshore lizardfish	*Archosargus probatocelphalus* (B,M)	sheepshead
Ictalurus punctatus (F)	channel catfish	*Cynoscion arenarius* (B,M)	sand seatrout
Arius felis (B, M)	sea catfish	*C. nebulosus* (B,M)	spotted seatrout
Stronglyura marine (B, M)	atlantic needlefish	*Leiostomus xanthurus* (B,M)	spot
Adinia xenica (F, B)	diamond killifish	*Mugil cephalus* (F,B,M)	striped mullet
Cyprinodon variegatus (F, B, M)	sheepshead killifish	*Eleotris pisonis* (B,M)	spiney sleeper
Fundulus confluentus (B)	marsh killifish	*Evorthodus lyricus* (B,M)	lyre goby
F. grandis (B)	gulf killifish	*Gobiosoma bosci* (B,M)	naked goby
Lucania parva (F,B)	rainwater killifish	*Microgobius thalassinus* (B,M)	green goby
Membras martinique (B)	rough silverside	*Achirus lineatus* (F,B,M)	lined sole
Syngnathus louisianae (B,M)	chain pipefish		

FUNCTIONAL ASPECTS

Life History

Elucidation of the role of a species within a community is not possible without a thorough understanding of its life history. Marshes of Mississippi Sound have been the primary source and the experimental sites of an extensive taxonomic revision and life history study of *Juncus roemerianus* (Eleuterius 1978). Populations of both perfect flowered (bisexual) plants and pistillate plants have been identified. A single rhizome produces only one flower type though mixed stands derived from more than one plants may be seen (Eleuterius 1974b).

Juncus seeds have a significant requirement for light relative to germination. Though plants may reach maturity in 12 months, a single rhizome may live for 3 years continuously producing culms. This creates a dense canopy with openings occurring only where older rhizomes in the center have died and the plant rhizomes fragment into separate younger portions of the plant. Sexual reproduction, therefore, is significant only in recolonization of these well-lit open pockets or in colonization of unpopulated new areas (Eleuterius 1975).

Primary Productivity

The most thoroughly examined aspect of marsh function is primary production by the aboveground portion of spermatophyte communities. Results in Mississippi Sound are summarized in Table 9. Saline and brackish marsh species have received most of the attention, especially *Juncus roemerianus* and *Spartina alterniflora*. Highest productivity levels are seen in dense *Juncus* (up to 3 kg m^{-2} yr^{-1}). *Spartina alterniflora*, the most frequently studied species elsewhere, grows as the short form over most of the Sound marshes because of factors related to low tidal amplitude. Levels of productivity are not, therefore, as high as reported in marshes of the east coast dominated by tall forms of the species. Most species within Mississippi Sound

Table 9. Summary of estimates of primary productivity for the marshes of Mississippi Sound. Locations include: Dauphin Island, AL (DI), Point aux Pins, AL (PAP), Bay St. Louis, MS (BSL) and Bayou Casotte, MS (BC).

		PRIMARY PRODUCTION (kg m^{-2})		
Species	Location	Above Ground	Below Ground	Source
Spartina alterniflora	DI	0.66-2.03*	3.60 (x)	Stout 1978a
	BC	1.96 tall (H)		Cruz 1974
	BC	1.09 short (H)		Cruz 1974
	DI	0.01-0.02 (PPM)	3-7 (SC)	Hackney, et al 1978
S. cynosuroides	BSL	2.90 (H)		Cruz 1974
	BSL	0.48 (H)		Gabriel & de la Cruz 1974
	BSL	1.74-2.86 (PPM)	6-9 (SC)	Hackney et al. 1978
S. patens	BSL	1.92 (H)		Cruz 1974
	BSL		5-8 (SC)	Hackney et al 1978
Juncus roemerianus	DI	1.18-3.08*	4.56 (x)	Stout 1978a
	BSL		1.36 (PPM)	Cruz & Hackney 1977
	BSL	1.70 (H)		Cruz 1974
	BSL	0.39 (H)		Gabriel & de la Cruz 1974
	BSL	0.58-0.75 (PPM)	5-7 (SC)	Hackney et al 1978
	DI	0.06-0.46 (PPM)	2-4 (SC)	Hackney et al 1978
		2.00		Eleuterius 1972
Distichlis spicata	BC	1.48 (H)		Cruz 1974
	BSL	0.06 (H)		Gabriel & de la Cruz 1974
	PAP	0.01 (PPM)	1-3 (SC)	Hackney et al; 1978
Scirpus robustus	BSL	1.06 (H)		Cruz 1974
S. olneyi	BSL	0.07 (H)		Gabriel & de la Cruz 1974
Phragmites australis	BSL	2.33 (H)		Cruz 1974

*Range of estimates for 4 methods of calculation.
H = Harvest Method of Milner and Hughes 1968
PPM = Predictive Periodic Model of Hackney and Hackney 1978.
SC = Standing Crop.
x = Annual Mean.

produce new biomass throughout the year, and have annual productivity rates similar to, or greater than, other geographic areas, though peak standing crops are often lower.

Comparison of amino acid and protein content of several marsh species demonstrate higher levels in *Juncus roemerianus*, a C_3 species, than in C_4 species examined (i.e., *S. alterniflora*, *S. cynosuroides*, *S. patens* and *Distichlis spicata)*. This may imply a potential herbivore preference for this more nutritious species and certainly indicates a large pool of high-quality food material as a result of its high productivity and extensive coverage (Cruz and Poe 1975a).

Recent initial efforts have provided information on the significance of belowground primary production of marsh plants. Standing crop levels of belowground biomass may be 2-3 times greater than aboveground levels (Table 9). Stout (1978b) found that on a yearly average 71% and 75% of production was attributable to belowground biomass for *Juncus* and *S. alterniflora*, respectively. Most of the belowground biomass is in the upper 20 cm of the substrate, with the 0-10 cm portion comprising up to 80% of the 20 cm total. This represents a nutrient source not yet assimilated into models of marsh function, but could be of potential significance.

Decomposition and Detritus Formation

Great variability exists in the decomposition of different marsh plants due to differences in tissue make-up and environmental conditions where the species occur. Dead leaves and stems of *Spartina alterniflora* break down most rapidly with up to 86% loss in a year (Table 10). Occurring in or near the intertidal areas, this provides an almost annual turnover of plant production to detritus by this species.

Other species studied have decomposition rates of 50% or lower, loss per year. Higher, drier marsh species, *S. patens* and *Distichlis spicata* are slow to decompose, losing 36% and 38% respectively.

Belowground biomass has much slower decomposition rates than aboveground rates for the same species. Faster decomposition in the upper 10 centimeters of substrate is demonstrated for all species except *Spartina alterniflora*. Greater aeration within this layer creates more favorable conditions for decomposing biota. A maximum of 25% loss is seen for *Juncus roemerianus* in the top 10 centimeters with a minimum loss of 8% in the lower 10 centimeters for *J. roemerianus* and *S. cynosuroides* (Hackney and Cruz 1980).

Analysis of dead, decomposing and detrital tissues of marsh species indicates several general patterns of composition changes during decomposition: (1) increase in amino acids and/or proteins; (2) retention or increase in caloric contents; (3) decline in crude fiber, carbohydrates, fats and organic content; and (4) increased respiration (Cruz 1975; Cruz and Poe 1975b; Cruz and Gabriel 1974; and Brown et al., 1978). All of these imply a rich nutrient source, readily assimilable to detritivores.

Organic Transport and Food Chain Dynamics

High primary production, rapid rate of decomposition, efficient formation of marsh plant detritus, and import of allochthonous organic materials characterize the fertility of estaurine and coastal systems. The actual linkages in the marsh-estuary food web have not been demonstrated, but information is becoming available which indicates some of the possible mechanisms and pathways of energy and nutrients.

Freshwater outflow from the major rivers into the Mississippi Sound estuary produces variably low salinity conditions and transports large quantities of carbon. Post and de la Cruz (1977) found that the Jourdan River, for example, transported 688,290 kg yr^{-1} of particulate organic matter into St Louis Bay estuary. They estimated that this transport could be as much as 920,517 kg yr^{-1} or as little as 450,061 kg yr^{-1} depending upon rainfall and tides. This particulate carbon is of terrestrial origin from forests that surround the numerous small streams which flow into the Jourdan River (Cruz and Post 1977).

Table 10. Summary of decomposition rate determinations for marsh plant species of Mississippi Sound. Locations include: Dauphin Island, AL (DI), Point aux Pins, AL (PAP) and Bay St. Louis, MS (BSL).

Species	Location	PERCENTAGE LOSS/YR. Above Ground	Below Ground (Depth)	Source
Spartina alterniflora	DI	86	14(0.10 cm)	Stout & Cruz 1981
	BSL	52	31(11-20 cm)	Cruz 1973
S. cynosuroides	BSL	26	21(0-10 cm) 8(11-20 cm)	Hackney & Cruz 1980
S. patens	BSL	36		Stout & Cruz 1981
Juncus roemerianus	DI	44	25(0-10 cm) 22(11-20 cm)	Stout & Cruz 1981
	BSL	48	18(0-10 cm) 8(11-20 cm)	Hackney & Cruz 1980
	BSL	40		Cruz & Gabriel 1974
Distichlis spicata	PAP	38		Stout & Cruz 1981
	BSL	38		Cruz 1973
Scirpus americanus	BSL	60		Cruz 1973

Hackney (1977) quantified the flux of suspended organic detritus, floating debris and animal biomass over both diurnal and semidiurnal tidal periods in a small tidal creek in Bay St. Louis. His results indicate (1) a net export of floating debris (3.1 kg); (2) a net import of suspended particulate detritus (38.5 kg); and (3) an annual net import of 4 million kilojoules for the 5.8 hectare drainage basin. Imports to the marsh occurred during high river discharge with the marsh exporting during low river discharge periods. The marsh may then serve to dampen oscillations in detritus availability to the estuary instead of providing a constant input or export.

Stout (1978b) found high levels of dead biomass remaining on marshes instead of being removed. This was especially true for *Juncus* with a live to dead ratio in June of 0.56. Passage of Hurricane Bob over the Mississippi coast in July, 1979, resulted in a net removal of 218 x 10^3 kg of dead plant material (wrack) from a 96 hectare study area (Hackney and Bishop 1981). It may be that within Mississippi Sound marshes which experience low tidal amplitude, the marsh acts as an energy reservoir, and storm surges may account for substantial portions of the total annual export of organic detritus from the marsh.

Examination of $^{13}C/^{12}C$ ratios in the tissue of common Mississippi marsh fauna exhibited no differences attributable to type of plant cover of the habitat. Instead results reflect a significant routine input of allochthonous terrestrial material to the estuary by river flow (Hackney and Haines 1980).

MARSH EXPLOITATION

Alterations For Various Water And Land Uses

For a long time the marshlands have been viewed as lands with very little value or use. Consequently, the value of marshlands was only enhanced by conversion (vis-a-vis destruction) to more "productive" uses. Table 11 summarizes published data and recent calculations of acreage of marsh which has been lost to the natural ecosystem by conversion to open water by dredging or to upland dry ground by filling. Using the more comprehensive figures of Eleuterius (1973), approximately 9,978 acres (4,040 hectares) or 11.5% of the marshes of Mississippi Sound have been removed. This is an underestimate as data is not up-to-date and only larger sites were included.

Loss of marshlands due to man's activity becomes more critical when the losses attributed to erosion are also considered (Table 12). Minimal estimates of annual marsh loss in Alabama along the Sound are 40-80 acres. Erosion rates for Mississippi marshes are not known, but are probably somewhat lower since most of the marshes are in lower energy environments than those of Alabama. The annual removal of marsh acreage should be of concern and should reinforce efforts to preserve remaining areas.

Table 11. Impacts of marshland alterations in Mississippi Sound resulting in marsh acreage loss. Numbers in parentheses are hectares.

Location	Dredging	Residential Industrial	Undeveloped Spoil	Others
Mississippi		8,170 (3,3080)[1]		1,085 (439)[1] 3,000 (1,215)[2]
TOTAL	9,255 (3,747)			
Alabama				
Coden			16 (6)	
Bayou La Batre			38 (15)	
Isle aux Herbes	4 (2)			
Point aux Pins	11 (5)			
Delta Port	9 (4)			
Dauphin Island		645 (261)		
TOTAL	723 (293)			
Mississippi Sound				
TOTAL	9,978 (4,040) = 11.5%			

[1] From Eleuterius 1973.
[2] From Wicker 1980 (loss from 1950-1978).

Farming For Chemical Products

High incidence of infection of *Spartina alterniflora* with the ergot *Claviceps purpurea* has been demonstrated throughout coastal Mississippi. Infection is highest in spoil areas and man-made beaches (100% infection with 95% seed loss) where exposure, aeration and drying favor germination. Potential yields of up to 160 lbs./acre (180 kg/hectare) are well within limits allowing economical harvest for the alkaloids within the ergot (Eleuterius and Meyers 1974; 1977). If the recent investigations on chemical derivatives (Miles and de la Cruz 1976), on the pulping characteristics and paper-making potential, and on the cellulose derivatives and alcohol production (Cruz and Lightsey 1981) of marsh plants prove to be feasible and of economic value, the prospect of cropping certain suitable marshland areas under managed farm-plantation schemes exists.

Farming For Fur Bearers

A small fur industry in coastal Mississippi and Alabama is dependent upon such marsh species as nutria and muskrats. Trapping ease and abundant food materials preferred by pelt mammals are favored by frequent burning of the coastal marshes. The impacts of this activity were recently evaluated by Cruz and Hackney (1980) in a 3-year study of controlled winter fire in Mississippi.

MANAGEMENT/RESTORATION

Since significant amounts of marshland have been permanently altered along Mississippi Sound and these marshes play a unique and critical role in the ecosystem, it is important that marshes be preserved, contributions per unit area be enhanced, and marshes restored where possible.

Experimental Enhancement

Several recent experiments have analyzed the success of controlled burning, harvest and artificial fertilization in enhancing the primary productivity of dominant plant species in the Mississippi-Alabama marshes. Indications are that burning and fertilization, either with commercial fertilizer or nitrogen-rich wastes, may provide tools to increase yield of plant production (Table 13) (Cruz and Hackney 1980; Cruz et al. 1981). Harvesting is of questionable value because of lack of technology and extreme resultant disruption of the substrate (Stout et al; 1980).

Restoration

Demand for suitable dredge material disposal sites and apparent successes with marsh creation on spoil may provide a solution to the need to both preserve remaining marsh and replace marsh acreage lost. Eleuterius (1974a) has shown success in Mississippi Sound with transplanting *Spartina patens, Distichlis spicata, S. cynosuroides, S. alterniflora, Phragmites australis* and *Juncus roemerianus* to spoil sites. Species specific and site specific recommendations may provide the basis for a restoration program within Mississippi Sound.

Table 12. Erosion of selected marsh shorelines along the Alabama portion of Mississippi Sound 1917-1958 (from Hardin et al. 1976).

Location	Area Loss Acres (Hectares)
Marsh Island (Portersville, Bay)	22.4 (8.92)
Isle aux Herbes	115.7 (46.85)
Point aux Pins	23.8 (9.67)
TOTAL	161.9 (65.57)

Erosion along entire shoreline 3.84-10.56 feet/yr. (1.17-3.77 m/yr)
Average annual erosion 3-7 feet/yr. (1-2 m/yr)
101 (162 km) miles of Alabama shoreline on Mississippi Sound
Using average annual rate of erosion applied along shoreline -
Loss = 162,000 to 324,000 m2 - 16.2 to 32.4 hectares/year
or
40.0 to 80.0 acres/year.

Table 13. Changes in primary productivity of selected marsh species experiencing experimental burning, harvesting, and fertilization as potential management practices (from Brown et al. 1978).

	PERCENTAGE INCREASE OVER CONTROL BY TREATMENT				
Species	Burn I	Reburn	Clip I	Reclip	Fert. (NH_4No_3) (136 g/m^2)
J. roemerianus (MS)	11	40	50	100	74
J. roemerianus (AL)					59
S. alterniflora				250	82
S. cynosuroides	19	24	140	45	24

RESEARCH NEEDS

In the preparation of this report on the status of our knowledge about the marshes of Mississippi Sound, more than 50 published works dealing with different aspects of the ecology of the Mississippi-Alabama marshes were reviewed and cited. We are proud to have contributed substantially to the marsh studies of Mississippi Sound, but we are appalled by the inadequacy of our knowledge. There is much more not known, and there are numerous basic and applied studies that need to be done to evaluate satisfactorily the importance of marshlands to man and to adequately understand the functioning of the marshes in the ecology of Mississippi Sound.

A more comprehensive ecological investigation of Mississippi Sound marshes invokes the application of the ecosystem theory. As a beginning, a simple energy flow chart similar to the one shown in Figure 2, can serve as a model in conceptualizing the general relationships of biotic components. The following gaps in the data of the model exist:

(1) Phytoplankton dynamics, primary productivity and tolerances;
(2) Zooplankton utilization of marshes, secondary productivity, and trophic role;
(3) Benthic algal productivity, population dynamics, environmental relations;

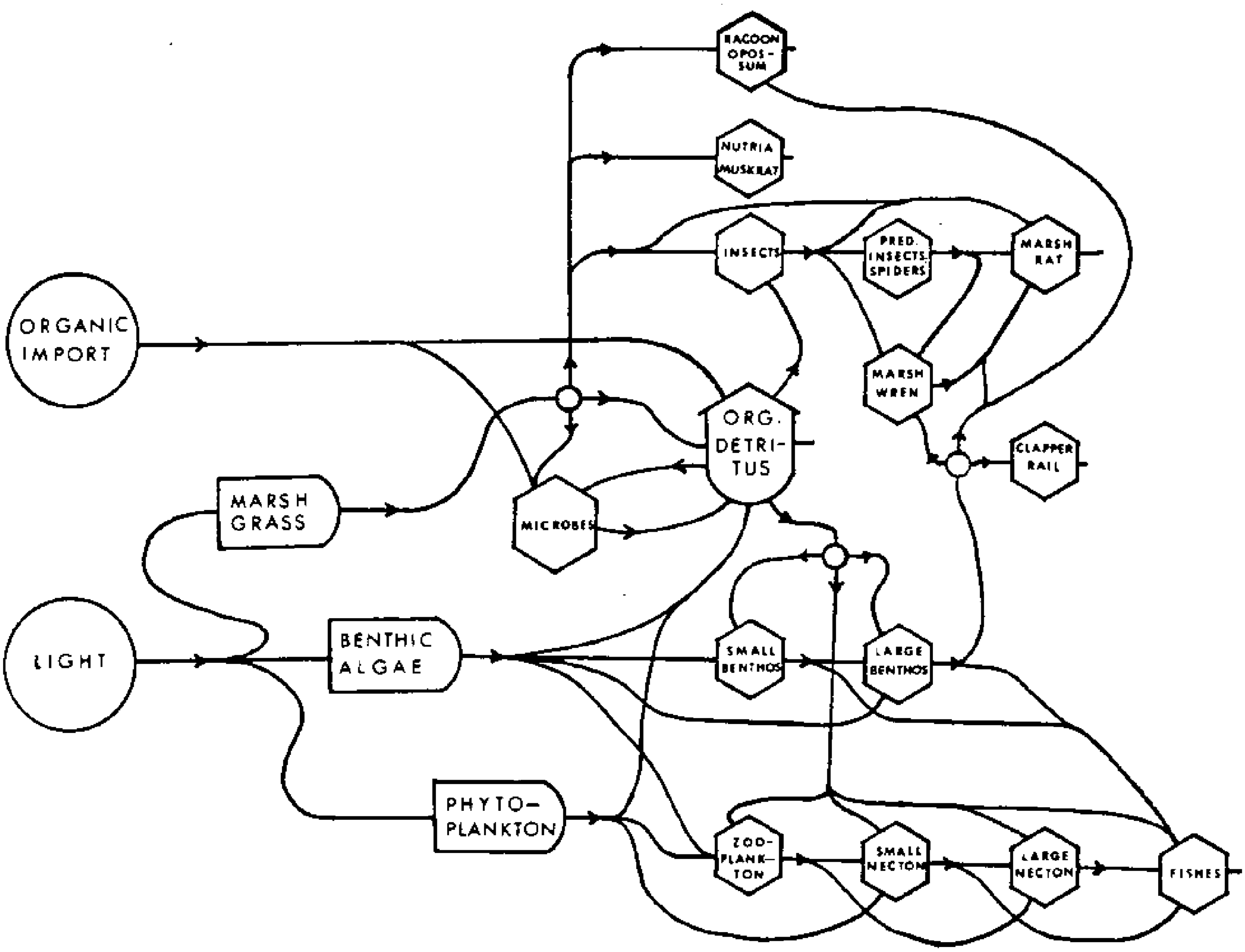

Figure 2. Conceptual energy flow model for the marshestaury of Mississippi Sound.

(4) Faunal population studies and energy budget of representative molluses, arthropods, birds, and mammals;
(5) Belowground biomass production and decomposition; role in nutrient and energy flow;
(6) Interrelationships of wetland types along the salinity gradient;
(7) Hydrological studies including freshwater discharge, nutrient and sediment input, toxic materials to estuary, etc.;
(8) Microbial ecology of detritus and decomposition processes; and
(9) Feeding chronology of fishes and fate of marsh detritus;
(10) Habitat role in faunal reproductive cycles.

POLICY RECOMMENDATIONS

The following are recommended to reduce, if not curtail, destruction and deterioration of vital estuarine marshes and attempt to ameliorate conditions from such activities.

1. Activities which cause direct, irreversible loss of estuarine marshes should be prohibited. Exception may be made for activities of critical local, regional or national need, but not for private gain.

2. Small size of marshes should not act to the disadvantage of marsh preservation. Cumulative loss of area and edge through repeated destruction or alteration of small tracts may have greater impact than equal areas lost in single large tracts.

3. When destructive or detrimental activities are necessary, best technology available should be required to minimize impacts of the activity throughout the project life. Cost effectiveness should take into consideration the unquantified natural values of the tract.

4. When destructive or detrimental activities are unavoidable, attempts to ameliorate effects should be required in the project design and financial arrangements. Amelioration may include, but not be limited to the following, where applicable.

   a. Revegetation of portions of site.
   b. Restoration following project site abandonment.
   c. Creation of similar habitat through use of spoil disposal sites, new canals, etc.
   d. Increase estuarine edge of interface through canal design.

5. Conduct a program of restoration of marsh tracts altered, but not destroyed by past activities.

6. Set aside specific marsh tracts to be preserved from any detrimental activity, regardless of need. Tracts may be designated for the following and other reasons:

a. Uniqueness either locally, regionally or nationally.
b. Particularly useful for educational purposes.
c. Exceptional recreational values.
d. Natural buffer between development and estuary.
e. Specific and limited habitat of designated Endangered Species (state or federal).
f. Value in research.
g. Unusual contribution to maintaining water quality due to location.

7. Design multiple-use projects for marsh tracts that may enhance their economic value while still preserving their natural roles (i.e., mariculture, water treatment, restoration or endangered species population, etc.).

8. Design study plans to:

a. Determine the status of the marsh resources where not known.
b. Evaluate utilization by itinerant species.
c. Examine edge-effect and criticial edge-to-area ratios.
d. Evaluate the relative roles played by inland delta and river marshes and estuarine coastal marshes.
e. Approach the research needs elucidated previously.

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THE MARINE FLORA OF MISSISSIPPI SOUND: A REVIEW

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ABSTRACT

This paper reviews and briefly summarizes the pertinent literature on the plant life of Mississippi Sound. The flora of the region was divided into five categories or components and the respective published information evaluated for each group. The least known components are the phytoplankton and large macroscopic or macrophytic marine algae. Little is known about the seagrasses in Mississippi Sound. The vegetation of the offshore barrier islands has received some intense study recently and except for Cat Island is reasonably well known. The plants of tidal marshes along the mainland have received a much greater amount of attention in comparison to the other floristic components mentioned above. A bibliography of papers reviewed have been compiled and it is included in the present paper. A tabular itemization and summary of references by floristic components is also included.

The scope of any scientific paper on the flora of Mississippi Sound should begin with some areal delineation. Restriction of the present review to the generally accepted, yet imprecise boundaries of Mississippi Sound, would also restrict the subject material to a coverage of seagrasses, macrophytic marine algae and phytoplankton. The purpose of this marine symposium is to list and review work done. "The marine flora of Mississippi Sound" is interpreted here in the broader sense to include tidal marshes and the peculiar vegetation of the local islands. There are other floristic components of Mississippi Sound which do not occur in situ. These are the floating plants which drift in from the Gulf of Mexico and others which are carried into Mississippi Sound from fresh waters by rivers, hence the emphasis on "marine" in the present paper.

The reference materials on each floristic component were reviewed by the same procedure. Scientific papers and reports were listed, grouped and summarized. This summary describes the kinds of work done but does not cite all papers, reports and abstracts in the text. Some published accounts contained information on two or more floristic components. No scientific work done on areas outside of the states of Mississippi and Alabama were cited. Although the results of some studies done elsewhere could be extrapolated to Mississippi Sound, the purpose here is restricted to the following question: What are the scientific observations and studies made specifically on the marine flora of Mississippi Sound? From this approach "information gaps" will be defined.

As a preface to this review, it should be noted that the flora of the State of Mississippi is regarded by most botanists to be poorly known and it is probably the poorest known region in the southeastern United States. Alabama is slightly better known floristically than Mississippi. The preceeding statement is based on a general comparison of published floristic accounts. Large numbers of papers on the marine botany or on estuarine botany simply do not exist.

Phytoplankton

The poorest known group of marine plants found in Mississippi Sound is the phytoplankton. These microscopic marine plants are often found in great numbers. Sometimes during periods of great flooding, the phytoplankton populations are greatly reduced. Sometimes only a few individuals may be found. Generally the composition of the phytoplankton of the water is diverse, but sometimes blooms occur which are monotypic. However, these are firsthand observations of the present author. There are no reports which describe the phytoplankton composition of Mississippi Sound. A considerable amount of work needs to be done on the phytoplankton (Table 1). A few species of phytoplankton for Mississippi Sound are reported in Eleuterius (1975). Woodmansee (1962, 1963) presented important work on one specific phytoplankton species. Several studies estimate the productivity of phytoplankton and two papers have been prepared on blooms of individual phytoplankton organisms (Eleuterius et al. 1981, Perry et al. 1979).

Observations made periodically by the author over a period of 12 years indicate a seasonality in phytoplankton abundance and diversity, with wide annual fluctuations in composition. Water, salinity, nutrient concentrations, temperature and wind conditions obviously play important roles in determining all distributional aspects of the phytoplankton of Mississippi Sound.

Marine algae (other than phytoplankton)

Taylor (1954) pointed out that the marine algae of Mississippi Sound were virtually unknown. Humm and Caylor (1957) reported 77 species of marine algae as part of the summer flora of Mississippi Sound. Most of those listed represent the epiphytic or attached algal flora from the intertidal zone of the mainland side of Mississippi Sound between Ocean Springs and Bay St. Louis. Eleuterius (1971) also reported on several of the major attached algal species forming extensive beds in Mississippi Sound and the approximate area of sea bottom covered. The winter epiphytic and attached algal flora has not been determined. One paper has been published on the diatom flora of seagrass beds (Sullivan 1979).

I know from personal experience that many more algal species exist in Mississippi Sound than those reported in the scientific literature (Table 1). Furthermore, this diversity reflects a seasonality and it is related to water salinity and the frequency of hurricanes.

Table 1. Publications on the plants of Mississippi Sound. The respective number and type of printed account for each floristic component is shown.

Plant group	Number of papers	Reports*	Abstracts	Total
Phytoplankton	5	2	2	9
Marine algae (macrophytes)	3	0	2	5
Seagrasses	14	0	0	14
Tidal marshes	57	12	5	74
Islands	10	2	2	14

*Includes theses and dissertations

Table 2. Publications on the Plant Life of Mississippi Sound.

Year	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
Phytoplankton										1	2				2	1							1	1			1		1
Marine algae (macrophytes)	1	1			1				1													1	1		2	2			
Sea grasses		1		1							1				1			1	1		1	1	1	1	1		1		
Tidal marshes			1		1		1		1									2	5	1	3	8	11	7	4	8	8	7	2
Islands										1					1	1		1			1			2			2		
Total	1	2	1	1	2		1		2	2	3				4	2		4	6	1	5	9	14	12	5	10	14	7	3

Seagrasses

Thorne (1954) stated that information on the marine spermatophytes of the Mississippi and Alabama coasts was at that time non-existent. There are presently about 14 published sources concerning the seagrasses in Mississippi Sound (Table 1). Most of these accounts describe or list the local species and their respective distribution (Eleuterius 1971, 1973). One large-scale transplanting study was carried out in Mississippi Sound. Seagrasses have not been successfully cultured anywhere in the world. Therefore, little is known about their physiology and growth. We know that vegetated sea bottom is a highly productive haven for many animals, yet we do not know the factors regulating seagrass growth. Locally seagrasses seem to be in a continuous decline. Whether or not this phenomenon is the result of pollution, world-wide climiate changes or just a phase in a cyclic pattern, is not known presently. Details of reproduction in Mississippi sound are not known. Furthermore, local populations may represent ecological races or genetic variants of the so-called "tropical seagrasses." Two primary reasons account for the lack of information on seagrasses in Mississippi Sound. One reason is that the beds are difficult to reach. Boat travel and other logistical expenses inhibit frequent visits. The second reason is that the beds are underwater which makes study of them difficult and dangerous. The scientist must get overboard to truly investigate seagrasses in Mississippi Sound.

Tidal marshes

The greatest amount of scientific work done in Mississippi and Alabama has been on the plants of salt or tidal marshes adjacent to Mississippi Sound (Table 1). Most of the research has been carried out on mainland tidal marshes in Mississippi; however, in Alabama much work has also been conducted on the marshes of Dauphin Island. Descriptive, productivity and decomposition studies including inventories are the primary kinds of work done, as reflected in about 30 published papers. Chemical aspects of plants are the second most common areas of work. A few cause and effect and other types of experimental field studies have been carried out. The algal and fungal components of our tidal marshes are poorly known and are represented by four papers. Tide and salinity relationships with marsh plants are addressed in a few papers. Several papers in tidal marsh diatoms have been prepared. One large-scale transplanting study has been carried out. Only a few papers deal with the relationships between tidal marsh plants and associated animals. Several studies represent work on various aspects of individual plant species, such as morphology, anatomy and life cycle.

The focus of scientific attention on salt marshes has been the result of several factors. Tidal marshes are easier to reach than the open waters of Mississippi Sound. Many coastal marshes can be reached by trucks or automobiles. Smaller boats can be used in coastal marshes than required to travel to seagrass or macrophytic marine algal habitats. Larger boats are needed for phytoplankton studies. Tidal marshes have been damaged more than seagrass or macro-algal habitats. It is difficult to assess the damage, if any, on phytoplankton. Furthermore, tidal marshes presently face the greatest threat of destruction in comparison to seagrasses and marine algae. Population (urban, residential and industrial) pressures along the coast continue to affect our coastal salt marshes. Trade-offs are always less than satisfactory in terms of ecosystem function. Insufficient attention has been directed toward seeking ways and means of restoring hundreds of acres of tidal marsh already damaged. Thus, these are the primary reasons that local scientists have concentrated in the recent past on these vital coastal areas.

Islands

There are about 14 published sources of information on the barrier islands, which form the southern border of Mississippi Sound (Table 1). Most of these studies concern descriptive accounts of the vegetation. The vegetation of Cat Island is the most poorly known. Penfound and O'Neil (1934) conducted an ecological study of Cat Island, which included a description of the vegetation and probable relationships between plant communities. Miller and Jones (1967) and Miller (1975) listed the plant species and determined plant community composition, respectively for Ship Island. Several detailed vegetation studies have been carried out on Horn Island, one on Petit Bois Island and several on Dauphin Island. No published accounts exist for Round, Little Dauphin, Deer and Half Moon Islands.

SUMMARY

This review presents the bulk of scientific work done on the plant life of Mississippi Sound. However, incomplete searches of M.S. theses and Ph.D. dissertations, abstracts of various scientific meetings and limited copies of reports for various funded projects, have undoubtly caused some excluded reference materials. Hopefully, the respective authors of those excluded papers, reports, abstracts and other scholarly works will notify me of such overlooked sources.

From a study of the literature review, a picture emerges showing that most scientific investigations on the plant life of Mississippi Sound have occurred recently (Table 2). Practically nothing was done prior to 1954 with a few published accounts occurring from 1960-1970. The bulk of the work on marine and estuarine plants occurred during the last decade. Most of the work has been carried out by a few dedicated individuals in Mississippi and Alabama.

DISCUSSION

Some future work relating drainage basins to the plant life of Mississippi Sound should be undertaken. This should be the beginning of a total ecosystem approach to the study of Mississippi Sound. The four botanical categories of greatest importance to Mississippi Sound are the phytoplankton, marine alga, seagrass and tidal marshes. To advocate that one of these four botanical regimes is more important than the other three would be foolish. They are all important. Very large "information gaps" or voids exist in our knowledge. If our overall objective is to maintain the integrity or enhance the productivity of Mississippi Sound inclusive of tidal marshes, then those areas still needing inventories of plant species, such as those of the phytoplankton and other marine algae should be conducted. A vast amount of scientific work needs to be carried out on seagrass and the larger forms of marine algae. Suitable substrate plays an important role in the distribution of certain marine algae. Studies which lead to a better understanding of plant and animal relationships are needed. Plant vs plant studies such as the relationship of algae to vascular plants and fungi in relation to vascular plants are important. Cause and effect studies should receive a high priority as a type of work needed in plant ecology. We do not know enough about individual species, even the major species such as *Spartina alterniflora*, *Scirpus olneyi* and *Distichlis spicata*. Submerged aquatics need considerable attention especially those in our bays, bayous and rivers.

Removal of large tracts of forest and a multitude of activities, either singularly or combined, which modify the drainage basin of local rivers, will affect Mississippi Sound. Denuding of forest lands may result in a modification of our coastal climate by changing land surface temperatures and consequently altering wind patterns. Developments in the drainage basin may alter runoff rates and change the amount of water flowing from the watershed. Erosion of the land surface and the resulting turbidity and siltation of riverine waters are also tied to the future status of the drainage basins. Pollution of Mississippi Sound may result from toxic materials brought from inland sources via the river systems. As the need for freshwater continues to increase, dam construction, river divergence and channel alteration projects will also increase. Major changes will occur in the flora of tidal marshes, phytoplankton and seagrass communities of Mississippi if the freshwater supply is significantly reduced. Thus, there is a limit to the number and size of river projects that can be allowed before major ecological changes begin to occur. A significant reduction in freshwater discharge would certainly cause a shift to a more saline, "open sea" type environment and result in less "estuarine" area. We do not know how much reduction in freshwater supply Mississippi Sound can tolerate, yet remain productive and retain other presently known characteristic attributes. Therefore, studies encompassing the "ecosystem approach" which would provide information or an evaluation on the potential large scale effect resulting from disturbance in the drainage basin and daming of river systems should be of high priority.

Causeways and roadfills, used in highway and road construction, have resulted in the modification of numerous tidal marshes by altering plant community composition and productivity. Roadfills cause total impoundments or some lesser effect by reducing tidal influence and freshwater discharge from local rainfall. The causeway across the mouth of the Pascagoula River is an excellent example of obstructed water flow into and out of an estuary. Some effort to rehabilitate these areas should be undertaken. However, rigorous scientific investigation should proceed these attempts.

Pollution of our estuaries has been essentially stopped with the advent of regulatory and enforcement agencies. However, the increase in number and size of industries on the Mississippi-Alabama coasts still results in some degradation of the environment. Furthermore, there are many hundreds of acres of polluted tidal marsh in the Escatawpa River that were degraded years ago which desperately need rehabilitation. To bring this large area of tidal marsh back into full productivity would be a wonderful accomplishment. We do not understand the basic problems because the estuarine, tidal marsh ecosystems are very complex. From the botanical standpoint, we do not know specifically why the plants do not regenerate vigorously in polluted marsh. Research on the rehabitation of tidal marshes should have a high priority since several hundred acres of polluted and otherwise degraded tidal marsh in Mississippi could be restored to its former high productivity. Mitigative procedures as alternatives in wetland regulation should also be developed as part of our future research efforts. A reevaluation of engineering activities such as canal dredging and mosquito ditching needs to be carried out. Plant physiological studies assessing the effect of toxic materials on plant growth should be carried out.

The production of oxygen by marsh plants, surely helps to cleanse the air, but we know little about this process. Research which explores the production and economic use of methane gas and other marsh gases would be of vital interest locally and nationally. Beach stabilization and marsh establishment on dredge spoil obtained by transplanting of marsh plants needs further investigation. Clarification of processes which increase the productivity of areas vegetated by marine plants are needed. The upper limits of productivity and the factors which maintain high productivity of marine plants need to be determined. Furthermore, we need answers to basic questions such as these: Does increased productivity (mass per unit area) of marsh plants or seagrasses mean that the related estuarine or marine animal component will increase correspondingly? What are the most productive components and areas of our estuaries? How do we assess the vitality (ecological condition or health) of marine plant habitats? We need to locate and protect special areas (which are unique and have exceptional attributes) such as the tidal marsh "salt flats" on Deer Island by stopping all activities in or around these areas, except functional, scientific investigations on them. Other special areas are the brackish lagoons and freshwater ponds on the barrier islands. Further study will reveal still other special areas. Botanical studies emphasizing taxonomy, population biology and other experimental work should be initiated because such information is basic to our understanding of the marine environment. Studies should be initiated involving the screening and practical use of marine plants in sewage treatment operations and as filters in marine aquaculture systems such as those developed for crab shedding.

The value of "so-called" pure science studies are not always immediately understood by the administrators and reviewers of proposals for funding agencies. Scientific work in such areas are needed and are of great importance for our overall interpretation of environmental and ecological data. Such studies of merit should be initiated immediately. Some botanical studies should be orientated toward determining whether or not we are dealing with ecological races of plants or distinct genetic entities. This information is important and basic to productivity assessments and other ecological aspects. The environmental effects on plant distribution and production need to be separated from those controlled by genetics. Furthermore, we should not neglect areas in which significant advanced work has been done, such as the chemical attributes of marine plants, as well as their productivity, decomposition and the various interrelationships with animals.

Pharmaceutical and medical uses of marine plants need to be investigated. The potential utilization of marine plants as food, fiber or sources of essential oils also needs further exploration. Aerial mapping studies using indicator plants and photographic documentation should be carried out on a continuous basis as part of a long range tidal marsh and seagrass monitoring program. Most vascular plants make good environmental indicators of disturbance because they do not move around. Preliminary work relating tides to coastal marshes, the relationship of marsh zonation and other vegetational features to accretion and erosion, the distribution and ecology of seagrasses and the array of marine algae, indicate that we have a relatively unique botanical regime within and associated with Mississippi Sound. The plant life of the Mississippi Sound region is diverse, relatively pristine and highly productive. We should use our scientific resources wisely. And it would be best for us to seek to understand the immediate and far reaching consequences resulting from our proposed scientific investigations so that considered decisions could be made as to where we should proceed and how.

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MONITORING OF POLLUTANTS IN MISSISSIPPI COALS COASTAL WATERS

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INTRODUCTION

Mississippi Sound forms the southern boundary of the states of Mississippi and Alabama. This elongated, shallow embayment is bordered on the north by a series of small bays, marshes, bayous and rivers and on the south by a chain of offshore islands. Fresh water input is primarily through the Pearl and Pascagoula drainage basins but also from St. Louis Bay and Biloxi Bay. On the western end of the Sound, water enters from Lake Pontchartrain-Borgne in Louisiana, and at the eastern extremity, water enters from Mobile Bay. Mississippi River water may also be introduced through the Chandeleur Sound. Water from the Gulf of Mexico enters the Sound by tidal exchange through the island passes.

Mississippi Sound is part of the "fertile fisheries crescent" of the northern Gulf of Mexico, a reference to the extensive seafood resources in this nursery region. In the past this resource has not been extensively utilized though some serious efforts are now being made to exploit the economic reserves of the seafood resource. There is some doubt, however, that the full potential of this area will ever be realized because of the concurrent interest by the states of Mississippi and Alabama to develop other resources. It is not surprising to note that these two states share some of the most desirable industrial climates of the country. At a time when already heavily industrialized areas in the United States are seeing the results of careless industrial development and are reacting with severe restraints, the Southeast is still holding to a doctrine of "industry at any cost." Neither Mississippi nor Alabama will anytime soon experience the phenomenal growth of Florida or Texas; however, some recent developments have created substantial concern among environmentalists. Several of the chemical plants in the Pascagoula River region are presently undergoing expansion; an oil refinery in the area will soon be one of the largest in the world; oil drilling continues in Mobile Bay and will escalate as our desire to become energy independent increases. Several new industries are in the process of locating in southeast Mississippi and southwest Alabama.

This region also has great potential for residential growth in the next decade as the populace migrates to the coastlines of the "sun-belt" states. All such development will put a strain on the environment because both industrial and residential expansion result in tremendous waste byproducts. Furthermore they will compete for the same aquatic habitats that are essential to support the fisheries industry. As Cairns[1] has stated succintly, "All industries discharging wastes are using the environment as an extension of their waste disposal system." Those responsible for making decisions with regard to coastal development should consider key economic factors in planning and accepting bids for future growth. Given little consideration in the past are environmental factors, particularly those relating to pollution. Among the more vital environmental issues are those relating to: the detrimental effects of pollution, the types of pollutants presently in the Sound and those likely to be introduced in the future, where the pollutants accumulate biota, water or sediments, what regions in the Sound are most polluted, how pollutants migrate in the Sound, the dangers of polluted sediments and measures that may be taken to prevent needless destruction of the environment. Though the economic data is substantial and sufficient for proper decisions, the scientific data is not.

Several studies have been completed and some are in progress that purport at least in part to establish guidelines or criteria for the assurance of environmental protection. St. Louis Bay, at the western end of Mississippi is the area of least commercial development on the Mississippi coast and until 1978 had almost no industry. A baseline study was completed in this bay in 1978 including a vast number of chemical monitoring measurements. In 1979 another study was begun at the eastern end of Mississippi Sound, the most industrialized region, to look at pollution transport. This study will be expanded in 1981-82 to include all of the Sound to look at the processes that are effective in the migration and fate of pollutants in the coastal estuaries of Mississippi and Alabama. Results of these two studies will be discussed with emphasis on the current pollutant transport study.

RESULTS AND DISCUSSION

St. Louis Bay. Prior to the start-up of a titanium dioxide plant on St. Louis Bay, a one-year baseline study was made in 1978 of this area and the rivers discharging into the bay. The survey included physical oceanography; benthic organism, fish and plankton studies; microbiology; marsh plant surveys and chemical surveys. Pesticides were one element of the chemical survey.[2] The authors were responsible for hydrocarbons and trace metals in sediments,[3,4] trace metals in organisms[4] and trace metals[4] and water quality parameters[5] in the water column. A map of the sampling area for these analyses is depicted in Fig. 1. The data for trace metal analyses have been compiled in Table 1. Trace metals in water (both soluble and particulate) were analyzed at two month intervals for a year. Surface sediment samples were collected twice during 1978, in May and December at eight stations for trace metal analysis. Surface sediment samples were collected twice, in December, 1977 and in October, 1978, at 13 stations for hydrocarbon analysis; monthly during 1978 at the same 13 stations for total organic carbon analysis.

In the water column only strontium ever exceeded the ppb (µg/1) level. Only arsenic, strontium, zinc and iron occurred consistently at levels that were detectable by the techniques commonly used in trace metal analysis. Some concern has been expressed for levels of trace metals in this bay exceeding what the U.S. Environmental Protection Agency (EPA) classifies as "safe."[6] Unfortunately many of

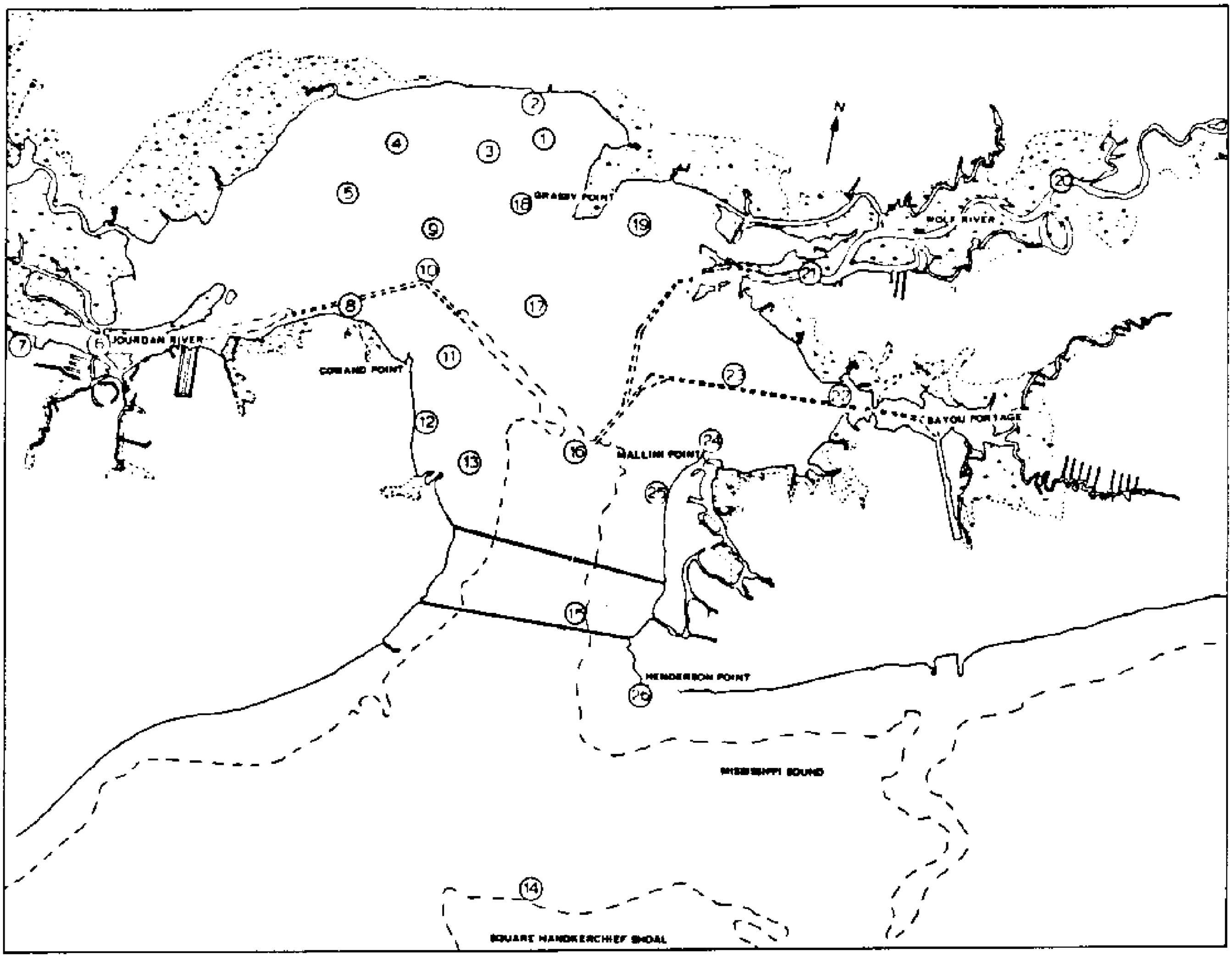

Figure 1. St. Louis Bay sampling sites.

the criteria established by the EPA apply only to water used for drinking purposes and are practically useless in determining the level of "safeness" of brackish bay waters. However, the detection limits for all metals surveyed are below the EPA criteria, therefore some comfort may be taken that the majority of metal concentrations fell below the EPA criteria throughout the year. Arsenic is one element whose concentration levels are rather puzzling; apparently considerable amounts of arsenic are introduced to this bay in a particulate form. Strontium, iron and zinc fluctutate from station to station in what might appear to be a random manner, however all three are sensitive to pH, temperature and salinity changes which were quite variable during 1978. None of the metals measured seriously deviated from concentration values determined earlier in this bay.[7,8]

Of particular interest in this study were values of heavy metals in the sediments of St. Louis Bay. The fact that sediments tend to preserve an integrated record of pollution is well documented in St. Louis Bay sediments. Within the bay, values of trace metals in surface sediments were very uniform, not displaying the erratic behavior of metals in the water column. Sediments may be characterized as reflecting long-term trends in trace metal input to this bay and other bays along the Mississippi coast.

The levels and distribution of hydrocarbons in St. Louis Bay also demonstrate the remarkable uniformity of chemical constituents in the bay sediments. Aliphatic and aromatic hydrocarbons occurred at low ppm levels at all sampling sites. The preservation of a long-term record of input is shown in the amazing similarity of 1977 and 1978 hydrocarbon values. The study of St. Louis Bay as well as a previous study of Biloxi Bay[9] suffer from some serious shortcomings. No effort was really made to look at the processes involved in pollutant transport and deposition. Because of the pressing need for this type of information, a four-year program was begun in 1979 to meet the following objectives:

(1) As completely as possible identify the type, source, and toxicity distribution of pollutants in the Sound,
(2) Investigate the processes operative in the dispersal and deposition of pollutants,
(3) Develop a system of guidelines to assure responsible coastal zone planning.

As a preliminary investigation surface sediment samples were gathered from sites in Biloxi Bay and the Pascagoula River in 1978. These two regions, especially the Pascagoula River, have heavy concentrations of industrial and residential activity relative to areas further west. Most evidence

Table 1. Trace Metals in Water & Sediments of St. Louis Bay*

Station Number	As	Sb	Be	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Se	Sr	Ti	V	Zn	Fe
1	<2†	<2	<0.2	<3	<100	<20	<10	<20	<0.2	<80	<30	<2	28.8-3400	<300	<200	14.7-272	<10-110
	<0.02-0.199§	<0.02	<0.02	<0.19	<2.1	<1.4	<1	<2.1	**	<16	<3.9	<0.01	<2.5	<73	<15	6.87-17.3	120-873
	5.55††	<0.025	0.632	<0.087	8.645	3.13	6.765	11.35	0.0534	<4.7	6.66	<0.13	<1.2	362.5	<6.4	65.6	17,900
3	<2	<2	<0.2	<3	<100	<20	<10	<20	<0.2	<80	<30	<2	<10-3540	<300	<200	<5-272	<10-110
	<0.02-0.302	<0.02	<0.02	<0.19	<2.1	<1.4	<1	<2.1	**	<16	<3.9	<0.01	<2.5	<73	<15	3.90-177	120-728
	6.72	<0.025	0.689	<0.087	9.73	7.54	10.335	13.8	0.0.1068	<4.7	8.26	<0.13	<91.2	277.5	<6.4	72.95	20,000
7	<2	<2	<0.2	<3	<100	<20	<10	<20	<0.2	<80	<30	<2	<10-1810	<300	<200	15.8-190	<10-102
	<0.02-0.168	<0.02	<90.02	<0.19	<2.1	<1.4	<1	<2.1	**	<916	<3.9	<0.01	<2.5	<73	<915	4.15-177	49.4-826
	0.766	<0.025	<0.193	<0.087	2.225	2.275	2.310	6.010	0.1678	<4.7	1.615	<0.13	<1.2	122.0	<6.4	17.10	3,590
16	<2	<2	<0.2	<3	<100	<20	<10	<20-70	<0.2	<80	<30	<2	117-3660	<300	<200	7.88-233	<10-87.1
	<0.02-.200	<0.02	<0.02	<0.19	<2.1	<1.4	<1	<2.1	**	<16	<3.9	<0.01	<2.5	<73	<15	5.88-85.4	83.8-391
	7.38	<0.025	0.888	<0.087	11.60	7.905	9.735	16.90	0.0988	<4.7	10.43	<0.13	<1.2	358.5	<6.4	65.70	21,800
18	<2	<2	<0.2	<3	<100	<20	<10	<20	<0.2	<80	<30	<2	39.2-2160	<300	<200	<5-179	<10-56.7
	<0.02-0.184	<0.02	<0.02	<0.19	<2.1	<1.4	<1	<2.1	**	<16	<3.9	<0.01	<2.5	<73	<915	3.90-14.3	134-606
	8.47	<0.025	<0.663	<0.087	9.48	6.96	7.06	15.9	0.908	<4.7	7.215	<90.13	<1.2	274	<6.4	50.45	18,150
19	<2	<2	<0.2	<3	<100	<20	<10-30	<20	<0.2	<80	<30	<2	<10-2640	<300	<200	<5-160	<10-209
	<0.02-0.172	<0.02	<0.02	<0.19	<2.1	<1.4	<1	<2.1	**	<16	<3.9	<0.01	<2.5	<73	<15	6.13-24.5	75.2-576
	8.325	<0.025	0.458	<0.087	12.18	7.64	8.545	17.8	0.1034	<4.7	8.365	<0.13	<1.2	306.5	<6.4	59.3	22,350
20	<2	<2	<0.2	<3	<100	<20	<10	<20	<0.2	<80	<30	<2	<10-123	<300	<200	5.96-157	<10-148
	<0.02-0.292	<0.02	<0.02	<0.19	<2.1	<1.4	<1	<2.1	**	<16	<3.9	<0.01	<2.5	<73	<15	3.90-38.1	376-949
	0.7685	<0.025	0.267	<0.087	5.365	2.623	3.165	9.77	0.0568	<4.7	3.38	<0.13	<1.2	224.75	<6.4	19.85	5,760
22	<2	<2	<0.2	<3	<100	<20	<10	<20	<0.2	<80	<30	<2	56.1-3500	<300	<200	5.93-265	<10-120
	<0.02-0.107	<0.02	<0.02	<0.19	<2.1	<1.4	<1	<2.1	**	<16	<3.9	<0.01	<2.5	<73	<15	8.36-29.7	138-855
	2.105	<0.025	0.1205	<0.087	4.64	0.658	3.165	6.375	0.0469	<4.7	2.34	<0.13	<1.2	158	<6.4	24.2	5,730

*Summary of data collected in a study in 1980 funded by E. I. du Pont de Nemours & Co.
†Range of soluble trace metal concentrations in μg/1.
§Range of particulate trace metal concentrations in μg/1.
**Inconclusive results.
††Mean of surface sediment trace metal concentrations in μg/g.

tends to indicate that organic pollutants are the dominant pollutant type in the Sound. National Pollutant Discharge Elimination Systems (NPDES) permits in the Pascagoula region list a wide variety of organic pollutants. Trace metals appear to be of secondary importance. Therefore, this preliminary study stressed the organic compounds in the sediments. Partial results are shown in Fig. 2. Location of the stations is not nearly so significant as the extreme variability seen in organic composition of sediments taken from these two areas. Stations not very far removed from each other and containing very similar geological structures contain quite different levels of organic pollutants. The grossly elevated levels of organics, not explainable by natural phenomena, clearly demonstrates the need for a comprehensive organic chemical monitoring program in the Sound.

The Pascagoula River is the site of most domestic development on the Mississippi Coast and also the most flagrant example of its improper management. Therefore, most work in 1979-80 has concentrated on this river system. NPDES permits, location and type of industry in the surrounding area and preliminary results shown in Fig. 2 suggested several types of organic pollutants as the prime candidates for investigation. Phenolics were included because of their abundance in waste discharges and because they are among the "priority pollutants" compiled by EPA.[10] Of even more significance are the hydrocarbons. These compounds hidden in such innocuous NPDES phrases as "oil and grease" include the polynuclear aromatics, many of which have known carcinogenicity.[11-16] The nearly

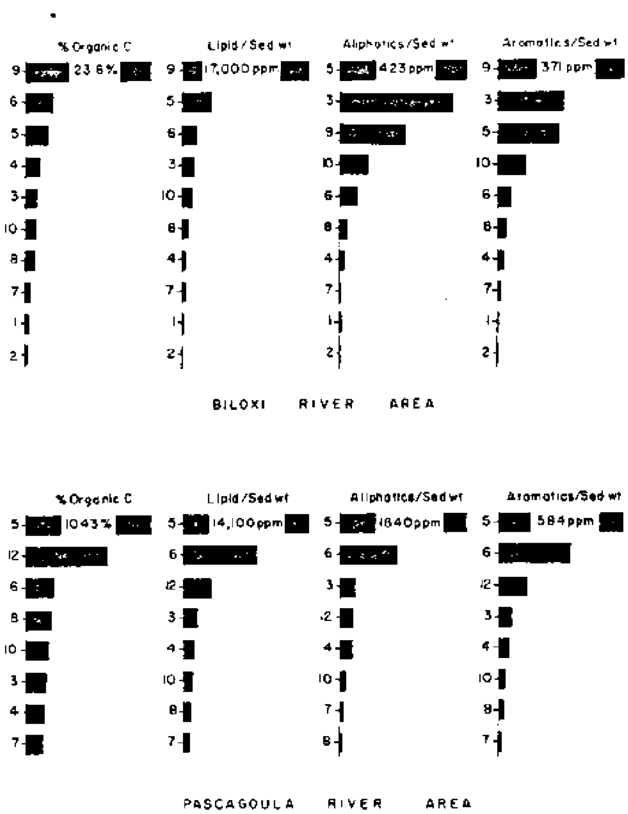

Figure 2. 1978 Sediment Survey of Biloxi Bay and Pascagoula River.

completed superport off the Louisiana coast, a one-billion dollar expansion of an oil refinery in Pascagoula, pipelines in the Sound, oil drilling off Louisiana and Alabama, local creosote plants,[17,18] coal generated power plants, urban run-off,[19] careless disposal of motor oils[20] and even sewage,[21,22] add to the hydrocarbon budget of the Sound.

Preference in analysis for this study has been given to sediments because of their tenacity for pollutants,[19,23-36] their capacity to retain pollutants in a locale, their preservation of pollution history and their potential toxicity over long periods of time. Surface sediments have been collected from large numbers of sites in the eastern Sound to document recent pollution incidents. The most comprehensive sampling was conducted in the Escatawpa River in which are located a large paper mill, a chemical manufacturer, seafood processors and some small shipyards. Figure 3 contains results of this study. The industrial zone was located midway along this transect, covering the five miles above the confluence with the E. Pascagoula River. Note that exceedingly high values of organic matter and hydrocarbons are not restricted just to the industrial area. Because tidal salt wedges penetrate beyond this point it may not be surprising to see elevated pollutant levels up-river of the source. Nevertheless there is convincing evidence that the majority of discharged pollutant does not migrate very far from the origin. Figure 4 depicts the gas chromatograms of hydrocarbons from two sites less than 100 feet apart in a canal near a paper mill in the Escatawpa River industrial zone. At one end of the canal (Site I) hydrocarbons are mostly low molecular weight with large quantities of branched-isomeric aliphatics looking very much like fresh fuel oil residues. At the other site (II) the hydrocarbons are more uniformly distributed over the entire molecular weight specturm. Lyons and Gaudette[37] also noticed this phenomenon in assaying pollutants as a function of distance from discharge. The limited mobility is some cause for guarded relief because pollutants may not be widely dispersed; however, caution is required since monitoring efforts must be very selective in the choice and number of sampling sites in order to give an accurate depiction of pollution profiles of these regions.

Sediment cores have been collected to give information about pollutant levels as a function of sediment depth. In November, 1979 10-foot cores were collected at the sites designated on the map in Fig. 5 in the Pascagoula River area to coincide with areas where polluted sediments would tend to accumulate. The extreme variability in analysis results reflects that seen in the surface sample analysis. One particularly interesting core sample was collected in Dead River, an oxbow lake just south of the newly constructed I-10 bridge over the W. Pascagoula River. The more salient points are included in the display in Fig. 6. The clay and silt composition of each core is very important in the interpretation of pollutant levels because of the affinity of organic pollutants for fine-grained materials. At most sites in the Pascagoula River a close correlation exists between levels of naturally occurring organic compounds and percent clay. However at Dead River (an excellent accumulation site for fine-grained materials), hydrocarbons near the surface exceed what would be expected if they were of natural origin. The distribution of hydrocarbons ascertained by gas chromatography and fluorescence spectrophotometry

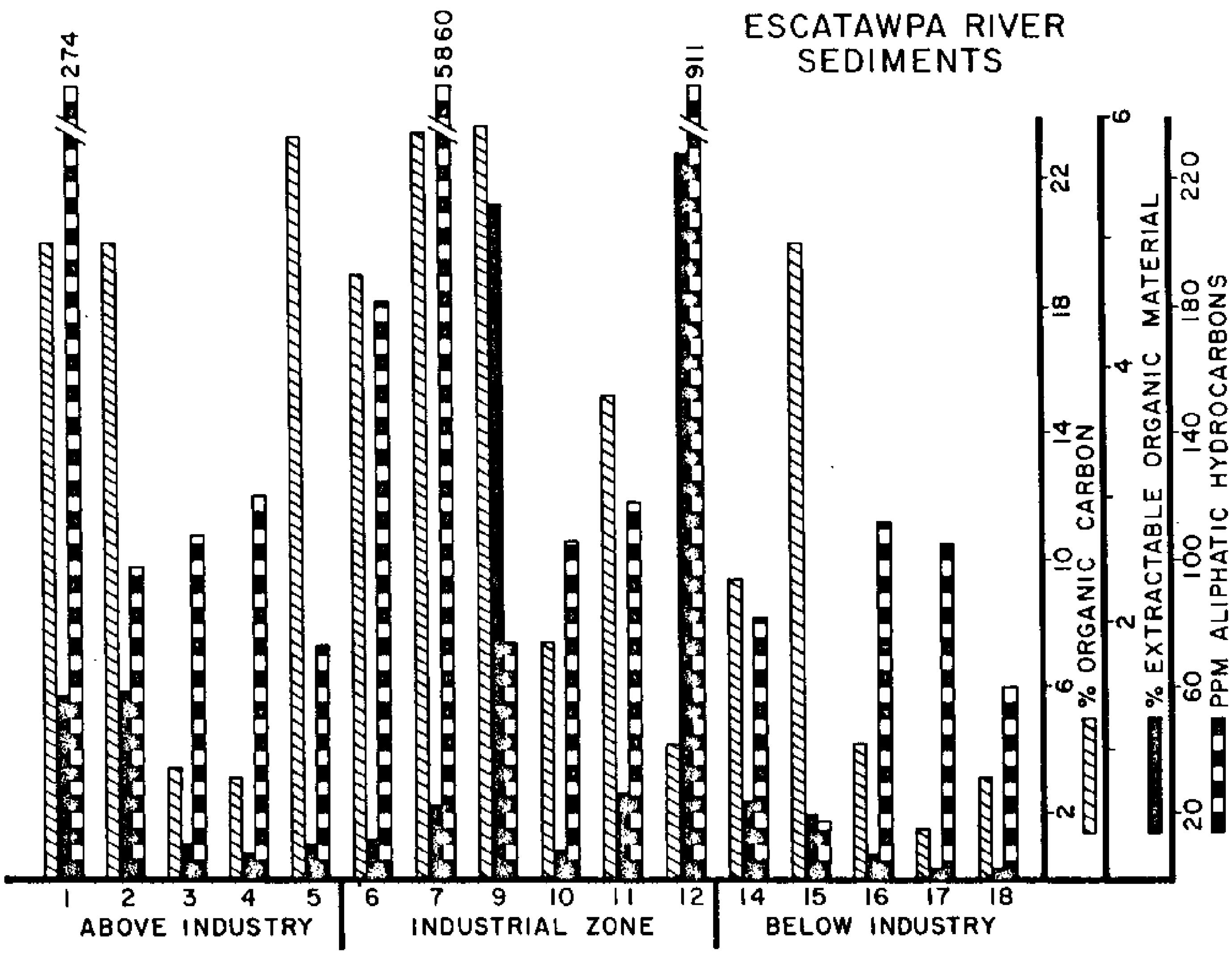

Figure 3. Organics in Escatawpa River. Stations 1-18 are located in sequence in the river with #1-5 being upriver of the principle pollution sources and #14-18 downriver of these sources.

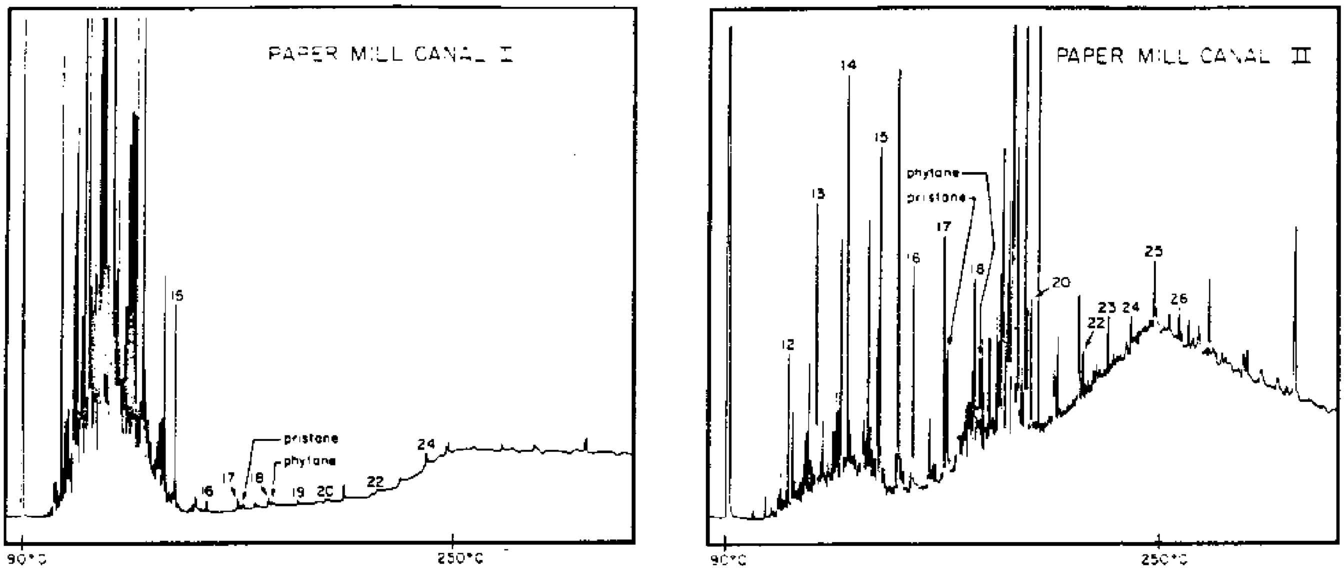

Figure 4. Gas Chromatograms of Hydrocarbons in a Paper Mill Canal. Site I is located at the deadend of a canal adjacent to a paper mill, site II is ca. 100 feet away at the mouth of the canal. Integers denote carbon numbers of identified alkanes. G.C. conditions are: 25m glass capillary OV-101, temperature programmed from 90° to 250°C @ 40/mm, the flow of 3 ml/mm using injection splitter.

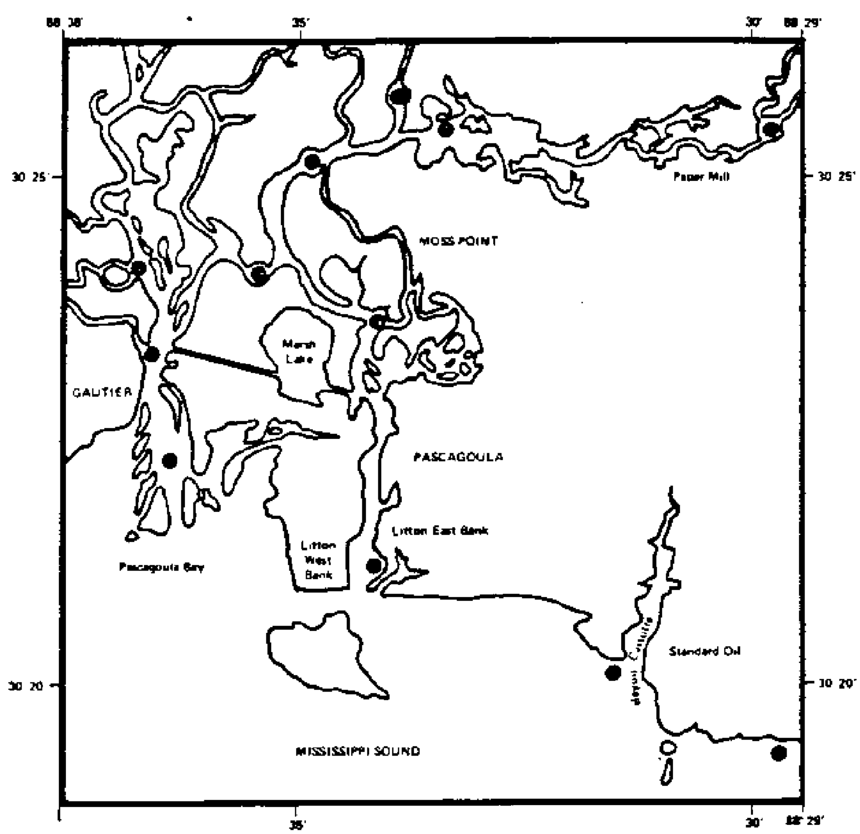

Figure 5. Pascagoula River Coring Sites. Dots designate the sampling stations for 10-foot sediment cores.

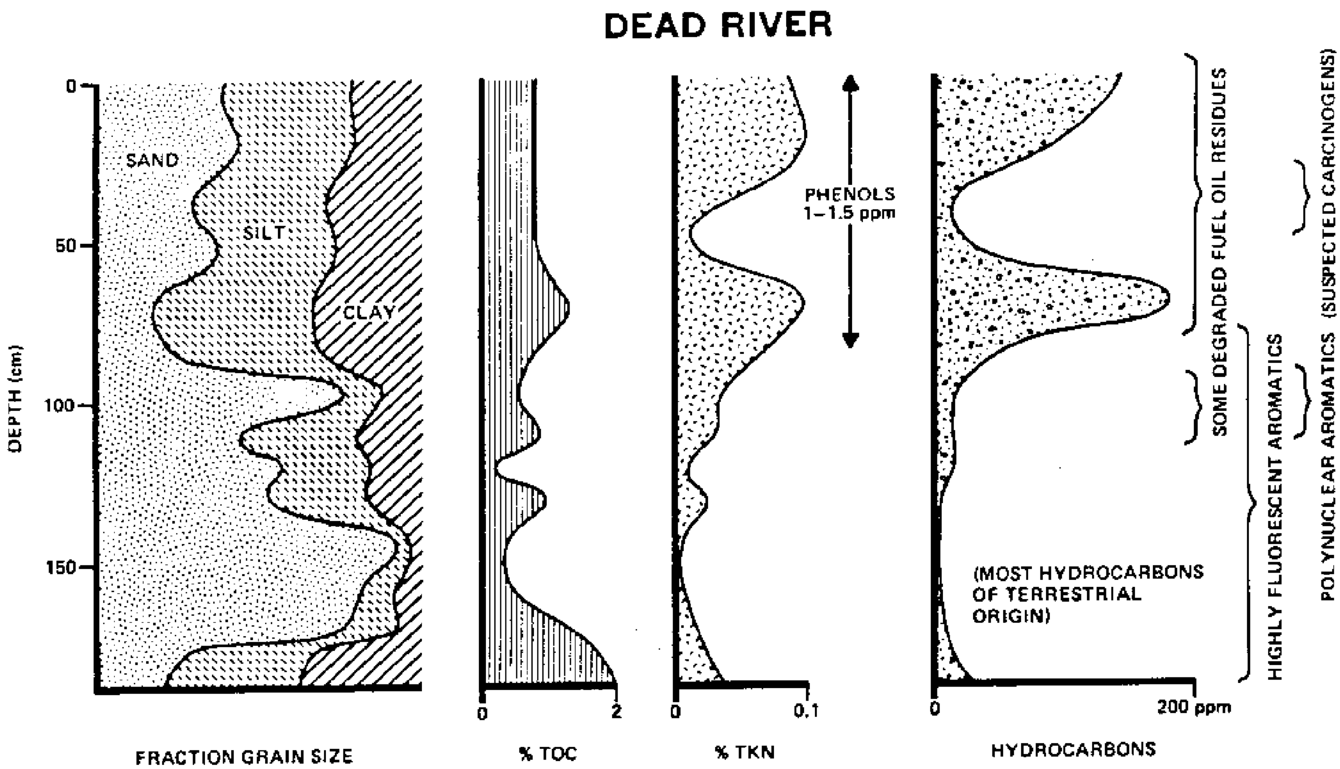

Figure 6. Geologic-Chemical Profiles of W. Pascagoula River sediments. Dead River is the site of an oxbow lake located on the W. Pascagoula River just south of the I-10 bridge.

indicate degraded fuel oil in the surface sediments; the presence of these residues have been noted at other sites as well, and as in Dead River, not always at maximum concentrations in the uppermost levels. Further elucidation by mass spectrometry of the aromatics revealed a very unusual assemblage of long chained alkyl substituted benzenes. This information definitely points to an anthropogenic source of the hydrocarbons. The definition of various strata in the sedimentary column by geological and chemical description will be presented to the Corps of Engineers to enable them to better assess the possible side-effects of dredging at various depths and to get estimates of overall pollutant levels in the dredge spoil taken from various locales.

Freshwater discharge and surface currents are primarily responsible for the sediment migration and deposition patterns seen in the Sound, though tidal currents[35] and macrobenthos also play a role.[36,38] Less obvious modes are storm scouring, dredging[39] and fish trawling.[40] The actual impact of disturbing polluted sediments is being determined for all polluted Sound sediments by various

Table 2. St. Louis Bay - High Molecular Weight Hydrocarbons 1977 Mean Value/1978 Mean Value

Station Number	%Organic Carbon	Aliphatic/ Dry Wt. (ppm)	Aromatic/ Dry Wt. (ppm)	n-alkanes/ Dry Wt. (ppm)	n-alkanes/ Aliphatics (%)
1	1.46/1.29	7.83/3.79	4.58/2.25	4.45/2.28	54.2/59.6
3	1.67/1.59	7.44/5.59	3.53/1.21	4.06/3.46	54.2/61.8
5	1.40/1.61	7.39/5.97	2.84/1.71	3.67/3.64	49.7/60.8
6	3.20/2.87	10.3/5.38	7.34/1.29	5.66/2.72	55.6/50.7
9	1.48/2.10	7.06/6.36	4.16/1.74	3.68/4.04	51.8/63.2
11	1.47/1.27	3.60/3.85	1.53/0.970	1.79/2.46	50.0/64.2
15	2.29/1.99	4.85/6.69	1.66/1.88	2.24/4.14	46.4/61.9
17	1.32/1.06	3.19/3.20	1.87/1.25	1.58/1.84	50.3/58.2
18	1.48/1.18	8.99/2.25	3.21/0.660	5.67/1.15	61.1/46.0
19	1.51/1.49	4.93/3.26	2.74/0.995	2.23/1.71	45.6/51.4
21	1.32/1.51	2.67/4.28	1.75/1.52	1.71/2.81	56.6/64.5
22	2.03/0.746	7.06/3.35	1.72/3.37	3.12/1.22	44.8/55.8
24	0.582/0.654	1.15/0.710	1.61/0.349	0.466/0.347	42.6/47.7

analysis. The stability of resuspensions of polluted sediments has been determined by resuspending sediments in site water, at various pH, salinity and temperature and measuring the rate of re-deposition. The rate of deposition varies considerably and sometimes in a very unpredictable manner. Examples of two quite diverse behaviors are shown in Fig. 7. Both areas have considerable industry and are in areas of high clay sediment composition. Though the Bayou Casotte sediment suspension initially is quite high, it very rapidly drops to background levels. Sediments from the Halter Marine site in the Escatawpa River, on the other hand, though initially at lower suspended solids values, maintain suspensions well above background for very long periods of time. This characteristic of sediments is quite important, for it affects the ability of associated pollutants to be leached from sediments and also will determine the efficiency with which polluted sediments can be dispersed over broad areas after a period of disturbance.

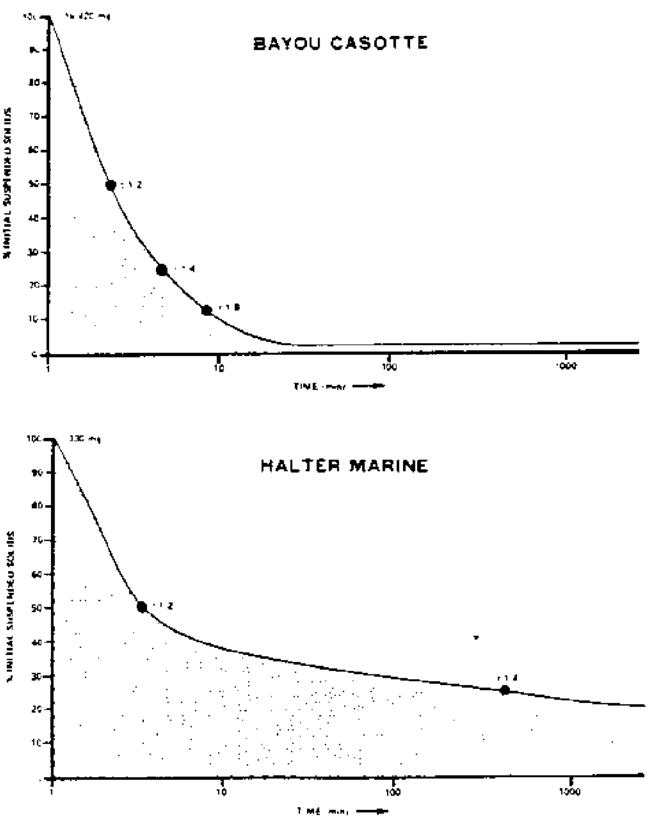

Figure 7. Sediment Settling Rates. Total suspended solids are plotted as a function of % of initial suspended solids following dispersal of sediment in site water (1:4; w:v). Times are marked when these values have fallen to ½, ¼ and 1/8 of the initial value. Halter Marine sediments were obtained from a region in the Escatawpa River.

Table 3 contains a listing of a number of characteristics of sediments found within the Pascagoula River system. Included is a rating of the stability of resuspended sediments, i.e. how effectively do the sediments remain in suspension after a period of resuspension. Table 3 also includes a compilation of results of tests to determine the actual toxicity of sediments to several ecologically valuable species of indigenous organisms. In these tests *Mysidopsis almyra* or mysid shrimp, *Cyprinodon variegatus* or sheepshead minnow and an amphipod, *Gammarus mucronatus* were exposed to water previously shaken with sediment then filtered, water with suspended material and sediment that was allowed to settle in a tank, to comply with EPA's three-phase bioassay conditions.[41] As a group, the sediments from the Escatawpa River appear to have the highest toxicity of any from this system. Of further concern is the fact that most of these sediments form fairly stable suspensions and are prone to being disturbed (see "disturbance potential", Table 3). Though a high rating in any one category e.g. "disturbance potential" or "suspension stability" may not be significant, consistently high ratings in all categories pertinent to considerations of the potential harm of polluted sediments is significant. Table 3 is not all-inclusive but contains much of the evidence that can be used in objectively evaluating the sediments of the Pascagoula River.

CONCLUSIONS

(1) These studies of St. Louis Bay and the Pascagoula River provided a considerable number of contrasts. St. Louis Bay prior to any major development displayed sediment profiles with almost complete lack of any elevated pollutant levels and a distribution of trace metals and hydrocarbons consistent with a relatively pristine environment. On the other hand, areas in the Pascagoula River, used for many years as prime industrial sites, have very high pollutant levels in the sediments, particularly hydrocarbon pollutants which serve as painful reminders of past disposal practices.

(2) Metal and hydrocarbon values were very uniformly distributed in the sediments of St. Louis Bay which is quite typical of areas subject only to natural inputs. Sediments of the Pascagoula River are extremely heterogeneous indicating not only anthropogenic sources of input but that the Pascagoula River has little ability to disperse or "dilute" polluted sediments which are deposited and concentrated near the point of origin.

(3) The Corps of Engineers typically makes dredge permit decisions based in part upon gross analysis of composite sediment samples from dredge areas. The extreme variability of pollutant levels and type with depth in the sediment column of the Pascagoula River indicates a need for a change in this policy. By carefully constructing profiles of the sediment columns by textural, foraminiferal and chemical analysis of different areas, a better estimation may be made of the actual amounts of pollutants involved in dredging operations.

(4) As important as the level of toxic substances in the sediments of an area, are other characteristics that are essential to an understanding of the threat posed by polluted sediments. Toxicity measurements, sediment settling characteristics, and knowledge of activities likely to cause disturbance all suggest that there are some real trouble spots in the Escatawpa River region of the Pascagoula River area of the Mississippi Sound. This information is being gathered into a format to aid decisionmakers in developing a more realistic consciousness of the impact of haphazard development and to promote more responsible coastal zone management in Mississippi.

Table 3. Sediment toxicity ratings.[1]

Area Tested (Selection Criteria)	Mysid Shrimp LP	Mysid Shrimp PP	Mysid Shrimp SP	Sheepshead LP	Sheepshead PP	Amphipods SP	Likely Agent	Suspension Stability[3]	Disturbance Potential[4]
	Exposure Mortalities, 3-Phase[2]								
Lake Yazoo (Mouth E. Pascagoula River; industrial discharge)	5(100%) 5(100%) 3(10%)	5(100%) 5(50%)	5	5(100%)	5(100%)	5	Caustic	3	4
Mary Walker Bayou (W. Pascagoula River; numerous marinas)			5			3	Aromatic Hydrocarbons	2	5
Elevator Bayou (E. Pascagoula River; down river of all industry)						1		2	1
Paper Mill (Escatawpa River canal; proximity of paper mill)	3(100%) 1(50%) 1(10%)	5(100%) 4(50%) 4(50%)	5			5		3	2
Halter Marine (Escatawpa River; manufacturing)	4(100%) 2(50%) 1(10%)	1(100%)						1	4
Pogey Plant (Chemical industry; fish meal processors)	5(100%) 5(50%) 1(10%) 1(1%)	5(100%) 5(50%) 5(10%)	5			5		5	5
Twin Island (Mouth W. Pascagoula River)					1(100%) 1(50%)			2	2
Bayou Cassote (industrial area)		2(100%) 1(50%) 1(10%)	1			1		2	5
Griffin Point (Sewage outfall)		1(100%) 1(50%) 1(10%)	3			2		5	4
McInnis Lake (Sewage outfall, bridge construction)						1		4	1

[1] The higher the number rating in each category, the greater the potential risk posed by polluted sediments in the respective areas. A ranking for biota susceptibility and pollutant level will be included at a later date.

[2] EPA 3-phase bioassays with exposure to soluble components of sediment (LP), suspended and solubles (PP), and settled sediment (SP). Organisms used are mysid shrimp (*Mysidopsis almyra*), *sheepshead minnows* (Cyprinodon variegatus), and an amphipod *(Gammarous mucronatus)*. Mortalities are listed as 5 (81-100% mortality at end of exposure; 4 (60-80% mortality); 3 (41-60% mortality); 2 (21-40% mortality); and 1 (5-20% mortality). Parentheses following rating indicate: (amount of soluble or particulate phase) (amount of soluble or particulate pahse + diluent water) x 100%.

[3] Rating depends on how high in the following rating system each sediment ranks: if time for a suspension in water to drop to ½ initial value ($t½$) ⩾ 15 mm and if ¼ initial value ($t¼$) is reached in ⩾ 30 min. and if the initial suspended solids (ISS) (after dispersal) ⩾ 5,000 mg/ℓ, sediment is ranked a 5; if $t½$ ⩾ 10 min., $t¼$ ⩾ 20 min. , ISS ⩾ 2,500 mg/ℓ = rank of 4; if $t½$ ⩾ 5 min., $t¼$ ⩾ 10 min., ISS ⩾ 1,000 mg/ℓ = rank of 3; if $t½$ ⩾ 2 mm, $t¼$ ⩾ 4 min., ISS ⩾ 500 mg/ℓ = rank of 2; all others, rank of 1. This ranking is still tentative because some sediments have bery unusual characteristics in the stimulated resuspension studies that are not reflected in this ranking scheme.

[4] Probability that sediments from this location could be disturbed, thereby exposing the water column and biota to toxic agents. The highest rating of 5 is applied to areas with considerable boat traffic, dredging activity, or to areas which are in the main river flow and subject to runoff disturbance or are subjected to high tidal and/or benthic activity. A rating of 4 designate areas where boat traffic is restricted and are somewhat protected from those elements characteristic of areas of rating 5. A 3 signifies an area that is moderately affected by tides, is isolated from most man-made disturbances, and is subjected to disturbances infrequently. A 2 is given to those regions with little potential to disturbances under usual conditions either because of isolation from main stream flow or because of characteristics undesirable to sports or recreational boating. A raint of 1 is reserved for those areas that are subjected to disturbances only under extra-ordinary circumstances.

ACKNOWLEDGEMENTS

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HABITAT MITIGATION AND RESTORATION: A COASTAL MANAGER'S DILEMMA

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INTRODUCTION

In recent years a great deal of attention has been focused on the wetlands and tidal marshes of the United States. In the early 1970's we witnessed a growth of scientific information regarding the ecological value of the tidal marshes. At the same time, we experienced a rapid growth in population along the coast which brought with it the widespread destruction and alteration of the coastal environment.

As biologists and ecologists began to piece together facts regarding the complex nature of wetlands, it became apparent that if our estuarine and marine ecosystems were to be preserved the wetlands too would have to be protected. Wetlands protection laws on the federal and state levels were enacted and much of the unrestricted wetlands destruction for waterfront housing and industrial expansion was curtailed.

While it can be said that the widespread wetlands alterations which once reeked havoc along the coast has been stopped by the regulatory agencies, there are still those who refuse to obey the wetlands protection laws. Unauthorized wetlands alterations have become a major area of work for resource management agencies.

Dealing with the problem of unauthorized activities brings with it a unique set of social, legal and ecological considerations which must be analyzed and molded into what is commonly called "The Restoration Plan." The purpose of the restoration plan is to lay out a procedure for returning the affected wetlands to their natural state; however, quite often the plan leaves something to be desired. In an attempt to expedite the resolution of a case, the regulatory agencies and violator sometimes agree to a restoration plan that looks good on paper but leaves very much to be desired in reality.

As we move into the 1980's, coastal management agencies will be facing another major problem which we refer to as the "mitigation syndrome." Caught between basic desire to maintain the structure and function of the natural ecosystem on one hand and recognizing the need for certain water dependent projects which are vital to our nation's economy and public interest on the other, regulatory agencies are faced with making trade offs.

Habitat mitigation which is essentially the process of creating wetlands habitat for wetlands habitat altered by man's activities is not like a win or lose situation. Nor is mitigation a case where everybody wins or everybody loses. For the most part, mitigation is like borrowing from Peter to pay Paul.

The object of this paper is to summarize the concept of restoration and mitigation from a coastal manager's point of view. Specific cases are presented and possible approaches to future projects are suggested.

RESTORATION

Restoration is defined as "the act or condition of being restored as in bringing back to a former condition." Habitat restoration is the process whereby natural areas, disturbed by the activities of man, are nurtured back to a level of productivity. The act itself usually involves removing misplaced sediment, grading and landscaping disturbed areas and transplanting various types of vegetation (Garbisch, 1977). While there is general agreement as to what restoration is, there is quite often a lack of agreement as to how restoration should be accomplished.

Restoration involves uncertainties which must be taken into consideration before an effective restoration plan can be developed. One of the most important factors to be considered is the impact of the restoration on the environment. There are cases where the work performed in restoring an area can cause more damage than the unpermitted work has caused. In most cases; however, restoration is necessary to return the damaged wetlands areas back to a certain level of productivity and usefulness.

Once it has been decided to require restoration, the question of how and, more importantly, how much must be addressed. This phase of the restoration process moves outside the arena of scientific thought and into the more complex arena of legal, social and economic thought. Although most restoration plans are developed in a cooperative manner with a view toward satisfying project needs and environmental requirements, complications can arise. The person responsible for the unauthorized work may not have the financial resources to undertake the restoration work. Quite often the person is willing in the beginning to restore the area, but he balks at the final restoration plan because the restoration involves more than he feels he should be required to do. For this reason, the regulatory agencies must be careful in developing a comprehensive restoration plan. The objective should be to restore the area to pre-existing conditions or at least to a condition where the natural processes can take over and complete the job. A compromise between what could be done and what should be done usually leads to the most successful restoration.

MITIGATION

Historically, major losses of productive tidal wetlands in Mississippi have been due to non-water dependent projects such as real estate developments and industrial land developments which could easily be located outside of the coastal wetlands. However, in recent years a different class of development activities has begun to take its toll on the estuarine environment. These projects are considered to be water dependent.

Water dependent projects such as navigational projects, marinas, boat building facilities and oil and gas exploration projects involving wetlands alterations receive a higher degree of consideration than non-water dependent activities due to the inherent public interest involved (Lindall, et. al., 1979). A specific example is those wetlands alterations which are deemed to be energy related in nature. Because all regulatory agencies involved are required to consider the public benefit to be derived from a project, the decision is often made in favor of the project over wetlands alterations, due to the overriding public benefits associated with the project. When the project involves energy exploration, the national interest to be served weighs heavily in deciding the outcome.

To the coastal management agency charged with balancing marine resources protection with reasonable coastal development which serves a higher public interest, the task is difficult and challenging. Although the argument for wetlands preservation may be strong, the argument for increased energy production is usually stronger. In an attempt to deal with this situation, the cry for mitigation is heard in regulatory offices at both the state and federal levels.

The concept of mitigation is a relatively new one and basically involves the trading of existing productive habitat for the promise of either artificially creating an equivalent habitat or insuring the long time preservation of a similar existing habitat (Lindall, et. al, 1979). The concept is often met with strong resistance, for many biologists feel that a contractor with a dragline and a bulldozer cannot duplicate what nature has taken hundreds of years to create.

Putting aside the argument of natural marsh versus created marsh, a major obstacle still stands in the way of a successful mitigation project. Mitigation more often than not tends to be a very complex biological and technical process. Often what seems to be an equitable trade off on paper becomes a biologist's nightmare when implemented. In addition, the task of getting various regulatory agencies to agree on one specific concept for mitigation is difficult to say the least.

THE EXPERIENCE

Notable examples of habitat mitigation and restoration efforts that have taken place in coastal Mississippi include case files for the Gulf Islands National Seashore Project, Bridges Properties, Inc., and the Popps Ferry Bridge Project. An examination of these projects will highlight the problems associated with this concept and allow the reader to form a better understanding of the complex issues involved in the process.

Case I: Gulf Islands National Seashore

The permit request by the U. S. Department of Interior, Gulf Islands National Seashore (GINS) provides a good look at the complex factors which must be considered in developing a plan to mitigate habitat losses.

In December of 1977, GINS requested permission to conduct maintenance dredging in the main access channel from the park off Davis Bayou to the open waters of the Mississippi Sound.

The main problem confronting the GINS staff was the location of a suitable area to deposit the approximately 24,000 cubic yards of spoil material to be removed from the channel. In previous dredging operations, spoil materials had been placed in a shallow open water area adjacent to the existing channel, resulting in the development of a rather large area of extremely shallow water with numerous mud flats exposed at low tides.

After reviewing the proposal, it was concluded that the continued use of this shallow area for spoil deposition was undesirable.

In an attempt to accommodate the needs of the GINS, consideration was given to mitigative measures which might offset the impacts of unrestrained spoil disposal in open water. After careful consideration, it was decided that the spoil material might be used to create a productive marsh island in the area.

The basic plan was simple. Using a dragline, containment berms would be created in the center of the disposal site. These containment berms would act as natural levees to contain dredge material from the access channel. The material from the access channel would be deposited between the berms to a height that would create a spoil island. The island could then be sprigged with characteristic marsh grasses from the area.

In April, 1978 the dredging project began. The containment berms were constructed with no apparent problems. The problems began with the placement of the first spoil material from the access channel into the area between the containment berms. Because the spoil material was contained on only three sides, each time the contractor placed the spoil within the containment area the material would slough off, filling in the work channel between the berms and preventing the barge from re-entering the area. The end result was a large submerged mud flat. The project produced no island, no marsh, and unnecessary environmental impacts in the project area. In short, the attempt at habitat mitigation had proved to be a failure.

One year later in March, 1979 the GINS submitted a new request for permission to conduct additional maintenance dredging in another part of the access channel. Realizing that the need for mitigation was greater now than it ever was, the GINS suggested a new method for marsh creation. The revised plan called for the containment of the spoil material by dikes constructed of bales of hay. The disposal site for island creation would be the same as the former site identified above. The dredging would be done by small hydraulic dredge with the material being pumped via pipeline into the haybale containment area. The porous nature of the hay bales would allow water to be filtered out of the containment area while the sediment would remain within the containment area and consolidate to eventually form an emergent island. Again, the proposal was to sprig the emergent island with characteristic marsh grasses from the surrounding area.

As a result of its previous experience with marsh creation, the staff was somewhat reluctant to once again sanction the use of spoil material to create a marsh island. The main concern was that the hay bales would not sufficiently contain the near liquid spoil material. Seeing is believing, so in order to sanction this new request, GINS was required to conduct a small scale test of the hay bale containment system. The test was performed in an area adjacent to the proposed site. The results were good. The material was contained within the hay bale dikes and eventually the material consolidated enough to support a GINS staff member.

The test was considered a success and proved that hay bales could be used to contain hydraulically pumped dredge spoils and allow for their consolidation into an emergent island.

As a result of the successful test, a second permit was granted to the GINS for maintenance dredging. The permit contained the provision that all spoil would be utilized to create the marsh island and that the island would be vegetated with characteristic marsh from the surrounding area. Additionally, the permit included a condition that if the marsh creation was not successful the GINS would remove the spoil material and restore the area to its original conditions.

In February, 1980 the dredging and island creation projects were begun. Spoil disposal in the containment areas proceeded as planned. No significant increase in turbidity in the project area was noticed and the spoil islands began to take shape. By March, the first of two marsh islands was finished and pumping into the second containment area for Island Number 2 began. As Island Number 2 began to grow, the material in Island Number 1 started to consolidate into fairly stable condition. When the material had consolidated to a point where it could easily be traversed by GINS crews, the sprigging process was initiated.

By this time, Island Number 2 was reaching completion. During the dredging process, GINS began to encounter heavy clay material. For reasons that are unclear, they elected to dispose of this clay material in the open waters immediately adjacent to Island Number 2 rather than within the containment area as required in their permit. This action was considered to be in direct violation of the Bureau of Marine Resources' permit and the U. S. Army Corps of Engineers permit issued for this project. In May, 1980, the U. S. Army Corps of Engineers issued an order to the GINS requesting that they cease and desist all dredging operations in the project area.

As a result of this Cease and Desist Order, the GINS ceased all activities associated with the project. This included the continuation of sprigging the first marsh island.

As the GINS became more entangled in the web of bureaucratic paperwork woven by the numerous government agencies involved in assessing the alleged violation, the uncontained spoil remained in the open waters of Davis Bayou and the unplanted sprigs of marsh began withering in the hot sun. The end result has been a growing mound of government paperwork instead of a flourishing productive wetlands habitat.

Today the project essentially remains the same as it did a year ago when the work was halted. Although the two proposed islands do exist, there is still very little productive marsh.

Even though GINS marsh creation project has met with numerous problems, and the desired end result has not been achieved, a small ray of hope still exists. This ray of hope is focused on one small corner of the first island which was sprigged prior to the issuance of the Cease and Desist Order. Growing there is a small but apparently healthy and alive stand of marsh grass, offering proof that the concept is workable. Based on this ray of hope, the Park Service is preparing to resprig the island in the hope that productive, healthy marsh is still an obtainable goal.

Case II: Popps Ferry Bridge Project

The Popps Ferry Bridge Project is a good example of mitigation by accident. Rarely is construction on a major water dependent project completed without some degree of adverse impact on coastal wetlands. More often than not, wetlands are sacrificed in the name of "public interest to be served." Occasionally the impacts are offset, or at least minimized through mitigation efforts. Unfortunately, as we have seen, all the scrutinizing, reviewing, debating and revising by as many as a dozen state and federal agencies for as long as a year, cannot insure that the end result will be desirable.

Many times, after the dragline is finished and the heavy equipment is gone, the results are a proud and happy owner of a shiny new project, a decrease in wetlands productivity, and a confused permit official wondering what went wrong and why the system didn't work.

Although the permitting system is beset with problems and inadequacies which often lead to scenes like this, a sincere and valid effort is made to preserve the wetlands. When the developer possesses a spirit of cooperation and a willingness to do what is right, the result can be completion of a much needed project and the developer and resource manager proudly agreeing that it is possible for man to co-exist with nature.

Such was the case at the Popps Ferry Bridge Project over the Back Bay of Biloxi. This project proves that permit agencies, the public, local government and the contractors can work together to meet the public's need while contributing to the surrounding ecosystems, rather than taking from it.

In November, 1976, work was initiated on a new swing bridge across Back Bay at Popps Ferry in Biloxi, Mississippi. One of the earliest activities conducted by the contractor in connection with the bridge construction was the excavation of an access channel and a barge channel to accommodate work barges during the construction of the bridge.

The access channel was approximately 1,000 feet long by 60 feet wide and was dredged to a depth of minus 8 feet. The work channel was approximately 2,000 feet along by 100 feet wide and was also dredged to a depth of minus 8 feet. All excavated materials were stockpiled in three designated spoil disposal areas adjacent to the channels and were to be returned to the channels after construction of the new bridge was completed.

As the bridge was nearing completion and word got out that the channels would be filled as per the original agreement, we began to receive reports from local fisherman that the channels had developed into popular fishing spots. With this in mind, local officials requested that the project sponsor consider leaving the channels unfilled. Pursuant to their request, the sponsor requested the Bureau of Marine Resources to make an investigation of the area and provide advice as to whether or not leaving the work channels unfilled was environmentally acceptable.

Based on the results of the staff's review, it appeared that the access channel and work barge channel were providing a deep water habitat in a relatively shallow area and by doing so, was creating a diversity of habitat for aquatic organisms which was judged to be ecologically beneficial. In addition, marsh establishment on the spoil area could provide additional wetlands habitat with its associated ecological contributions.

In light of this, the original plan to fill the channel and return the area to natural conditions did not appear to be ecologically sound. In addition to creating obvious environmental disturbances, (increased turbidity, disrupting the re-established benthic community) the restoration of the project area would result in the loss of deep water habitat and 3.5 acres of potentially productive marsh habitat.

After giving full consideration to the facts associated with the project, the Bureau of Marine Resources recommended that the access and work channels not be refilled. It was also recommended that the existing cuts through the spoil areas be enlarged to insure adequate movement of water in and around the spoil area, and that the existing spoil disposal areas be planted with suitable marsh vegetation to insure the establishment of a productive marsh habitat.

During the summer of 1979, the above referenced mitigative restoration work was carried out by the contractor. In the two years since that time, the artificially created marsh has continued to grow and flourish on the one time spoil islands. Although a few areas are not as yet fully vegetated, the overall goal of establishing new healthy stands of marsh without restricting or redirecting water currents or flows in the area seems to have been accomplished.

The Popps Ferry Bridge project and the resulting marsh creation is an example of developers, ecologists and sportsfishermen working together to best solve the problem to the benefit of all.

Case III: Bridges Properties, Inc.

The concept of restoring coastal wetlands in Mississippi has played an important role in the rehabilitation of natural areas altered by man. Since the passage of the Coastal Wetlands Protection Law, the number of major violations which require significant restoration has been limited. However, based on the projects we have observed, the concept of marsh restoration has been quite successful. A case in point is the restoration work performed by Bridges Properties, Inc. in response to the request by environmental agencies to remove unauthorized fill material from the tidal marshes along Fort Bayou in Jackson County, Mississippi.

In 1973 Bridges Properties, Inc. constructed a canal approximately 2,500 feet long from the bank of Old Fort Bayou east along the marsh upland ecotome to their existing marina. Dredged material was placed on the marsh adjacent to the canal. Initial calculations indicated that approximately 1.52 acres of tidally influenced marsh vegetated primarily with needlerush, (*Juncus roemarianus*) and smooth cordgrass, (*Spartina alterniflora*) had been destroyed.

In addition to the marsh vegetation destroyed by the dredged material, an undetermined amount of marsh vegetation was actually removed and replaced by the canal.

Because of the involvement of innocent third parties who purchased waterfront property along the newly excavated canal, it was decided that the canal would remain in place. However, Bridges Properties, Inc. was required to remove all dredged material from the tidal marsh and deposit the material in upland areas outside of the marsh.

Restoration was completed within sixty days. Once the material was removed from the marsh, the area began to recover immediately. Recent inspections revealed that the area has been completely revegetated and is returning to its once high level of productivity.

CONCLUSIONS

Coastal resource managers operate in a highly uncertain environment where feedback from past program activities can provide important information for future decisions. Judging from past experiences, there is a strong tendency to look unfavorably on mitigating the loss of wetlands habitat by creating new wetlands areas. The case of Gulf Islands National Seashore would point to this. However, there are more significant results as is seen by the case of the mitigation at the Popps Ferry Bridge site and the restoration of the Bridges Properties, Inc. unauthorized work.

Significant achievements have been made in the area of habitat rehabilitation. The Corps of Engineers Dredged Material Reserach Program has developed a vast resource of information and it can be said that the technology for building a marsh is available (Reimold, 1978;Seneca, 1980). However, there are certain problems associated with mitigation that negate these achievements.

Individual philosophies, as well as legal, environmental and economic issues make habitat mitigation a very complex process. Even when a comprehensive plan is developed the success often depends on the ability of the contractor to accomplish the work.

In order to accommodate man's activities in the coastal area and at the same time maintain a high quality environment, the concept of habitat mitigation must be refined and incorporated into the overall management scheme. While the potential problems appear to be significant, they are not insurmountable. In the long run, habitat mitigation appears to offer promise and it is our feeling that even in the most extreme cases of failure, any attempt at habitat mitigation is better than no mitigation at all.

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REHABILITATION OF NATURAL OYSTER REEFS DESTROYED OR DAMAGED BY A NATURAL DISASTER

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INTRODUCTION

Oyster production in Mississippi Sound waters has declined sharply in recent years (Table I). While a number of factors have contributed to this decline, the primary causes usually implicated are: (1) adverse water salinities, (2) closure of reefs in bay waters, and (3) the effects of periodic hurricanes and other tropical disturbances (McKenzie, 1976).

Recently, the oyster reefs in the most western areas of the Mississippi Sound showed an unusually high incidence of mortality (Ogle, 1979; Cirino, 1979). General scientific opinion attributes such mortality to the effects of extended periods of depressed salinities caused by heavy spring rains, the resulting flooding, and the concomitant opening of the Bonnet Carre' Floodway (Gunter, 1953). As a consequence, Mississippi oyster production is expected to be low in 1979-80 and may not rise to favorable levels for some time unless intensive reef rehabilitation measures are carried out.

The Mississippi Bureau of Marine Resources has historically and periodically planted cultch materials (either oyster or clamshells) on the natural oyster reefs to replenish cultch material routinely lost during harvest or fouled by barnacles and epibenthos (Table II). Replenishment of cultch material on oyster reefs is a widely used practice in oyster management and is encouraged by the National Marine Fisheries Service as a means to revitalize an otherwise depauperate resource (U.S. Department of Commerce, 1977; Gunter and Demoran, 1970).

The overall success of such a program of shell planting, however, is entirely prerequisited by the accurate identification of sites suitable for oyster growth and harvest. Such sites must satisfy the physiological requirements of oysters; the substrate must be able to physically support the weight of the planted shell and the future adult oyster; and to be of value to the harvest sector, these sites must be located in waters free from unacceptable levels of fecal coliform bacteria as mandated by Public Health Laws (Mississippi State Department of Health, 1979). In addition to these siting criteria which will be discussed in greater detail later, the program's success is further dependent upon the timely conduct of the shell planting operation. A proportionately greater probability of success is expected during oyster spawning peaks and periods of reduced growth of fouling organisms.

Table 1. Mississippi oyster landings.

Year	Quantity (thousands of pounds of meat)	Value (thousands of dollars)
1950	2,188	623
1951	1,623	487
1952	2,852	847
1953	3,758	892
1954	3,339	683
1955	3,973	818
1956	3,781	778
1957	3,533	740
1958	1,857	391
1959	1,095	257
1960	2,391	535
1961	3,241	753
1962	2,074	538
1963	4,680	975
1964	4,829	1,099
1965	2,696	627
1966	2,232	597
1967	3,786	1,066
1968	3,786	1,163
1969	1,430	552
1970	548	238
1971	1,214	472
1972	1,220	581
1973	612	366
1974	276	157
1975	1,080	534
1976	1,516	1,015
1977	1,386	1,156
1978	682	735
1979	41	44

Table 2. Record of Shell Planting Operations in Mississippi Waters

Year	Type Shell	Quantity (Cubic Yards)
1960	Oyster	4,392
1961	Oyster	1,470
1962	Oyster	1,280
1963	Oyster	1,661
1964	Oyster	875
1965	Oyster	290
1966	Oyster	8,202
1967	Oyster	6,824
1968	—	—
1969	Oyster	6,642
1970	Oyster & Clam	*27,949
1971	Oyster & Clam	16,018
1972	Clam	5,354
1973	Clam	5,317
1974	Clam	*22,773
1975	Clam	2,774
1976	—	—
1977	Clam	4,335
1978	Clam	4,500
1979	Clam	*71,000
1980	Clam	*21,108
	TOTAL	212,764

*Funding through PL88-309 4(b) Disaster Funds

The biology of the American oyster is well studied and documented for the Gulf of Mexico (VanSickle, et al., 1976), consequently much of the needed management information can be obtained from this existing literature pool. Particular details regarding specific planting sites and times must, however, be determined on a case by case basis.

Since the intent of this work is directed toward the rehabilitation and revitalization of existing oyster reefs and not toward the creation of new reefs, determining the condition of these existing reefs is a priority consideration. Those reefs determined to have been maximally impacted will receive a maximum of attention. Typically these determinations are based upon percent mortality detected in a one-cubic foot sample of the reef in question. At the same time, useful information regarding the condition of living oysters, the incidence of fouling organisms, and, most importantly, the number of spat sets, can be obtained.

In determining the optimum time for planting, it is useful to note that two spawning peaks occur in Mississippi Sound waters (Demoran, personal communication).

The first of these peaks occurs during the spring at which time the fouling organisms are also in a period of accelerated growth. Thus, it becomes a matter of competition for the limited resource (i.e. suitable substrate for attachment), an agonistic contest not always won by the oyster.

The so-called trailing mode of setting, or the second spawning peak, occurs in early to mid-autumn. During this period, the competitive advantage appears to go to the oyster spat. The incidence of fouling is greatly reduced and the probability of spat success is correspondingly increased. There is some recent evidence as well to suggest that early setting larvae produce superior oysters (Losee, 1979).

The problem of identifying suitable waterbottoms for oyster growth is a laborious though not difficult task. Oysters grow best on bottoms that are hardened with firm mud, rock, or shell. They do not, however, do well on sandy or soft mud bottoms (VanSickle, et al., 1976).

This is apparently because the abrasive action of shifting sand will cause valve injury while shifting, soft mud may cause death by suffocation. Otvos, (1972) mapped sediment type distribution in Mississippi Sound and adjacent waters. He describes the sediment type in the Sound as being predominantly sandy silt. More recently, the Gulf Coast Research Laboratory (1978) developed a map depicting waterbottoms suitable for growing oysters. Despite these general guidelines for identifying prospective planting areas, however; the task of marking the sites for the planting crews is one requiring considerable time and effort in the field.

METHODOLOGY

The Oyster Reef Rehabilitation Program was initiated August 20, 1979, discontinued in September of that year; and it was subsequently reinstated and completed in June 1980. During the initial phases of the program, candidate reef sites, specifications and planting techniques were discussed between staff members of the Bureau of Marine Resources and members of the Oyster Biology Section of the Gulf Coast Research Laboratory.

Data regarding the reef conditions and oyster mortalities, compiled by the Gulf Coast Research Laboratory prior to the initiation of the project were utilized to select candidate sites for the receipt of cultch material. Prior to the actual planting, staff members of the Bureau of Marine Resources and the Gulf Coast Research Laboratory conducted bottom investigations of the proposed reef sites which had been tentatively selected to ascertain the presence of suitable bottom types.

Once the bottom investigation was completed, the area was temporarily marked with floating, high visibility buoys anchored by masonery blocks.

The planting of the clamshell was performed by Radcliff Materials, Inc. of New Orleans, Louisiana who submitted the lowest and best bid for these contractual services. A copy of the bid specifications and contracts are provided in the Appendix for both the September 1979 and June 1980 planting efforts.

The shells provided by Radcliff Materials were estuarine clamshells (*Rangia cuneata*) dredged from Lake Maurepas and Lake Pontchartrain in the State of Louisiana. The estuarine clamshell has been shown to be a good type of cultch material and is desirable for several reasons including abundance, availability, relatively low cost, ease of planting and a characteristic single oyster set. (Pollard, 1973).

The shells were transported by barge to various staging areas located within close proximity to the reef sites where they were measured, and the total cubic yardage delivered by each barge was calculated according to the following formula:

$$\frac{V=L(A+a+4M)}{162} = \text{CUBIC YARDS}$$

WHERE: A=AREA OF TOP OF SHELL PILE
a=AREA OF BASE
M=AREA OF CROSS SECTION MIDWAY BETWEEN TOP AND BASE
L=HEIGHT

The shells were washed overboard at the selected sites using high pressure waterhoses. The pressure jet of water was directed against the shells in such a way as to spray them in a thin layer for a distance of 20 to 50 feet from the barge (Figure I). The shell barge was maneuvered in a fashion over the planting site so that the shells were spread in an even layer over the entire area. This type of operation was used in the past for shell plantings in Mississippi Sound, and the work was under the direct supervision of the Bureau of Marine Resources and the Gulf Coast Research Laboratory.

In conjunction with the shell plantings, staff members of the Gulf Coast Research Laboratory set out cultch bags and asbestos plates to monitor spat set and spat density in the vicinity of the selected sites. This information will be used to evaluate the overall success of the planting program in precipitating the recovery of damaged reefs.

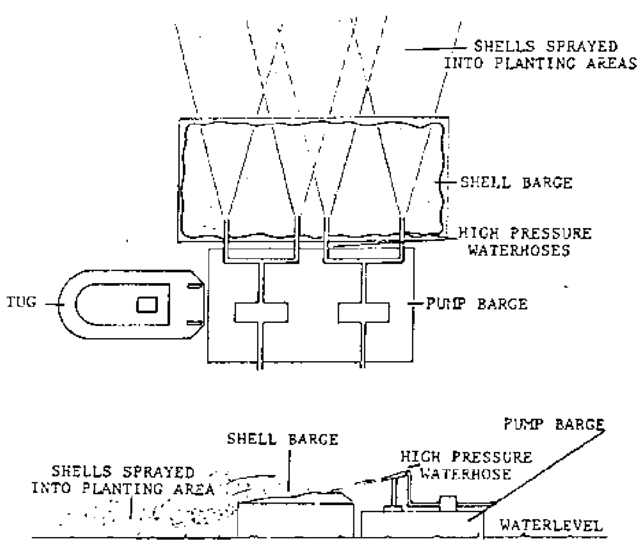

Figure 1.

RESULTS & DISCUSSION

Extensive spring rains and accompanying widespread flooding experienced in April and May 1979 caused high mortalities to Mississippi's oyster populations. This was first evidenced in the routine field samples collected by the Gulf Coast Research Laboratory (Cirino, 1979) as shown in Table III. At this time, the Pass Christian reef showed the greatest incidence of mortality (87%) while the Waveland and adjacent reefs experienced considerable lower mortality rates (i.e. 54.5%).

The following month, a total of 23 samples were processed from stations throughout the impacted area. Very few live oysters were taken in the cubic foot samples during this time (Ogle, 1979). The percent mortality ranged to a maximum of 100 percent in the Pass Marianne Reef area. The Waveland samples once again exhibited encouragingly low mortalities (Table III).

Table 3. Flood-associated 1979 reef mortality.

Site	Date	Bottom Salinity	Percent Mortality
Square Handkerchief	5/09	.14 ppt	–
Square Handkerchief	5/17	.50	35%
Square Handkerchief	5/21	–	60
Square Handkerchief	5/31	8.0	87
Square Handkerchief	6/15	8.0	93
Square Handkerchief	7/01	6.0	95
St. Joseph's Point	5/09	.36 ppt	7%
St. Joseph's Point	5/17	.20	20
St. Joseph's Point	5/31	0.0	56
St. Joseph's Point	6/15	4.0	59
St. Joseph's Point	7/01	6.0	60
Waveland	5/09	.02 ppt	–
Waveland	5/17	.22	12%
Waveland	5/31	1.0	54
Waveland	6/15	–	70
Waveland	7/01	4.0	–
Bay St. Louis	5/09	.50 ppt	–
Bay St. Louis	5/17	.20	–
Bay St. Louis	5/31	0.0	51%
Bay St. Louis	6/15	–	–
Bay St. Louis	7/01	–	–
Pascagoula	6/15	12.0 ppt.	20%
Pascagoula	7/01	–	24
Graveline Bay	6/15	10.0 ppt	6%
Graveline Bay	7/01	–	4
Horn Island	6/15	18.0 ppt	35%
Horn Island	7/01	11.0	10
Biloxi Bay	6/15	14.0 ppt	6%
Biloxi Bay	7/01	10.0	10

Soon after the results of these latest samples had been completed, the notice that disaster funds monies had been obtained reached the Bureau of Marine Resources. Within two weeks, a contract proposal had been drawn up, was advertised, and awarded to Radcliff Materials, Inc. of New Orleans, La. The contract called for a total of 66,000 cubic yards of clamshells to be delivered and deposited in areas from St. Joe Point to Pass Christian (Figure II).

It became readily apparent that a maximum of 3-4 barges per day could be delivered and planted. The initial delivery was made at St. Joseph's Point on August 20, 1979. Planting was continued on this 14 acre site until 6,000 cubic yards had been planted yielding a density of approximately 432 cubic yards per acre.

Considerable differences of opinion exist in regards to optimal planting densities and configurations. The Louisiana oyster industry may plant cultch at densities as high as 500 yd^3/acre on relatively small plots while the Louisiana Wildlife and Fisheries Commission plants cultch at rates of 30-50 yd^3/acre on state oyster bottoms (VanSickle, et al, 1976). Typically the cultch materials are evenly spread; but in Texas, planting in mounds or piles has been successful for many years (Gunter, 1972). Reefs of this nature were first created in Texas waters in 1948 and still remain productive. For the purposes of this project, it was decided to apportion cultch based solely upon need but within the limits of accepted procedures.

On this basis, the St. Joe Reef was planted at the greatest shell density; the reef was depauperate of existing shell, and the mortality rate was second only to the Pass Christian area. While the Pass Christian reef suffered the highest mortality, it also exhibited bottoms with vast quantities of consolidated and loose shell, hence little need for dense cultch planting. For this reason, this largest area, consisting of some 545 acres, was planted only to a density of 59 yd^3/acre.

In most cases, the barges were continuously underway dispersing shells in an even pattern across a marked site. The Waveland reef, however, was mounded as was the small tonging reef between the bridges in the Bay of St. Louis. These relatively small areas (15 and 4 acres, respectively) precluded much movement by the barge.

The exact quantities of shell delivered and the dates and sites of planting are shown in Table IV.

Because of an expected reduction in spawning, the project was terminated for the year and resumed in the Spring of 1980.

SUMMARY & CONCLUSION

A total of 87,000 cubic yards of clamshell (*Rangia cuneata*) was deposited at nine preselected sites in Mississippi Sound during August - September 1979, and June 1980, covering approximately 642 acres of waterbottom. The shell deposits were made to revitalize reefs damaged by spring floodwaters released by the Bonnet Carre Spillway.

Periodically and with some degree of unpredictability, such flooding can be expected to continue to affect the

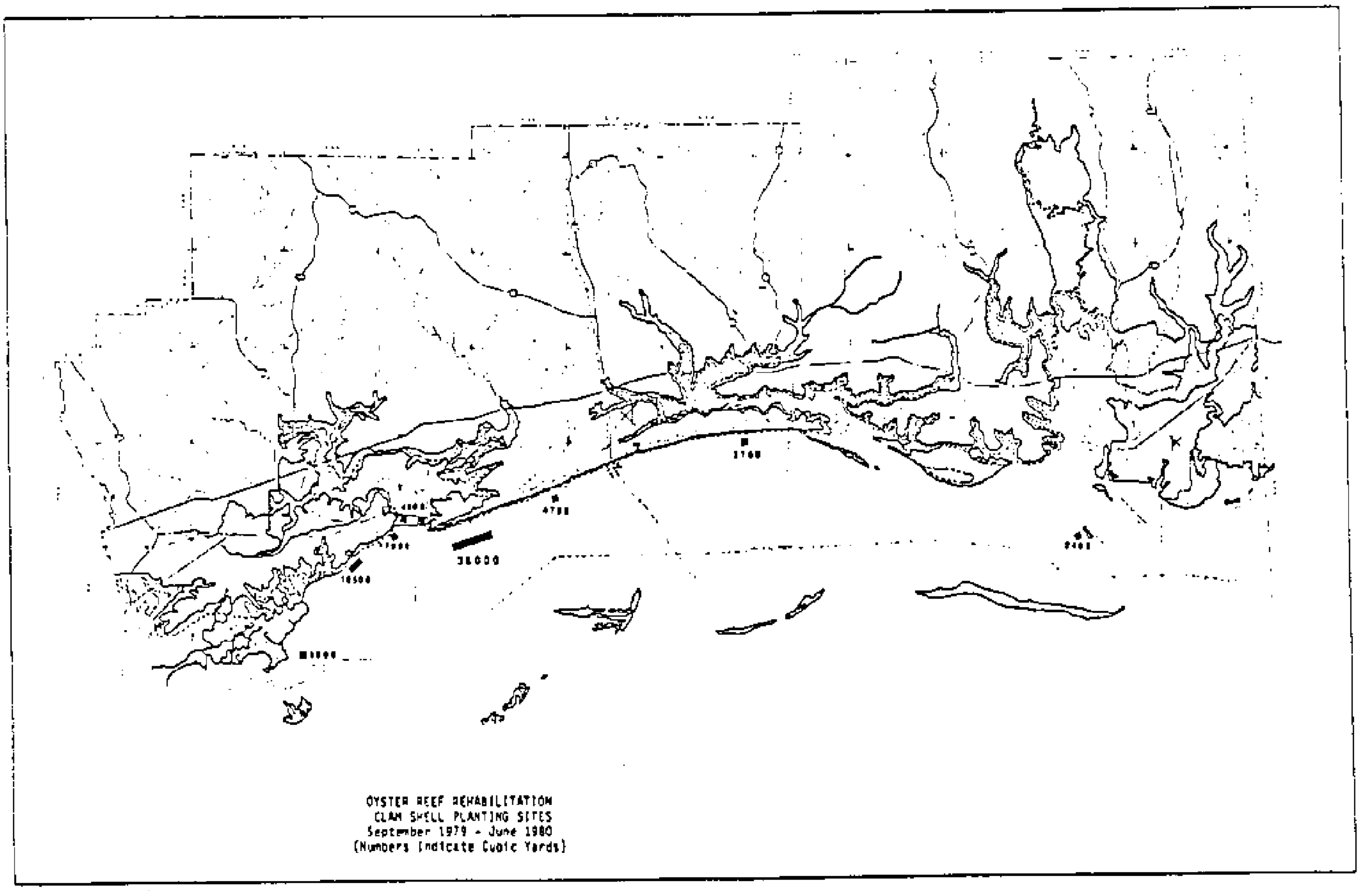

Figure 2.

Table 4. Oyster reef restoration effort.

Barge No.	Receipt No.	Date Measured	Date Planted	Site	Quantity
401	3678	8/20/79	8/21/79	St. Joe	916
M653	3677	8/20/79	8/21/79	St. Joe	887
M827	82351	8/20/79	8/20/79	St. Joe	1173
M824	82353	8/20/79	8/20/79	St. Joe	1094
M818	82352	8/20/79	8/20/79	St. Joe	1223
414	82355	8/21/79	8/22/79	St. Joe	790
M818	82354	8/21/79	8/22/79	Waveland	1237
M827	3686	8/22/79	8/22/79	Waveland	1349
ST19	3685	8/22/79	8/24/79	Waveland	1681
M824	3683	8/22/79	8/23/79	Waveland	1190
M690	3684	8/22/79	8/24/79	Waveland	1120
M818	3691	8/23/79	8/24/79	Pass Christian	1303
414	3690	8/23/79	8/24/79	Pass Christian	950
401	3689	8/23/79	8/25/79	Pass Christian	780
A214	3688	8/23/79	8/25/79	Pass Christian	896
M692	3687	8/23/79	8/25/79	Pass Christian	1231
411	3693	8/24/79	8/25/79	Pass Christian	946
402	3692	8/24/79	8/26/79	Pass Christian	914
M690	68802	8/26/79	8/26/79	Pass Chrsitian	1327
M827	68801	8/26/79	8/26/79	Pass Christian	1227
401	3695	8/27/79	8/27/79	Pass Christian	970
M824	3696	8/27/79	8/27/79	Pass Christian	930
ST19	68803	8/27/79	8/28/79	Pass Christian	1666
411	82360	8/29/79	8/29/79	Pass Christian	993
A214	68805	8/29/79	8/29/79	Pass Christian	1276
M804	82361	8/29/79	8/30/79	Pass Christian	1143
414	3700	8/29/79	8/30/79	Pass Christian	737
M824	82366	8/31/79	8/31/79	Pass Christian	1324
M692	82365	8/31/79	8/31/79	Pass Christian	1437
M827	82367	8/31/79	9/01/79	Pass Christian	1340
M690	82368	8/31/79	9/02/79	Pass Christian	1199
414	68814	9/01/79	9/02/79	Pass Christian	1022
M818	82369	9/01/79	9/01/79	Pass Christian	1461
M804	82370	9/01/79	9/01/79	Pass Christian	1432
ST19	68813	9/02/79	9/02/79	Pass Christian	1500
M824	68819	9/02/79	9/02/79	Pass Christian	1408
M690	68820	9/02/79	9/03/79	Pass Christian	1368
M818	68821	9/03/79	9/03/79	Pass Christian	1413
M692	68822	9/03/79	9/03/79	Pass Christian	1331
A214	82371	9/03/79	9/04/79	Pass Christian	1180
402	82372	9/03/79	9/04/79	Pass Christian	1065
M827	82428	9/03/79	9/04/79	Pass Christian	1097
411	82373	9/04/79	9/05/79	Pass Christian	1107
414	68826	9/05/79	9/05/79	Bay St.Llouis	709
M804	82374	9/05/79	9/06/79	St. Stanislaus	1414
A214	68827	9/05/79	9/07/79	St. Stanislaus	1372
ST19	82375	9/05/79	9/07/79	St. Stanislaus	1406
M818	3801	9/06/79	9/08/79	St. Stanislaus	1327
M690	68829	9/06/79	9/08/79	St. Stanislaus	1376
M827	68828	9/06/79	9/09/79	St. Stanislaus	1253
402	68831	9/06/79	9/07/79	St. Stanislaus	1051
411	68830	9/06/79	9/08/79	St. Stanislaus	1060
M804	68833	9/07/79	9/09/79	St. Stanislaus	1529
M824	68834	9/08/79	9/09/79	St. Stanislaus	1365
M827	68836	9/08/79	9/10/79	St. Stanislaus	1394
M837	8103	6/16/80	6/16/80	Waveland	1383
M831	8104	6/16/80	6/16/80	Waveland	1082

M842	8105	6/16/80	6/16/80	Waveland	1417
M822	8106	6/16/80	6/17/80	St. Stanislaus	1393
M696	8107	6/17/80	6/17/80	St. Stanislaus	1064
M838	8108	6/17/80	6/18/80	Bay St. Louis	1224
M845	8109	6/17/80	6/18/80	Bay St. Louis	1388
M830	8110	6/17/80	6/18/80	Bay St. Louis	1432
M810	8111	6/18/80	6/19/80	Long Beach	1218
M696	8112	6/18/80	6/19/80	Long Beach	1061
M824	8113	6/18/80	6/19/80	Long Beach	1276
M822	8114	6/18/80	6/19/80	Long Beach	1132
M851	8115	6/19/80	6/20/80	Round Island	1249
M849	8116	6/19/80	6/20/80	Round Island	1109
M509	8117	6/19/80	6/21/80	Whitehouse	2319
M839	8118	6/19/80	6/21/80	Whitehouse	1361

productivity of Mississippi's oyster reefs. Thus, the need for a continuing program of cultch planting is recognized. A reason for serious concern in regard to any cultch planting program is that prolonged low salinity may cause very brief periods of spat set, and only by careful monitoring and assessment can these limited, minor peaks be recognized and the planting operation be rendered successful. It is hoped that the spat concentrations monitored thus far do not lead to false optimism, rather that they are indicative of a good set and will herald a season of record oyster production in the very near future.

The success of this revitalization effort will depend entirely upon the survival to maturity of the oysters which result from the excellent spat sets observed during both phases of the project. Harvestable oysters are expected from the September 1979 planting by the latter part of the 1980 season (vi. February - March - April, 1981) (Cake 1979, personal communication), and additional marketable oysters should result from the second, very successful spat set observed in June 1980 by the following year's season (Demoran personal communication).

BENTHIC COMMUNITY CHARACTERIZATION OF MISSISSIPPI SOUND

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SUMMARY

Mississippi Sound serves as a vital navigation route for both intracoastal and inshore-offshore transport of water-borne commerce. The numerous channels which cross the Sound require maintenance by the Army Corps of Engineers to facilitate such traffic. A review of impacts of waterway dredging on the Sound ecosystem has indicated a need for substantive baseline data collection, including a characterization of the benthos and their distribution in relation to physical-chemical conditions. Barry A. Vittor & Associates, Inc. was contracted by the Mobile District Corps of Engineers to perform these studies. The field sampling program involved examination of 56 points throughout the Sound. These stations were distributed proportionately among the several sedimentary zones present, and were sampled during the Fall (1980) and Spring (1981). Parameters measured included sediment texture, total organic carbon, species abundance, and biomass. The data base and statistical programs used to analyze it have been incorporated into the Spatial Data Management System for Mississippi Sound. Although the benthic characterization study will not be completed until December of 1981, it has already resulted in three major accomplishments: (1) creation of the first geographically and taxonomically comprehensive macro-infaunal data base for the Sound; (2) creation of an updated surface sediment distribution map for the Sound; and (3) development of a workable system for relating sediment and hydrographic habitat parameters to benthic infaunal communities. Our initial analyses of the Fall, 1980 sample set has produced at least 330 infaunal taxa, excluding Oligochaeta and Insecta. Polychaetes dominate all habitats in the study area, as expected. In fact, one polychaete *(Myriochele oculata)* comprised over 40% of the total organisms encountered (over 198,000). Three other poly-chaetes-*Owenia fusiformis, Paraprionospio pinnata,* and *Mediomastus spp.*-together represented over 13% of all individuals. One mollusk-*Gemma gemma*-comprised over 5% of all organisms, but this was primarily a result of exceptional abundance at one station. Species diversity (Shannon-Wiener, log base) ranged from 0.22 to 3.16. (The extremely low diversities resulted from localized unusual numbers of species such as *Gemma gemma* and *Myriochele oculata.)* Mean diversity was 2.15 while mean individual abundance was 7090/m^2. Although no general correlation existed between abundance and diversity, stations with very low diversities often also had high numerical abundance. Cluster analysis of the Fall data set delineated community (species) and station groupings. How these groupings are interrelated will be determined through factor and canonical correlation analyses. The principal objective of these pending analyses is to define how benthic community structure may vary in response to dredging-induced changes in Mississippi Sound habitats. An additional goal of the overall benthic program is to document relationships between benthic communities and selected demersal fishes of commercial importance.

GEOLOGIC EVOLUTION OF THE MISSISSIPPI SOUND AREA, MISSISSIPPI-ALABAMA; A BRIEF ACCOUNT

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INTRODUCTION

The post-late Miocene geologic development of the general Mississippi Sound area, including the surrounding mainland coast and islands is summarized. Results, provided by extensive core-drilling and field work at the Gulf Coast Research Laboratory over the past decade greatly increased previously available knowledge. Understanding of the geological history and the present hydrological-sedimentological setting of the Sound is an indispensable prerequisite for the study of physical, chemical and biological conditions and processes that prevail here.

MIOCENE EPOCH

The oldest unit that outcrops a few kilometers inland from the present shoreline is the several hundred m thick Upper Miocene Pascagoula Formation (McGee, 1891). Consolidated, bluish-green, bluish-gray clays and muddy (silty-clayey) beds alternate with sand lenses that provide artesian water supply for the Gulf coastal area. The Formation's total thickness, due to serious problems of stratigraphic correlation, is still unknown. Without adequate bio- and lithostratigraphic justification (Otvos, 1973, p.3; 1981a, p. 1b-1) the upper part of this sequence had been designated by Brown and others (1944) as the "Pliocene Graham Ferry Formation." Authors of Geological Survey water-supply papers (Harvey and others, 1965; Newcome and others, 1968) also adopted this formation name. These sediments were deposited in paralic, estuarine and nearshore marine environments, including stream floodplains, bays, lagoons and full, marine salinity facies. Surface elevations of the unit commonly range between +18 m, about 15 km inland, and -18-to- -22 m, under the offshore islands.

PLIOCENE EPOCH

The silty-sandy, occasionally sandy-gravelly Citronelle Formation, an alluvial deposit, is often characterized by bright yellowish-brown, orange and reddish colors. Usually only 12-24 m thick, it overlies the Pascagoula beds with pronounced unconformity. The upland terrain, a few kilometers inland and farther north, is 18-30 m above sea level, is formed and is underlain by Citronelle beds. Seaward, the Formation often is terminated by relatively steep, scarp-like slopes (Fig. 1). Occasional slope-parallel depressions parallel the scarp-toes in south Hancock County and resemble sag ponds, caused by fault movements. The assumption that at least some of the scarps are of tectonic (fault?) origin is suggested by the linear continuity between a 15 m-high, shore-parallel (E-W) Citronelle scarp and an adjacent, low scarp, cut in the late Pleistocene Prairie Formation, north and northeast of Bayou la Batre, Alabama. Other drainage lineaments on the Prairie surface, to the north run semi-parallel with it. Due to the absence of correlatable stratigraphic horizons at shallow depths, the fault origin of the scarps has not yet been conclusively proven. Enclosed, oval and semi-circular depressions on the Citronelle surface indicate eolian erosion that probably occurred soon after the closing phase of Citronelle sedimentation (Otvos, 1976a).

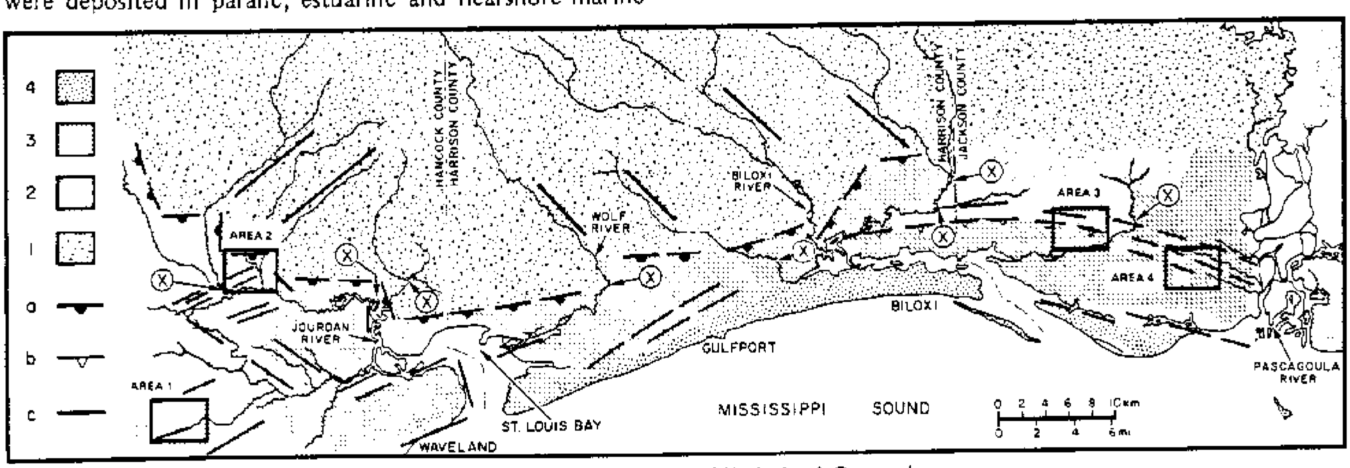

Fig. 1 Surface geology of the Mississippi Coast, between Pearl and Pascagoula Rivers. Key: 1-Citronelle Formation; 2-early Pleistocene unit; 3-Prairie Formation; 4-Gulfport Formation. Blank land areas: Holocene; a-Citronelle scarp; b-Big Ridge Scarp; c-drainage and shoreline lineaments; x-abrupt stream course change.

PLEISTOCENE EPOCH

Silty-sandy, occasionally gravelly deposits, with +12-+15 m summit elevations in isolated areas are remnants of a once-continuous coastwise plain. Unlike the present, younger, lower and still continuous Prairie coastwise plain, it has been subjected for a long period to erosion. Dusky red and pink, cross-laminated silty sand beds intertongue in the Lamey Pit, 4 km north of Big Ridge Scarp, with clayey-sandy silt beds that accumulated in floodplain lakes and ponds. 25-75 cm thick lenses of carbonized pine tree fragments (loblolli and slash pine cones included) occur in the lake deposits (Figs. 2,3). Pale yellow, oxidized silty sands commonly form the surface deposits. Brackish water and marine fossils were absent in all outcrops and pits.

The largest contiguous area of the early Pleistocene unit is located north of 20 km-long Big Ridge Scarp that bounds the unit on the south and faces the coastwise Prairie plain, present at +6 m elevation. In the past four decades (Brown and others, 1944; several more recent meeting-abstracts) repeated attempts have been made to correlate the Atlantic marine terrace surfaces with Mississippi-Alabama higher coastwise plain levels. The Scarp and various interfluve ridges elsewhere in the coastal area (Otvos, 1972a) have been claimed to be wave-cut surfaces, barrier beach ridges and spits. Such claims disregarded the total absence of fossil evidence and the presence of sedimentary textures that disproved the shoreface, beach and littoral dune origins of the sediments involved. The level summit along the Scarp provides no morphological similarity with beach ridge or littoral dune ridge profiles either.

In the absence of correlatable subsurface horizons in the shallow subsurface and appropriate seismic information, the fault origin of this scarp is yet to be conclusively proven. Sagpond-like features along the scarp toe and the lateral continuity of the scarp in Area 3, Figs. 1,4) eastward of the unit, with sets of rectangular drainage lineaments on the Prairie surface (Otvos, 1978a), however, strongly suggests such an origin.

The apparent absence of pre-Sangamon Pleistocene marine coastal features in the Mississippi-Alabama area and probably also in other Gulf coast areas is significant and may be related to regional uplifts and subsequent erosion.

LATE PLEISTOCENE: BILOXI, PRAIRIE AND GULFPORT FORMATIONS

Biloxi Formation. During the period of high sea level of the Sangamon Interglacial (130-120 yr B.P.), the transgressing Gulf deposited silty-muddy, silty-sandy sediments in bays, stream estuaries (Fig. 6) and along the open shore. These formed the various facies of the 4-16 m thick Biloxi Formation (Figs. 1,5). Lateral gradation between highly brackish and open marine sediments were best documented in southern Hancock County drill samples. A marine embayment that apparently existed at the site of present Big Lake (west end, Back Bay of Biloxi), seem to have opened southward into the Gulf. The absence of barrier islands offshore in Biloxi times is shown by the great variety of open marine foraminifer species in the full-salinity facies under the present mainland (Otvos, 1975, 1976b, 1979, 1981b). A Mississippi River influence in southwestern Hancock County was manifested by the admixture of Upper Cretaceous planktonic foraminifers from Oklahoma-Texas source areas, Mississippi River-type mineral spectra were present in the heavy mineral fraction (Otvos and Bock, 1976). Biloxi beds occasionally were encountered as far as 2-4 km inland of the present shoreline.

Prairie Formation. Landward of the brackish Biloxi Formation facies, the Formation intercalates with and is overlain by silty-sandy beds of the Prairie Formation that was deposited in floodplains and stream channels. It contains also occasional lenses of lignite (from wood, accumulated in floodplain lakes and ponds) and gravel lenses (Fig. 7), from stream channels. The Prairie land surface that bears traces of relict meanders at a few locations (e.g., Area 1, Fig. 1) is continuous with Prairie surfaces in southeastern Louisiana, the site of its original designation. Two late Pleistocene horse teeth, the size of *Equus fraternus* and *E. hemionus* (E.L. Lundelius, Jr., written comm.), found at shallow depth beneath the Prairie surface in Moss Point, Mississippi (Otvos, 1973, 1975), represent the only animal fossils known to me from the Formation.

Diagenetic silica overgrowth over quartz grains is believed to be responsible for the frequent accumulation of angular, brick-shaped fine sand grains in and just below the soil horizon. The sand grains that were separated by carbon-tetrachloride, in the light fraction, contain pores. One outcrop, exceptionally rich in these grains is located in the trench on the side of the Chevron-USA Refinery, Bayou Casotte Road, Pascagoula, Mississippi.

In addition to previously cited lineaments, parallel and rectangular sets of drainage lineaments occur at several locations on the Prairie surface, including in Areas 2 and 4 (Fig 1).

Gulfport Formation. The predominantly well-to-very well sorted white sands that overlie the Biloxi beds represented a prograding, maximum 2 km wide barrier strandplain on the mainland shore at the Harrison County and the St. Andrews-Belle Fontaine areas, Mississippi (Figs. 1,4). Ridge summit elevations range between 4.5-10.0 m. A small segment of the Formation also exists at Bay St. Louis on the surface. Field work in recent years significantly reduced the area of earlier mapped (Otvos, 1972a) Gulfport deposits. The barrier system is part of a discontinuous ridge chain that girds the northern Gulf. Its equivalent in Texas is the Ingleside (Live Oak) barrier system (Otvos, 1972b). Unlike in Texas, no lagoonal deposits existed landward of the Mississippi Gulfport ridges.

The lower Gulfport sands, as elsewhere (Swanson and Palacas, 1965) often are cemented by the dark brown humate. This formed from downward percolating soil solutions some time after deposition of the Gulfport sands. North of Pass Road in Gulfport and Biloxi, Mississippi, the Gulfport Formation directly overlies oxidized silty sands of the Prairie Formation, instead of Biloxi beds. These Gulfport sands probably represent exclusively eolian dune sands, blown over the alluvial plain, located landward of the prograding barrier.

Fig. 2 South wall, Lamey Borrow Pit (NW ¼ of sec. 34, R. 9 W., T. 6 S.; Jackson County, Mississippi). 25-75 cm thick lenses (arrows) of carbonized pine wood fragments, overlain by light gray, yellowish-orange silty-clayey fine sand units.

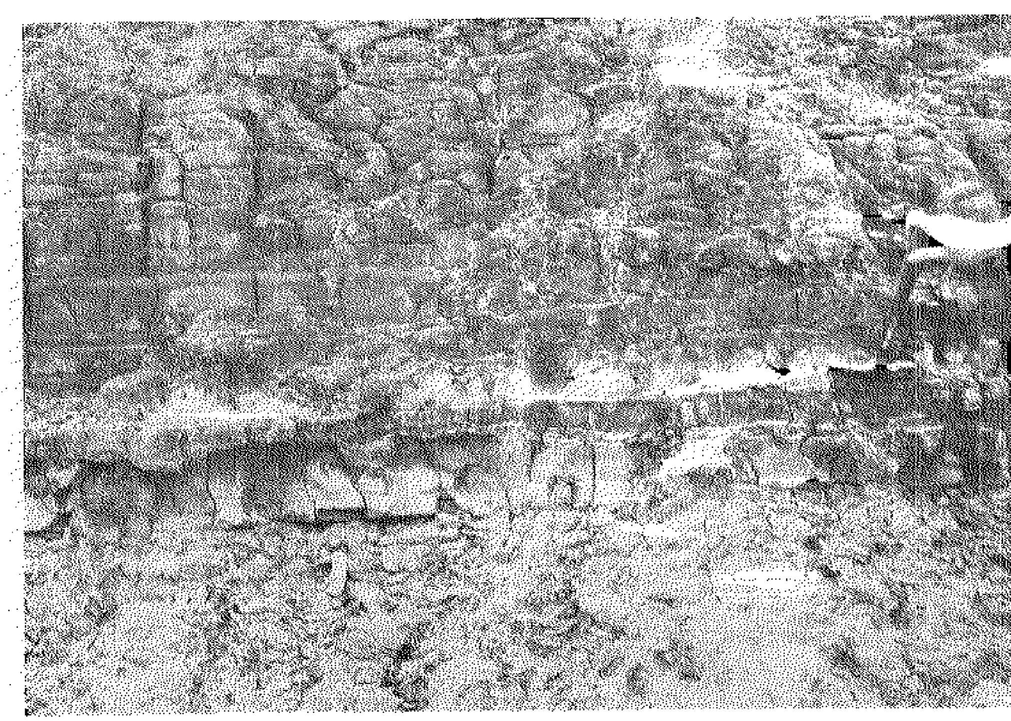

Fig. 3 West-central part, Lamey Pit, Finely laminated and bedded gray, clayey-sandy silts, 1.5-2.5 m thick. With occasional roots in growth position and carbonized wood fragments (floodplain lake facies). Scale: hammer.

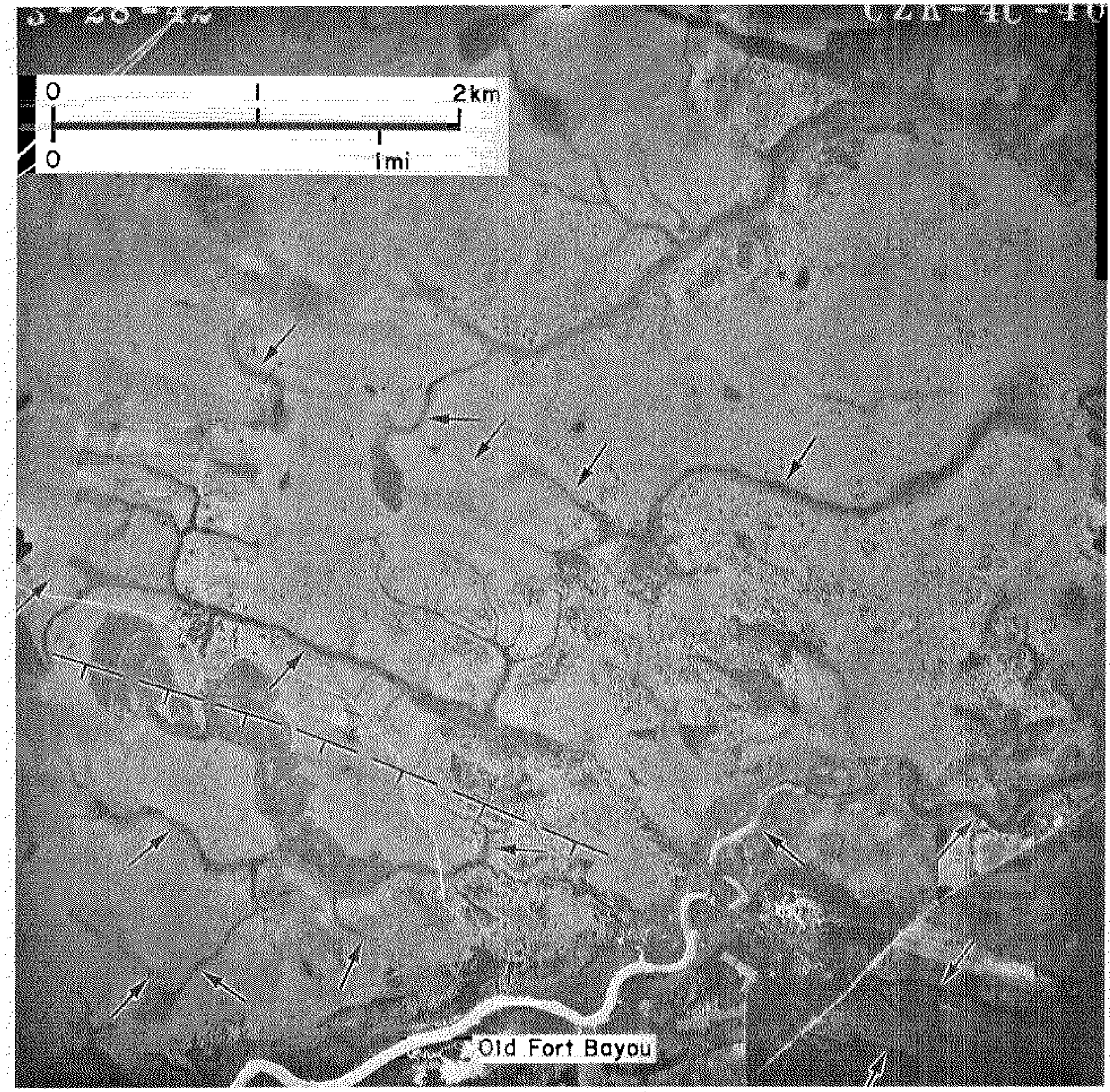

Fig. 4 Parallel and perpendicular sets of fine drainage lineaments (arrows), Area 3, Jackson County (see: Fig. 1). Barbed-dashed line: Big Ridge Scarp that ends at Old Fort Bayou. Lineaments continue from earlier Pleistocene (north of Scarp), into Prairie surface (south of Old Fort Bayou and of Scarp).

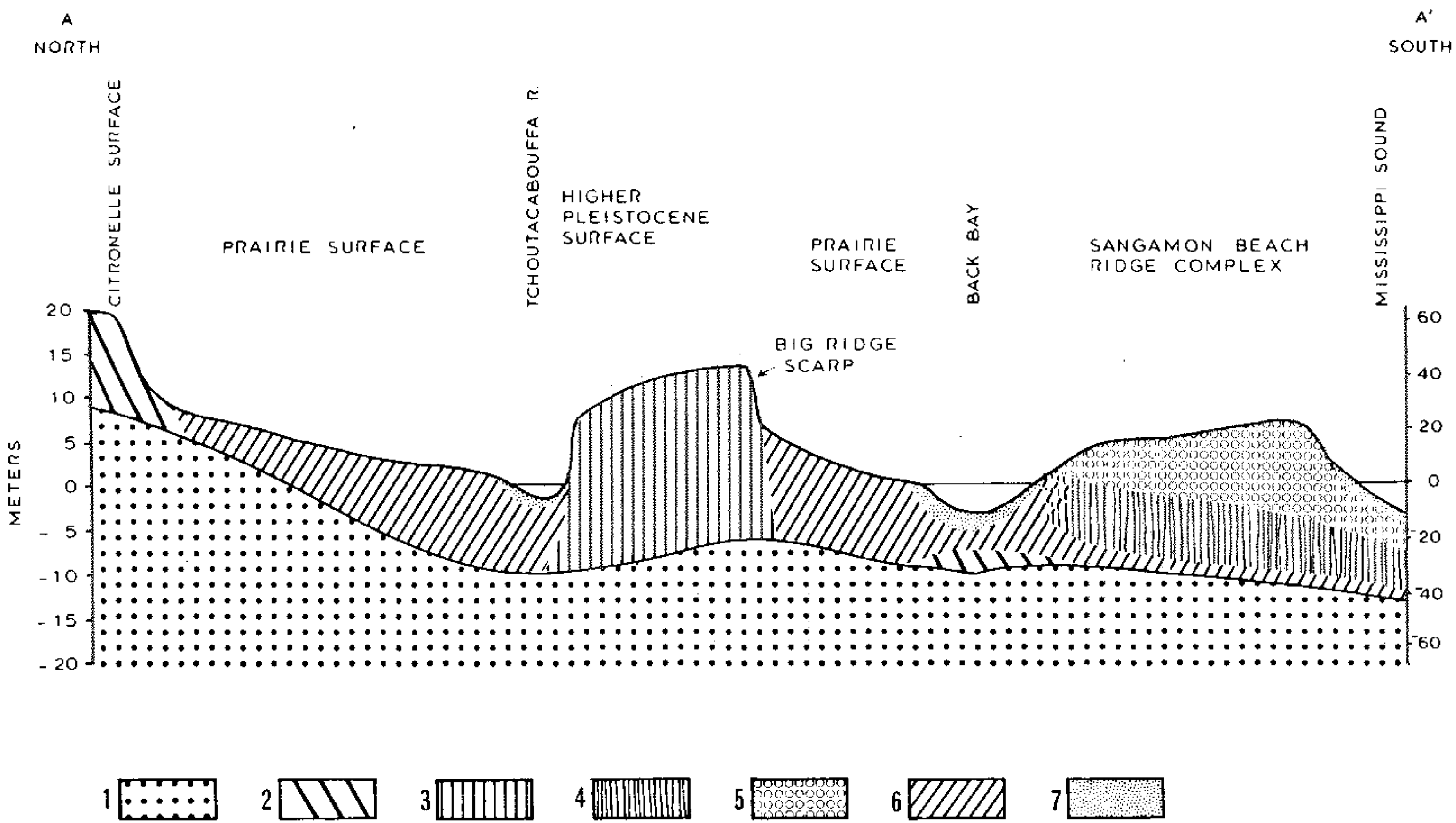

Fig. 5 Schematic north-south cross section across coastal area just west of Harrison-Jackson County line. Key: 1-Pascagoula Fm (Miocene); 2-Citronelle Fm (Pliocene); 3-earlier Pleistocene unit; late Pleistocene: 4-Biloxi Fm; 5-Gulfport Fm; 6-Prairie Fm; Holocene: 7-beach and stream deposits.

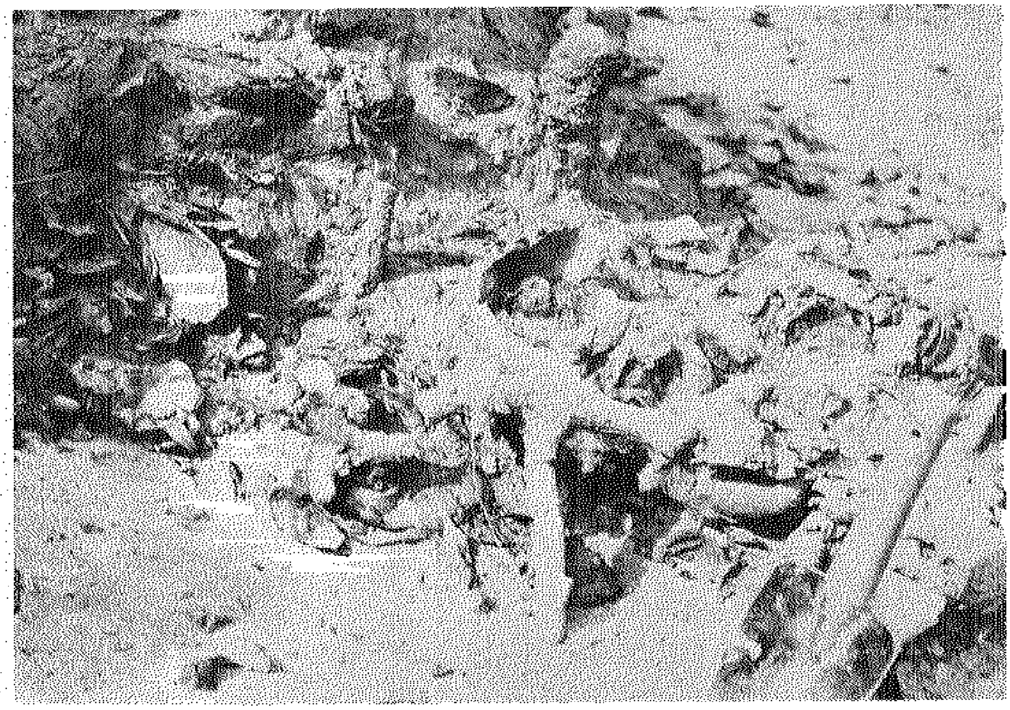

Fig. 6 Oyster reef and *Upogebia* (shrimp) burrow tubes in estuarine Biloxi Formation deposits. Lorraine Road bridgehead, Industrial Seaway, Harrison County, Mississippi. Scale: hand shovel.

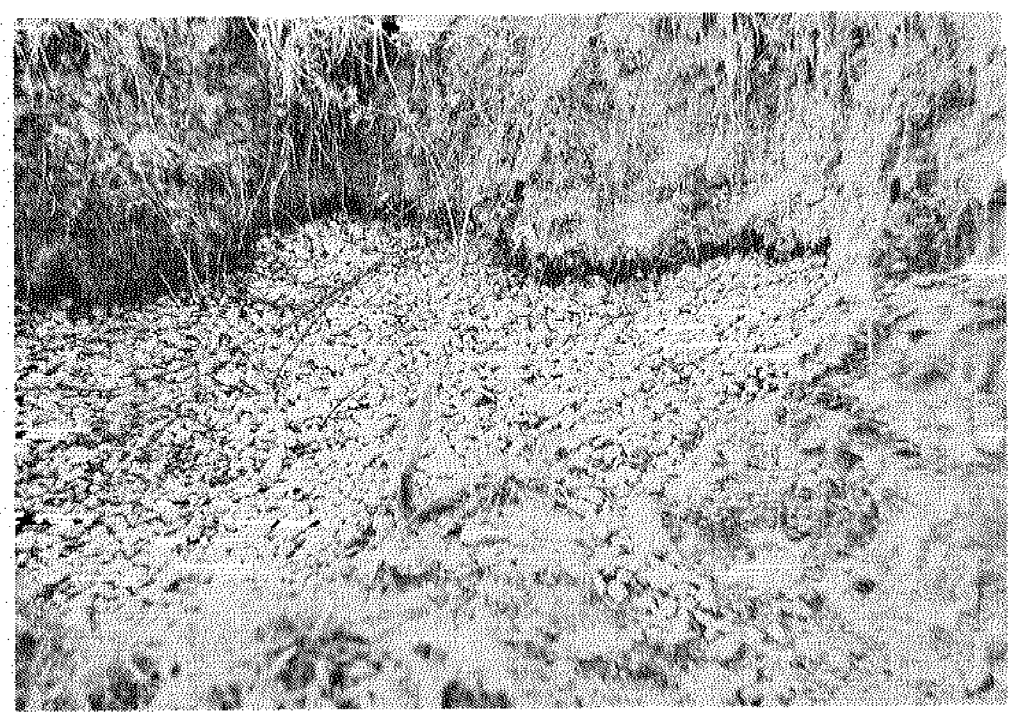

Fig. 7 Sandy gravel lense (stream channel deposits; Prairie Formation) overlying Biloxi sandy-muddy deposits. South bank, Industrial Seaway, Harrison County.

HOLOCENE

Transgressive phase

As sea level rose in very late Wisconsin and early-mid Holocene times, river valleys in the inner shelf gradually became estuarine embayments. Among the incised former river channels, as of now, only the Pascagoula channel under Horn Island has been positively identified in seismic surveys. The valley of the ancestral Biloxi River that evolved behind the Gulfport barrier plain during Wisconsin times was inundated in the closing period of the transgression and turned into the Back Bay of Biloxi. Other, partly enclosed and open bays, as St. Louis and Pascagoula Bays in Mississippi; Grand and Portersville Bays in Alabama, evolved in the same time. Radiocarbon dates proved that in the Back Bay area fresh marshes existed at about -8.5 m elevations at 6,580 yr B.P. Due to the transgression, about 5,690 yr ago when the sea level reached -7 - -7.5 m, conditions turned brackish here (Otvos, 1976b). The outline of the present mainland shoreline was influenced both by the positions of the Gulfport barrier segments and, in the St. Louis Bay, Back Bay and Graveline-St. Andrews areas by topographic lows, apparently related to tectonic lineaments. These lineaments, including certain segments of the present shoreline (Fig. 1), parallel the earlier discussed Pliocene-Pleistocene lineaments.

The microfauna content in the Holocene sediment sequence under Mississippi Sound in a number of drillhole-sections (Figs. 8,9; Otvos, 1979, 1981b) shows that the present barrier island chain (Ship, Horn, Petit Bois and Dauphin Islands) did not exist before the eustatic sea level rise greatly slowed down about four thousand years ago. Despite the absence of the islands, due to fresh water influx from two major (Pearl and Pascagoula) and numerous minor streams (Jourdan, Wolf, Biloxi, Tchoutacabouffa, Old Fort, Escatawpa and others), conditions remained fairly brackish immediately adjacent to the mainland shore. While full-marine salinities prevailed only some distance offshore, the salinity gradient seaward was still much steeper at this time than it is today, in the protection of the barrier islands.

Due to their somewhat higher elevations, areas the form parts of present-day eastern Dauphin, Round and Deer Islands and underlain by oxidized late Pleistocene deposits, escaped inundation. Only Holocene beach and dune sands cover them. Littoral drift from the mainland shores of southeastern Alabama reached the present eastern Dauphin Island via a new, large ebb-tidal delta off Mobile Bay entrance. Sand transmitted westward along the south shore of Dauphin Island formed the foundation of an about 230 km long late Holocene barrier island-shoal chain that emerged from the sea between Dauphin Island and the present Jefferson Parish-New Orleans metropolitan area (Otvos, 1978, 1979). While the offshore distance of the large Mississippi islands is unusually great (12-17 km), two small islands (Point Clear and Campbell) east of the Pearl River delta aggraded above the sea level only 450-900 m from the mainland shore (Figs. 8, 10).

St. Bernard subdelta phase

The growth of the two large "St. Bernard" subdeltas of the late Holocene Mississippi River, south of the present coast of Mississippi (delta lobes #8 and #9; Frazier, 1967, p. 308) had a great impact on coastal conditions. Between c. 3,000-2,300 yr. B.P., the northern subdelta (#8) extensively prograded into the Gulf. The northern-northeastern shores of the delta were located probably only 3-20 km south of present Cat, Ship and Horn Islands. Large volumes of suspended river sediments must have reached the Mississippi coastal area during this period. The new land area, by considerably reducing wave energy west of Ship Island, stopped any further strandplain progradation on Cat Island. The eastern end of that island, not receiving sufficient sand drift volumes from the east, started to erode. North of present-day New Orleans, a broad marine embayment was closed off by deltaic growth and became Lake Pontchartrain (Otvos, 1978). The Pearl River delta steadily expanded into recently formed Lake Borgne.

Griffin and Parrott (1964, p. 65-66), by using clay samples from the Beauvoir (west Biloxi) - east Ship Island line of drillholes, attempted to establish a threefold subdivision of the Holocene sequence under the Mississippi Sound. By plotting montmorillonite/kaolinite peak ratios from X-ray diffraction curves, they claimed that the "kaolinitic" basal unit represented conditions during the Holocene marine transgression when suspended Mississippi River sediments did not yet reach the area of the present Sound "and the oxidized kaolinitic Pleistocene surface was being reworked." The middle unit, with large montmorillonite content, was derived largely from Mississippi River sediments of the St. Bernard phase; while the "kaolinitic top unit" was believed to represent present-day conditions, the influence of streams from the Mississippi mainland.

To test these claims, twenty glycolated Holocene clay samples were analyzed in 1977-78 from nine of our coreholes on Ship and Horn Islands and from the Mississippi Sound between Ship and Petit Bois Islands. In four drillholes the samples came from four depth intervals, ranging from within 0.15-0.9 m above the Pleistocene-Holocene interface, up to the recent bottom sediments. The X-ray analysis methods were identical to methods discussed in the Appendix of a related paper (Otvos, 1978). The results failed to prove the existence of a threefold subdiyision in the Holocene sediments at Ship Island or elsewhere under the central sound.

Only a single sample, taken at about 65 cm above the Plesitocene unit in a drillhole, adjacent to S-2 (Fig. 8) contained larger amounts of kaolinite (45.4%). All other samples, including those taken immediately above the Pleistocene-Holocene interface; from or slightly below the present Sound bottom; or from positions intermediate between these, contained 77.5-94.1% montmorillonite, 8.2-16.7% kaolinite and 0.6-13.8% illite. Several of the high-montmorillonite samples came from samples that predated the St. Bernard delta phase and contained open marine foraminifer faunas. The range of clay mineral content agrees well with the ranges found in three samples from bottom sediments in the Pearl and Pascagoula Rivers (montmorillonite: 79.7-90.9%; kaolinite: 6.1-14.7%; and illite: 1.0-7.6%). In comparison, nine bottom samples from the lower Mississippi River (provided by C. Ho) and five samples from late Holocene, New Orleans-area Mississippi River deposits (Otvos, 1978, Table 4) yielded clay mineral ranges that overlap the previously quoted ones (montmorillonite: 82.1-90.4%; kaolinite: 4.3-10.1% and illite: 3.9-8.6%).

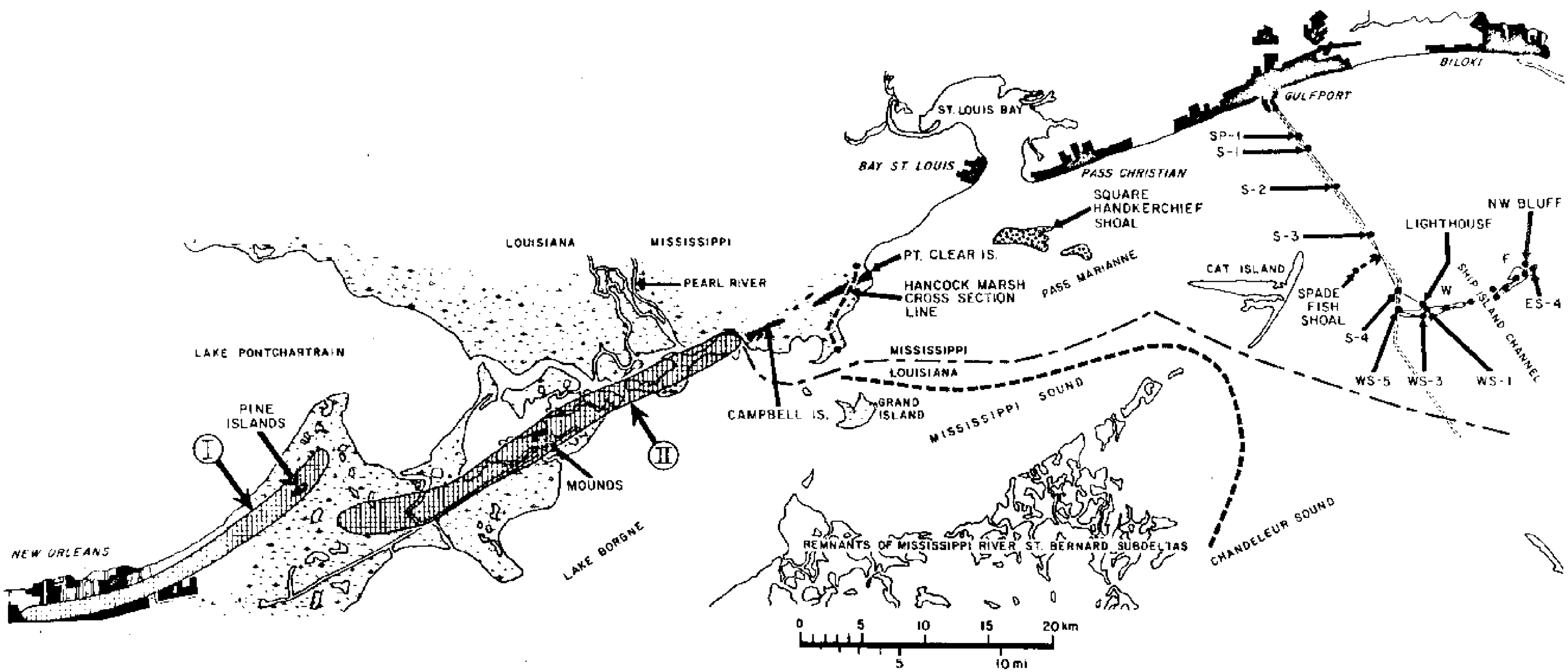

Fig. 8 Drillhole locations, western Mississippi Sound. I and II: mid and late Holocene barrier island-barrier shoal trends, present Orleans Parish area.

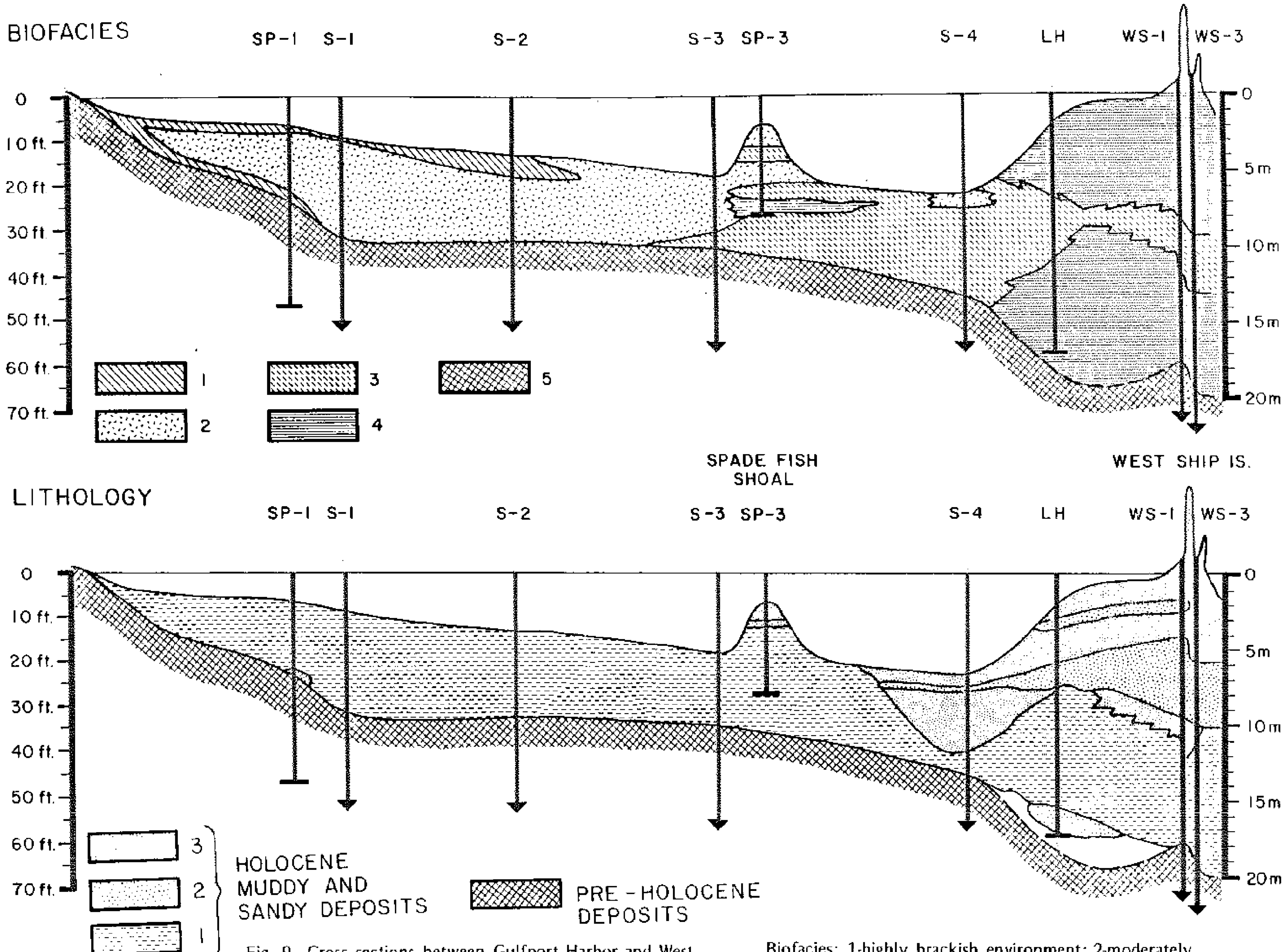

Fig. 9 Cross sections between Gulfport Harbor and West Ship Island (Fig. 8) showing depositional biofacies and lithology of Holocene deposits under Mississippi Sound.

Biofacies: 1-highly brackish environment; 2-moderately brackish; 3-intermediate; 4-open marine; 5-Pleistocene.

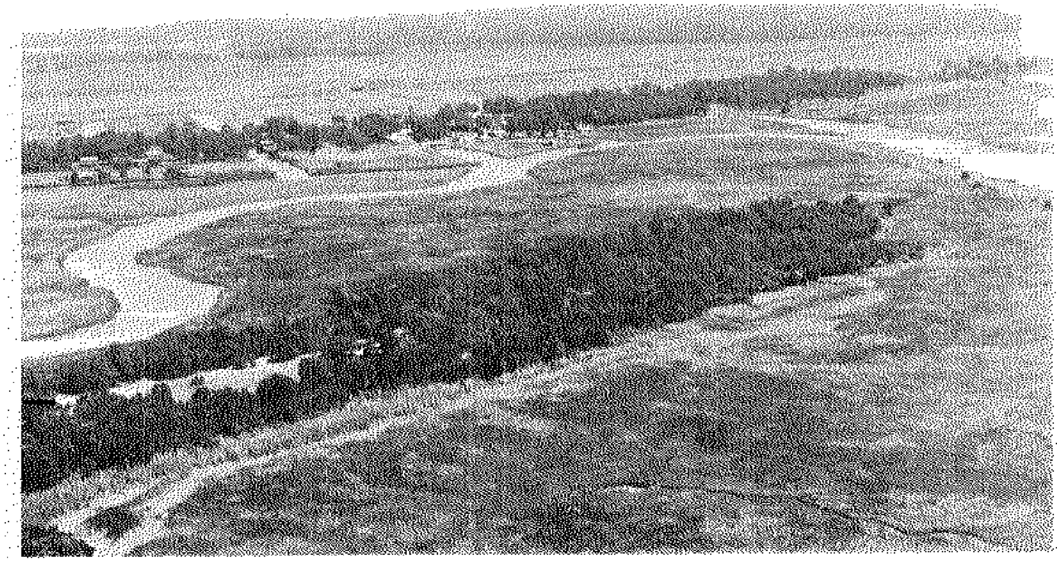

Fig. 10 Campbell Island ("stranded" late Holocene barrier island), surrounded by south Hancock County marshland (Fig. 8). Wooded zone in mid-distance: Magnolia Ridge, Holocene mainland shore dune ridge.

Clearly, our semi-quantitative clay mineral spectra were practically identical in the late Holocene and present-day Mississippi River deposits as well as in the Holocene sedimentary sequence under Mississippi Sound and in the Mississippi Sound tributary streams.

Late Holocene developments.

Following another shift of the main Mississippi River channel, away from the St. Bernard subdeltas; their subsequent destruction led to severe erosion also of the Hancock County marshlands. A remnant of the earlier, more extensive marshland survived south of Waveland into the early 20th century as one km-long St. Joseph Island. An arcuate barrier island system, the Chandeleurs, emerged roughly parallel with the original delta lobe shores and slowly shifted westward (Otvos, 1979).

On the east, a delta of the Escatawpa River was active in the Mississippi-Alabama border area in late Holocene times. Near the shore, where presently the Escatawpa abruptly turns westward, earlier the river occupied meandering channels of a previous Pascagoula River course that had been incised into the Prairie surface in early Wisconsin times between Coll Town (sec. 23, R. 6 W, T. 5 S.) and the present shoreline. A line of islets with narrow Gulf-side beaches used to front the abandoned delta before total destruction in the 1960's-1970's (Grande Batture Islands).

The Sound and the barrier islands in modern times

Historically documented hurricane-erosion (Fig. 11), normal beach erosion (Fig. 12) and steady, westward littoral drift-progradation continued to dominate island evolution over the past centuries. In the early 18th century, Dauphin Island was connected by a long, narrow sand spit to what today is known as the eastern bulge of Petit Bois Island. This 35 km-long island was cut in two parts and later segmented further several times by storm erosion (Otvos, 1979). Similarly, Ship Island was cut five times during the past 130 years (1852, 1893, 1947, 1965 and 1969). Of all the islands, the eastern end of Petit Bois retreated most between 1848-1974 (11.5 km), while the western tips of the barrier islands prograded 1.3-7.4 km westward. Land- and seaward shifts of the island shores were localized and of negligible extent. Radiocarbon-dated marsh-peat layers, originally formed in the island interiors, outcrop on many retreating shore segments. Two large sand spits that stretch N-S from the eroding east end of Cat Island, prevented littoral drift from reaching the island beaches to the west. The shores of this island are steadily eroding. Subsidence, caused largely by compaction, converted the inter-ridge swales of the original strandplain surface into elongated, narrow embayments of the Mississippi Sound.

Construction of new "embryonic" islets (Figs. 13,14) and even of a few larger islands has been documented at numerous locations, including Sand Island on the Mobile Bay Entrance ebb-tidal delta, at Dog Keys ("Isle of Caprice", between Horn and Ship Islands) and off the east tip of Horn Island, as well as in the Chandeleur island chain of Louisiana, following storm erosion (Otvos, 1981b). Permanent establishment of such barrier islands may help to explain the fact why, despite westward migration, the islands do not disappear from the eastern parts of the

Fig. 11 Parabola-shaped washover fan off Soundward shore of east-central Dauphin Island, Alabama, formed due to Hurricane Frederic, September, 1979.

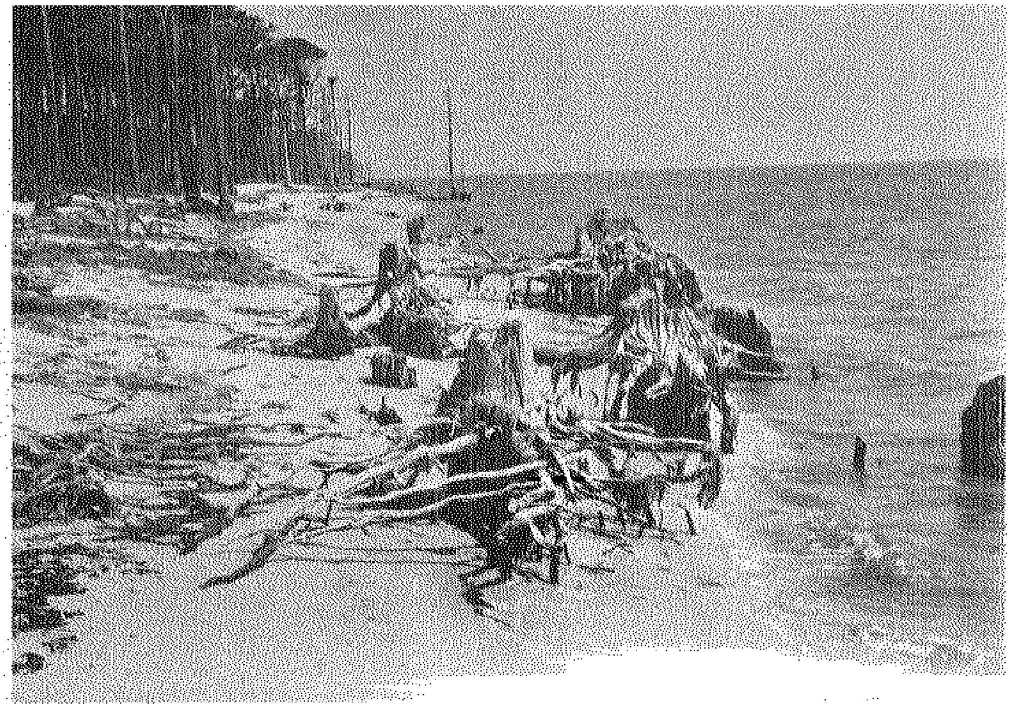

Fig. 12 Eroding beach, SW shore, Deer Island, Harrison County, Mississippi.

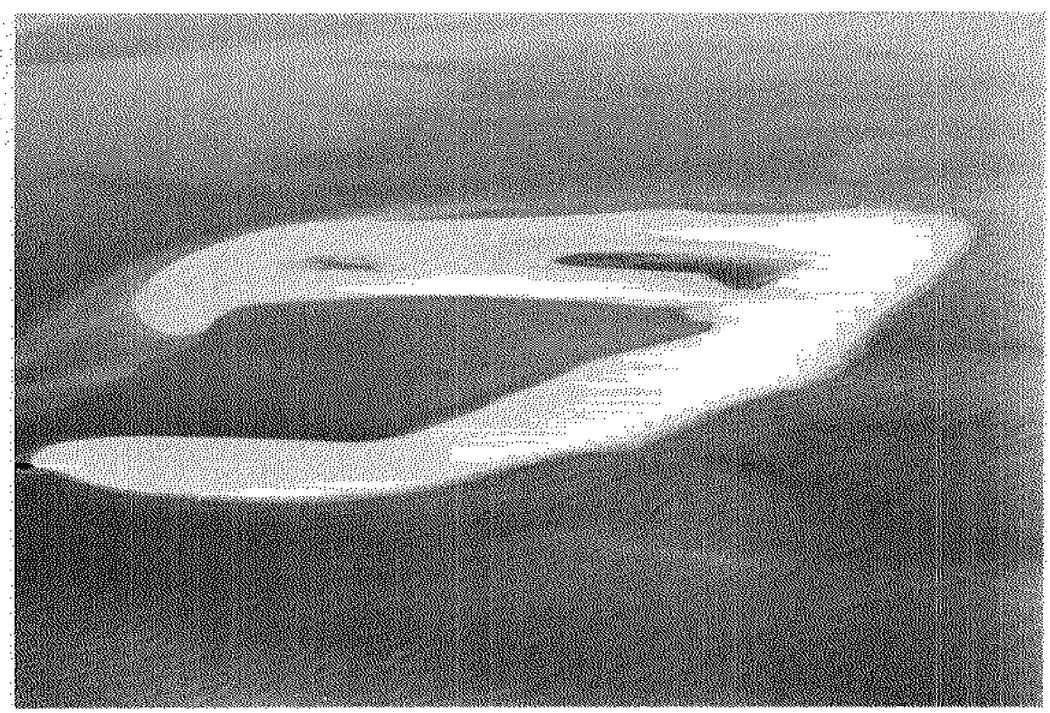

Fig. 13 Prograding "Horseshoe Island", offshore east tip of Horn Island, Mississippi (Nov. 20, 1980). Island first emerged following Hurricane Frederic, 1979.

Fig. 14 Recently emerging and prograding islet, south of Sand Island, Alabama (Otvos, 1981b) Gulf: left and top of picture. October 14, 1980.

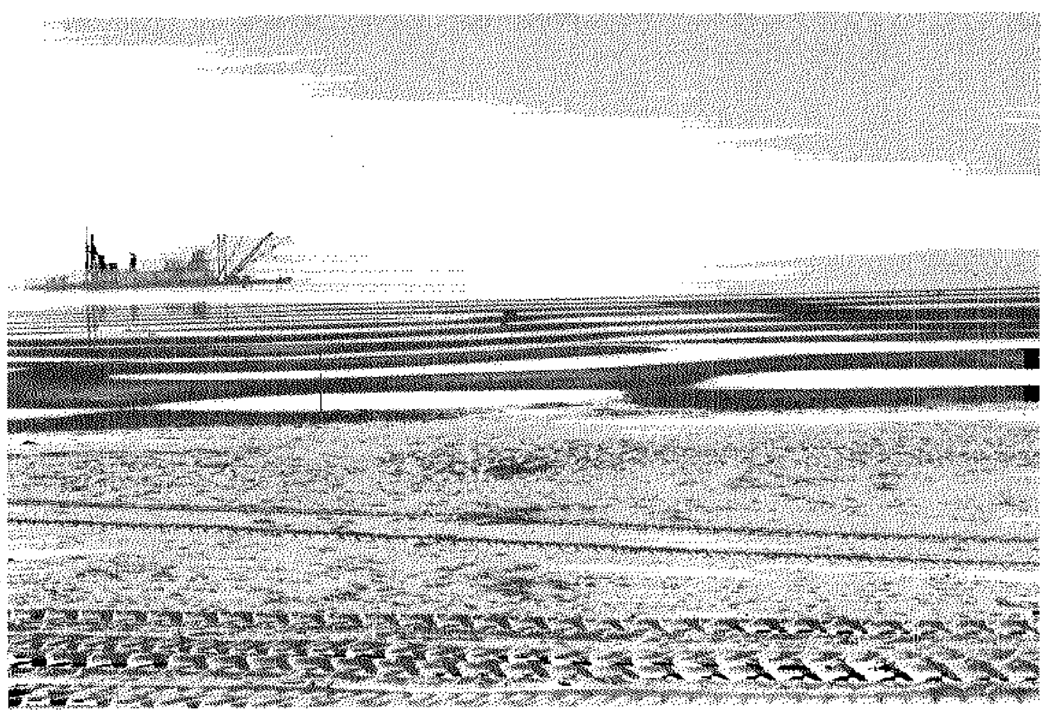

Fig. 15 Low-tidal level and offshore bar ridges. Low sea level of 1972-73 winter season. Broadwater Beach, Harrison County. Barge (background) pumps sands for beach restoration.

Sound. New islands thus may "repopulate" shallow island platform areas, vacated earlier by wholesale erosion of western island segments.

The Mississippi Sound presently occupies an area of 2,128 km^2 (Eleuterius and Beaugez, 1980). It is 131 km long and 24 km at its widest. Average depths in the central Sound range between 3.5-6.0 m; overall average depth is 2.97 m. Low-microtidal (45-55 cm) range prevails. The passage of winter weather fronts occasionally results in tidal ranges of 1.2 m or more (C. Eleuterius, pers. comm.) on the mainland shores where strong north winds significantly lower sea level. Tides are primarily diurnal. Throughout most of the year wave approach is from the SE, S and SW. This results in the dominantly westward littoral drift. Salinities vary greatly in the Sound and depend on distances from passes, the mainland shore and the estuaries, as well as on the fresh water runoff (Eleuterius and Beaugez, 1980). During half the year the water column is predominantly uniform and well-mixed, in one-third of the measurements partially mixed. Only in less than 2% of the observations was part of it a stratified estuary (Eleuterius, 1978).

Bottom sediments along the mainland and island shores are sandy and in major central Sound areas, dominantly "muddy" (silty-clayey). Complex nearshore bar patterns characterize the mainland and island shorefaces (Fig. 15). A patchwork of sediment textures characterize sediments in intermediate Sound areas and in St. Louis, Biloxi and Pascagoula Bays (Upshaw and others, 1966; Otvos, 1976c). The largest recent oyster reefs exist south of St. Louis Bay (Square Handkerchief, Pass Marianna and Telegraph Reefs) with a total area of about 7,500 acres and a maximum thickness of 4m. In historic times the growth of subaerial river deltas was not significant. Charts indicate the emergence of small delta-front islands in the western Pascagoula Delta between the 1850's and 1917.

Erosional retreat on mainland shores was most intensive in low, salt marsh-backed areas (south Hancock County and the Alabama border zone). Periodic hurricane erosion causes steady retreat of the high Belle Fontaine bluffs, composed of Gulfport sands. Low-level beach erosion on the "world's longest artificial beach" since construction of the Harrison County seawall necessitated repeated beach restoration (1951; 1972-73) with sand pumped in from offshore locations (Watts, 1958; Capozzoli, 1972).

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NUMERICAL MODELING OF MISSISSIPPI SOUND AND ADJACENT AREAS

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INTRODUCTION

Based upon a comprehensive review of currently available two-dimensional models for predicting hydrodynamic and/or constituent transport, a multioperational alternating direction implicit finite difference model was selected for application to Mississippi Sound and Adjacent Areas. The model selected was the Waterways Implicit Flooding Model (WIFM) (Butler 1980). In order to predict spatial and temporal salinity concentrations, a separate algorithm consistent with the WIFM hydrodynamics will be applied. To provide flexibility of grid location and minimize boundary data collection efforts, Texas A&M University will develop a numerical model for the Gulf of Mexico (Reid 1979). This model employs a spherical coordinate equation formulation on a 15-min longitude and latitude grid to predict the 0_1, K_1, P_1, M_2, and S_2 tidal constituents for water surface elevation and currents. The Gulf Tide Model (GTM) will be exercised to provide the boundary information necessary to drive the Mississippi Sound Circulation and salinity model (WIFM).

Model development considerations are presented initially, followed by a description of calibration/verification procedures and anticipated applications of the models.

Model Development Considerations

The general equations of the classical hydrodynamics for incompressible flow are given as follows (Lai 1979):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

$$\rho\frac{Du}{Dt} = \rho F_x - \frac{\partial P}{\partial x} + \mu\Delta^2 u \qquad (2)$$

$$\rho\frac{Dv}{Dt} = \rho F_y - \frac{\partial P}{\partial y} + \mu\Delta^2 v \qquad (3)$$

$$\rho\frac{Dw}{Dt} = \rho F_z - \frac{\partial P}{\partial z} + \mu\Delta^2 w \qquad (4)$$

With

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z} \; ; \quad \Delta^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

where

x,y,z = cartesian coordinates

u,v,w = velocity components in the x, y, and z directions, respectively

F_x,F_y,F_z = body forces

ρ = fluid density

μ = fluid viscosity

P = pressure

t = time

The following assumptions are made:

1. The water is not deep compared with the length of the wave and the shallow water theory applies.
2. The vertical velocity of flow is small.
3. The vertical acceleration of the fluid particle is very small compared with the acceleration of gravity, g, and hence, can be neglected.
4. The pressure is hydrostatic (from the above assumption).
5. The frictional resistance coefficient for unsteady flow is the same as that for steady flow; thus it can be approximated from the Chezy or Manning equation.
6. Only shear stresses due to horizontal velocity components are significant.
7. The bottom of the embayment is rigid or relatively stable and fixed with respect to time.
8. The water is nonhomogeneous but incompressible. The density-induced flow appears only in the pressure gradient terms.

The following two equations are necessary to account for the density-induced flow:

$$\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} + w\frac{\partial S}{\partial z} = \frac{\partial}{\partial x}\left(K_x\frac{\partial S}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y\frac{\partial S}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial S}{\partial z}\right) \quad (5)$$

$\rho = f(S, T)$ (wherein T, the temperature is specified and not simulated). (6)

where

S = salinity

T = temperature

K_x, K_y, K_z = turbulent dispersion coefficients in the x, y, and z directions, respectively

$f(S,T)$ = equation of state

$\rho, x, y, z, u, v, w, t$ = defined as previously

Integrating Equations 1-6 over the vertical, employing Leibniz rule, and the kinematic boundary conditions, the following depth integrated flow equations are obtained (Lai 1977):

$$\frac{\partial \overline{u}}{\partial t} + u\frac{\partial \overline{u}}{\partial x} + v\frac{\partial \overline{u}}{\partial y} = \Omega\overline{v} + \frac{1}{\rho}\zeta_h\left(\frac{\partial^2 \overline{u}}{\partial x^2} + \frac{\partial^2 \overline{u}}{\partial y^2}\right) + \frac{g(\overline{u} + \overline{v})^{1/2}\overline{u}}{c^2 h}$$

$$+ \frac{KV_w^2}{\rho h}\cos\theta - \frac{1}{\rho}\left(\frac{\partial p_a}{\partial x} + \overline{\rho} g\frac{\partial \eta}{\partial x} + g\frac{h}{2}\frac{\partial \overline{\rho}}{\partial x}\right) \quad (7)$$

$$\frac{\partial \overline{v}}{\partial t} + u\frac{\partial \overline{v}}{\partial x} + \overline{v}\frac{\partial \overline{v}}{\partial y} = -\Omega\overline{u} + \frac{1}{\rho}\zeta_h\left(\frac{\partial^2 \overline{v}}{\partial x^2} + \frac{\partial^2 \overline{v}}{\partial y^2}\right) + \frac{g(\overline{u} + \overline{v})^{1/2}\overline{v}}{c^2 h}$$

$$+\frac{KV_w^2}{\rho h}\sin\theta \quad -\frac{1}{\rho}\left(\frac{\partial p_a}{\partial y} + \bar{\rho} g\frac{\partial\eta}{\partial y} + g\frac{h}{2}\frac{\partial\bar{\rho}}{\partial y}\right) \tag{8}$$

$$\frac{\partial\eta}{\partial t} + \frac{\partial(h\bar{u})}{\partial x} + \frac{\partial(h\bar{v})}{\partial y} = 0 \tag{9}$$

where

$\bar{u},\bar{v}$ = vertically averaged velocity components in the x and y directions, respectively.

ζ_h = horizontal eddy viscosity

g = gravitational acceleration constant

K = wind coefficient

h = local water depth

V_w = wind speed

θ = angle between wind vector and the positive x axis

c = Chezy c friction factor

η = water surface elevation

p_a = atmospheric pressure

$\bar{\rho}$ = vertically averaged fluid density

Ω = Coriolis parameter

x,y,ρ,t are as previously defined

For the salinity equation we obtain:

$$\frac{\partial(h\bar{s})}{\partial t} + \frac{\partial(h\bar{u}\bar{s})}{\partial x} + \frac{\partial(h\bar{v}\bar{s})}{\partial y} = \frac{\partial}{\partial x}\left(hK^*_H\frac{\partial\bar{s}}{\partial x}\right) + \frac{\partial}{\partial y}\left(hK^*_H\frac{\partial\bar{s}}{\partial y}\right) \tag{10}$$

$$\rho = f(\bar{s},T) \tag{11}$$

where

K^*_H = horizontal effective dispersion coefficient

$\bar{s}$ = vertically averaged salinity

$\bar{T}$ = vertically averaged temperature

$f(\bar{s},\bar{T})$ = vertically averaged equation of state

$x,y,t,h,\bar{u},\bar{v}$ are as previously defined.

Consider the following exponential stretch transformation (Butler 1980):

$$x = a_1 + b_1\alpha_1^{c_1}$$
$$y = a_2 + b_2\alpha_2^{c_2} \tag{12}$$

where

x = vertical coordinate

y = horizontal coordinate

a_1, b_1, c_1 = vertical mapping coefficients

a_2, b_2, c_2 = horizontal mapping coefficients

α_1 = transformed vertical coordinate

α_2 = transformed horizontal coordinate

Transforming the hydrodynamic Equations 7-9, the following result is obtained omitting the bar notation if density-induced flow effects are not considered.

$$(u)_t + \frac{u}{\mu_1}(u)_{\alpha_1} + \frac{v}{\mu_2}(u)_{\alpha_2} - fv + \frac{g(\eta - \eta_a)_{\alpha_1}}{\mu_1} + \frac{gu}{c^2 d}(u^2 + v^2)^{1/2}$$
$$- \zeta\left[\frac{1}{\mu_1^2}(u)_{\alpha_1\alpha_1} + \frac{1}{\mu_1}\left(\frac{1}{\mu_1}\right)_{\alpha_1}(u)_{\alpha_1} + \frac{1}{\mu_2^2}(u)_{\alpha_2\alpha_2} + \frac{1}{\mu_2}\left(\frac{1}{\mu_2}\right)_{\alpha_2}(u)_{\alpha_2}\right] = F_{\alpha_1} \tag{13}$$

$$(v)_t + \frac{u}{\mu_1}(v)_{\alpha_1} + \frac{v(v)_{\alpha_2}}{\mu_2} + fu + \frac{g(\eta - \eta_a)_{\alpha_2}}{\mu_2} + \frac{gv}{c^2 d}(u^2 + v^2)^{1/2}$$
$$- \zeta\left[\frac{1}{\mu_1^2}(v)_{\alpha_1\alpha_1} + \frac{1}{\mu_1}\left(\frac{1}{\mu_1}\right)_{\alpha_1}(v)_{\alpha_1} + \frac{1}{\mu_2^2}(v)_{\alpha_2\alpha_2} + \frac{1}{\mu_2}\left(\frac{1}{\mu_2}\right)_{\alpha_2}(v)_{\alpha_2}\right] = F_{\alpha_2} \tag{14}$$

$$(\eta)_t + \frac{1}{\mu_1}(du)_{\alpha_1} + \frac{1}{\mu_2}(dv)_{\alpha_2} = 0 \tag{15}$$

where

$$\mu_1 = \frac{dx}{d\alpha_1}$$

$$\mu_2 = \frac{dy}{d\alpha_2}$$

$$\zeta = \zeta_h \quad , d = h$$

$$(\;)_t = \frac{\partial}{\partial t}$$

$$(\;)_{\alpha_1} = \frac{\partial}{\partial \alpha_1}$$

$$(\;)_{\alpha_2} = \frac{\partial}{\partial \alpha_2}$$

$$(\;)_{\alpha_1\alpha_1} = \frac{\partial^2}{\partial \alpha_1^2}$$

$$(\;)_{\alpha_2\alpha_2} = \frac{\partial^2}{\partial \alpha_2^2}$$

η_a = atmospheric pressure anomaly

F_{α_1} = surface forces in α_1 coordinate direction

F_{α_2} = surface forces in α_2 coordinate direction

Transforming the salt balance equation (Equation 10) again omitting the bar notation obtain with variables as previously defined:

$$(hs)_t + \frac{(hus)_{\alpha_1}}{\mu_1} + \frac{(hus)_{\alpha_2}}{\mu_2} = \frac{1}{\mu_1}\left(\frac{hK_H^*}{\mu_1}(s)_{\alpha_1}\right)_{\alpha_1} + \frac{1}{\mu_2}\left(\frac{hK_H^*}{\mu_2}(s)_{\alpha_2}\right)_{\alpha_2} \qquad (16)$$

The equation of state (Equation 11) also holds in the transformed coordinate system.

In previous modeling efforts, Equations 13-15 have been approximated using a multioperational alternating direction implicit three-time level finite difference scheme (Butler 1980). This stabilizing correction scheme is given in turn for the X and Y sweeps of the computational grid.

In what follows the position and time coordinate (x, y, t) is represented on a space staggered grid by (nΔy, mΔx, kΔt). For compactness we define the following quantities (Butler 1980).

$$\delta\alpha_1(F_{n,m}) = F_{n,m+(1/2)} - F_{n,m-(1/2)}$$

$$\delta\alpha_2(F_{n,m}) = F_{n+(1/2),m} - F_{n-(1/2),m}$$

$$\delta_2\alpha_1(F_{n,m}) = F_{n,m+1} - F_{n,m-1} = \delta\alpha_1\delta\alpha_1(F_{n,m})$$

$$\delta_2\alpha_2(F_{n,m}) = F_{n+1,m} - F_{n-1,m} = \delta\alpha_2\delta\alpha_2(F_{n,m}) \qquad (17)$$

$$\delta\alpha_1\alpha_1 F_{n,m} = F_{n,m+1} + F_{n,m-1} - 2F_{n,m} = \delta_2\alpha_1\delta_2\alpha_1 F_{n,m}$$

$$\delta\alpha_2\alpha_2 F_{n,m} = F_{n+1,m} + F_{n-1,m} - 2F_{n,m} = \delta_2\alpha_2\delta_2\alpha_2 F_{n,m} \qquad (17)$$

$$\frac{\alpha_1}{F_{n,m}} = \frac{F_{n,m+1} + F_{n,m}}{2} \qquad \frac{\alpha_2}{F_{n,m}} = \frac{F_{n+1,m} + F_{n,m}}{2}$$

$$F_{n,m} = \frac{F_{n+(1/2),m-(1/2)} + F_{n+(1/2),m+(1/2)} + F_{n-(1/2),m-(1/2)} + F_{n-(1/2),m+(1/2)}}{4}$$

X - Sweep:

$$\frac{1}{\Delta t}(\eta^* - \eta^{k-1}) + \frac{1}{2\mu_1\Delta\alpha_1}\left[\delta_{\alpha_1}(u^{k+1}\bar{d}^{k} + u^{k-1}\bar{d}^{k})\right] + \frac{1}{\mu_1\Delta\alpha_1}\left[\delta_{\alpha_2}(v^{k-1}\bar{d}^{k})\right] = 0 \quad \text{at } (n,m)$$

$$\frac{1}{2\Delta t}(u^{k+1} - u^{k-1}) + \frac{1}{2\mu_1\Delta\alpha_1}u^k\delta_{2\alpha_1}(u^k) + \frac{1}{2\mu_2\Delta\alpha_2}\bar{v}^k\delta_{2\alpha_2}(u^k) - f\bar{v}^k + \frac{g}{2\mu_1\Delta\alpha_1}\left[\delta_{\alpha_1}(\eta^* + \eta^{k-1} - 2\eta_a^k)\right]$$

$$+ \frac{g}{(C^2\bar{d})^k}u^{k+1}\left[(u^{k-1})^2 + (\bar{v}^{k-1})^2\right]^{1/2} - \epsilon\left[\frac{1}{(\mu_1\Delta\alpha_1)^2}\delta_{\alpha_1\alpha_1}(u^k) + \frac{1}{(\mu_2\Delta\alpha_2)^2}\delta_{\alpha_2\alpha_2}(u^k) + \frac{1}{2\mu_1\Delta\alpha_1^2}\delta_{\alpha_1}\left(\frac{1}{\mu_1}\right)\delta_{2\alpha_1}(u^k) + \frac{1}{2\mu_2\Delta\alpha_2^2}\delta_{\alpha_2}\left(\frac{1}{\mu_2}\right)\delta_{2\alpha_2}(u^k)\right] = F_{u_1}^k$$

$$\text{at } (n, m+1/2) \qquad (18)$$

Y - Sweep:

$$\frac{1}{\Delta t}(\eta^{k+1} - \eta^*) + \frac{1}{2\mu_2\Delta\alpha_2}\left[\delta_{\alpha_2}(v^{k+1}\bar{d}^{k} - v^{k-1}\bar{d}^{k})\right] = 0 \quad \text{at } (n,m)$$

$$\frac{1}{2\Delta t}(v^{k+1} - v^{k-1}) + \frac{1}{2\mu_1\Delta\alpha_1}\bar{u}^k\delta_{2\alpha_1}(v^k) + \frac{1}{2\mu_2\Delta\alpha_2}v^k\delta_{2\alpha_2}(v^k) + f\bar{u}^k + \frac{g}{2\mu_2\Delta\alpha_2}\left[\delta_{\alpha_2}(\eta^{k+1} + \eta^{k-1} - 2\eta_a^k)\right] \qquad (19)$$

$$+ \frac{g}{(C^2\bar{d})^k}v^{k+1}\left[(\bar{u}^{k-1})^2 + (v^{k-1})^2\right]^{1/2} - \epsilon\left[\frac{1}{(\mu_1\Delta\alpha_1)^2}\delta_{\alpha_1\alpha_1}(v^k) + \frac{1}{(\mu_2\Delta\alpha_2)^2}\delta_{\alpha_2\alpha_2}(v^k) + \frac{1}{2\mu_1\Delta\alpha_1^2}\delta_{\alpha_1}\left(\frac{1}{\mu_1}\right)\delta_{2\alpha_1}(v^k) + \frac{1}{2\mu_2\Delta\alpha_2^2}\delta_{\alpha_2}\left(\frac{1}{\mu_2}\right)\delta_{2\alpha_2}(v^k)\right] = F_{u_2}^k \quad \text{at } (n+1/2, m)$$

A multioperational finite difference scheme will be applied to Equation 16, consistent with the present WIFM Code Equations 17-19.

Calibration/Verification Procedures

A complement of approximately 40 current meters and 18 conductivity and temperature sensors were distributed among 20 oceanographic moorings within Mississippi Sound. Meteorological data, consisting of wind speed and direction, air temperature, and air pressure measurements, were collected at five sites around the periphery of the Sound. Bottom pressure measurements, from which tidal height data can be extracted, were recorded at three oceanographic moorings in the Gulf of Mexico, south of Mississippi Sound (Raytheon 1980).

The data collected have been provided the Waterways Experiment Station (WES) and is being categorized. A harmonic analysis of tidal elevations and current data is also under way. A preliminary analysis of salinity transect data is presented in Table 1. Stations T26, T28, T30 are located at the western end of the Sound, T2 in the middle, and T80 at the extreme eastern end of Mississippi Sound (Figure 1).

The five-day period (25 April-1 May) represented a period of large freshwater inflow and large horizontal salinity gradients (Raytheon 1980). The period 21-26 July characterized a typical summer salinity condition. These two periods have tentatively, pending a complete data analysis, been selected as calibration and verification periods, respectively.

For each of these five-day periods, the GTM will be run to produce the reconstructed tide (K_1, 0_1, P_1, S_2, M_2) while salinity concentration will be directly specified at the seaward boundary of the WIFM global grid (Figure 2). This grid extends from the Mississippi Delta to above Mobile Bay in the South-North direction, and from New Orleans, La., to beyond Pensacola, Fla., in the West-East direction. The grid employs 6785 computational cells with a minimum spatial resolution of between 3000-3500 ft. Average daily freshwater inflows will be considered for the rivers listed in Table 2.

Manning's n roughness coefficients (Vennard 1961) will be adjusted on a cell-by-cell basis until simulated tidal amplitudes and currents correspond to the results of the harmonic analysis. Wind and atmospheric pressure effects will also be considered.

These effects will be imposed on the WIFM global grid and simulated tidal amplitude, currents, and salinity compared with the measured unfiltered values of these parameters. Additional adjustments to cell Manning's n values and horizontal dispersion relations will be made to enable model application under wind conditions.

The output from the above work will be a completely calibrated and verified numerical model WIFM employing a global grid to represent global circulation and salinity conditions under wind conditions or without wind.

Model Application

The GTM will be employed to provide hydrodynamic boundary conditions to WIFM. WIFM will predict circulation and salinity patterns in Mississippi Sound under a range of alternatives.

Initially, alternative channel alignments and/or depth modifications and dredge disposal island sites will be represented in the global grid. Effects on circulation and salinity will be studied employing this grid. This approach will allow a determination of the range of impacts (magnitude and areal extent) for modifications of various types. It is anticipated that large-scale regional offshore island disposal and closing of barrier island passes may be studied effectively employing the global grid directly. However, for channel deepening and alternative alignments, the effects may be local and not able to be resolved on the global grid. In order to verify this assumption, a refined grid will be developed around a typical navigation channel (Pascagoula or Gulfport Channel). The calibration period condition will be simulated to insure that circulation and salinity conditions may be represented on the refined grid. This being completed, the alternate channel condition and configuration will be simulated and the differences in circulation and salinity patterns determined.

Table 1. Mississippi Sound salinity transect data preliminary analysis.

Date (1980)	STATION NUMBERS Concentration (ppt)				
	T26	T28	T30	T2	T80
4/28 - 4/29	2.4	1.0	.4	12.9-13.	2.0
5/21 - 5/22	1.8	2.0	1.5	14.2-18.0	4.6-11.6
6/12 - 6/13	4.4	7.6	5.2	16.6-18.0	9.0-18.0
7/23 - 7/24	17.0	20.0	20.0	28.4	24.0
8/22 - 8/23	14.2	16.3	17.8	27.1	17.2
9/2	18.4	17.2	17.2	N.D.	N.D.
9/8 - 9/9	13.9	14.8	14.0	25.6	24.0
9/20 - 9/21	16.0	17.0	17.0	26.1	22.2
9/24 - 9/25	14.0	15.0	17.0	25.6	N.D.
11/6 - 11/7	11.5	11.3	12.0	28.0	20.8

N.D. = No Data

Table 2. Flow inputs Mississippi Sound global grid system.

1. Rigolets
2. Chef Menteur Pass
3. Bayou Bienvenue
4. Mississippi Gulf Outlet Canal
5. Biloxi River System (Back Bay Biloxi)
6. East Pascagoula River
7. Pascagoula River
8. Mississippi River: Pass a Loutre, Southeast Pass, South Pass
9. Mississippi River: Main Pass
10. Mobile River
11. Spanish and Raft Rivers (Right Branch)
12. Tenesaw River (Left Branch)
13. Apalachee River
14. Blakeley River
15. Pearl River
16. Jourdan River

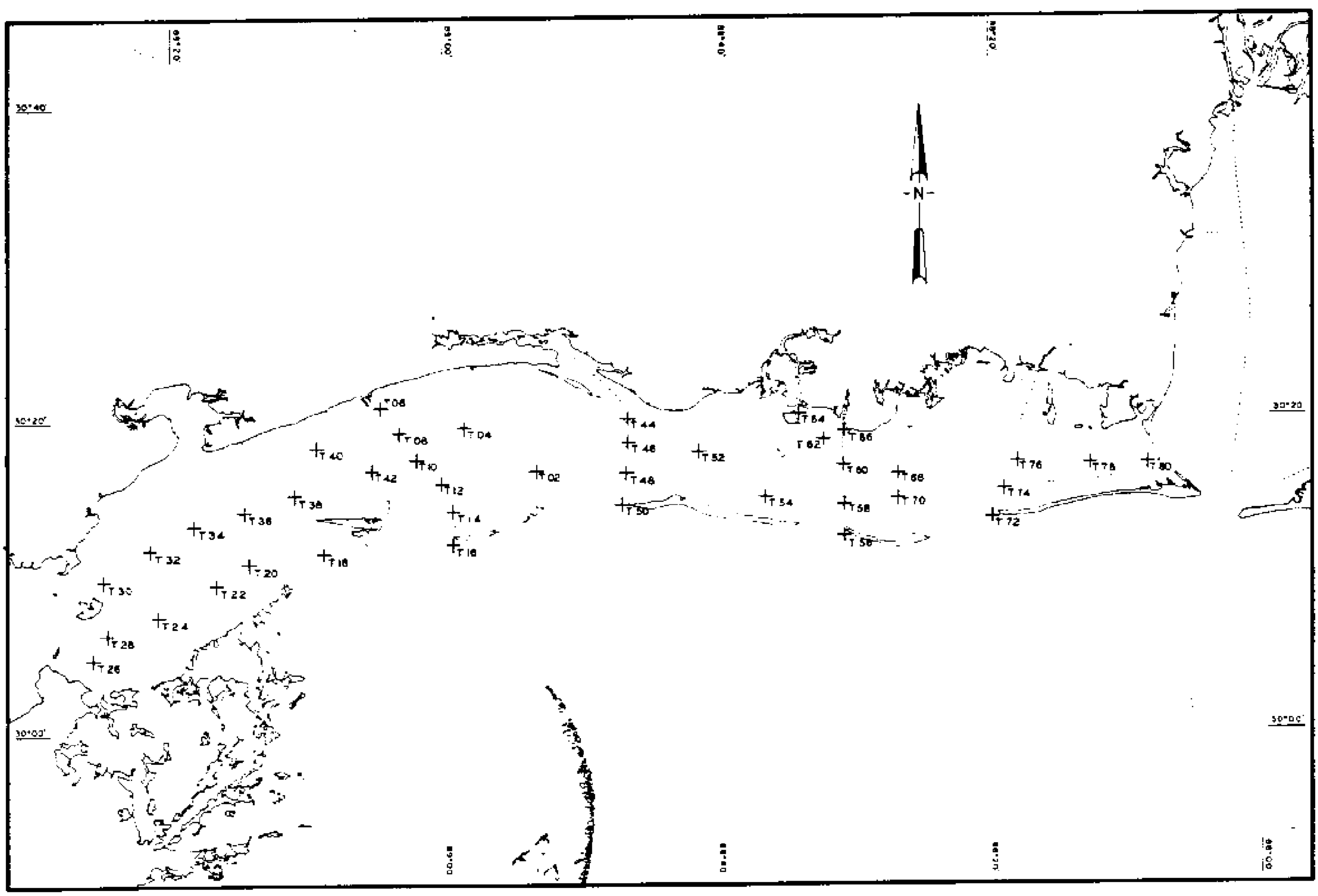

Figure 1. Conductivity/temperature profiling station locations.

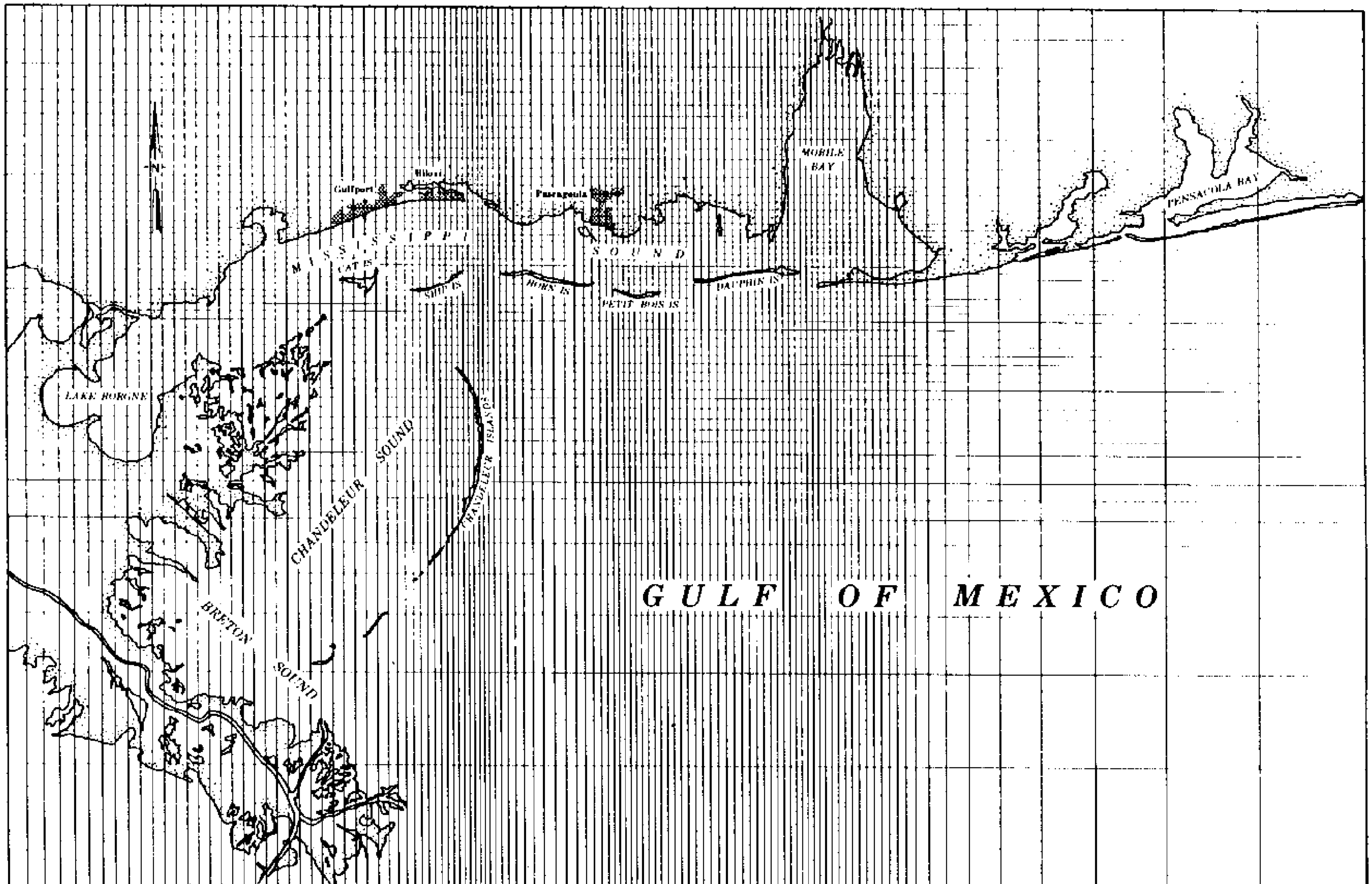

Figure 2. Station locations - Mississippi Sound and Gulf of Mexico.

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THE MISSISSIPPI SOUND AND ADJACENT AREAS STUDY OF DREDGED MATERIAL DISPOSAL

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INTRODUCTION

This presentation on the Mississippi Sound and Adjacent Areas Dredged Material Disposal Study is to summarize the progress and outcome to date of the second stage of a three-stage study program on dredging activities in the Gulf Coast area.

In 1977, the Federal Legislature authorized the Corps of Engineers to conduct a study to determine whether present and proposed dredging activities in the Gulf Coast area could be modified to increase economic efficiency and promote environmental quality. This action was precipitated by the recognition of several factors:

One, ports are critical to the development of the area. Over one-fourth of the employment and over one-half of the wages of the Alabama-Mississippi Gulf Coast have been estimated to be directly related to port activities. In order for the ports to be accessible, their channels must be kept at adequate depths which requires maintenance dredging.

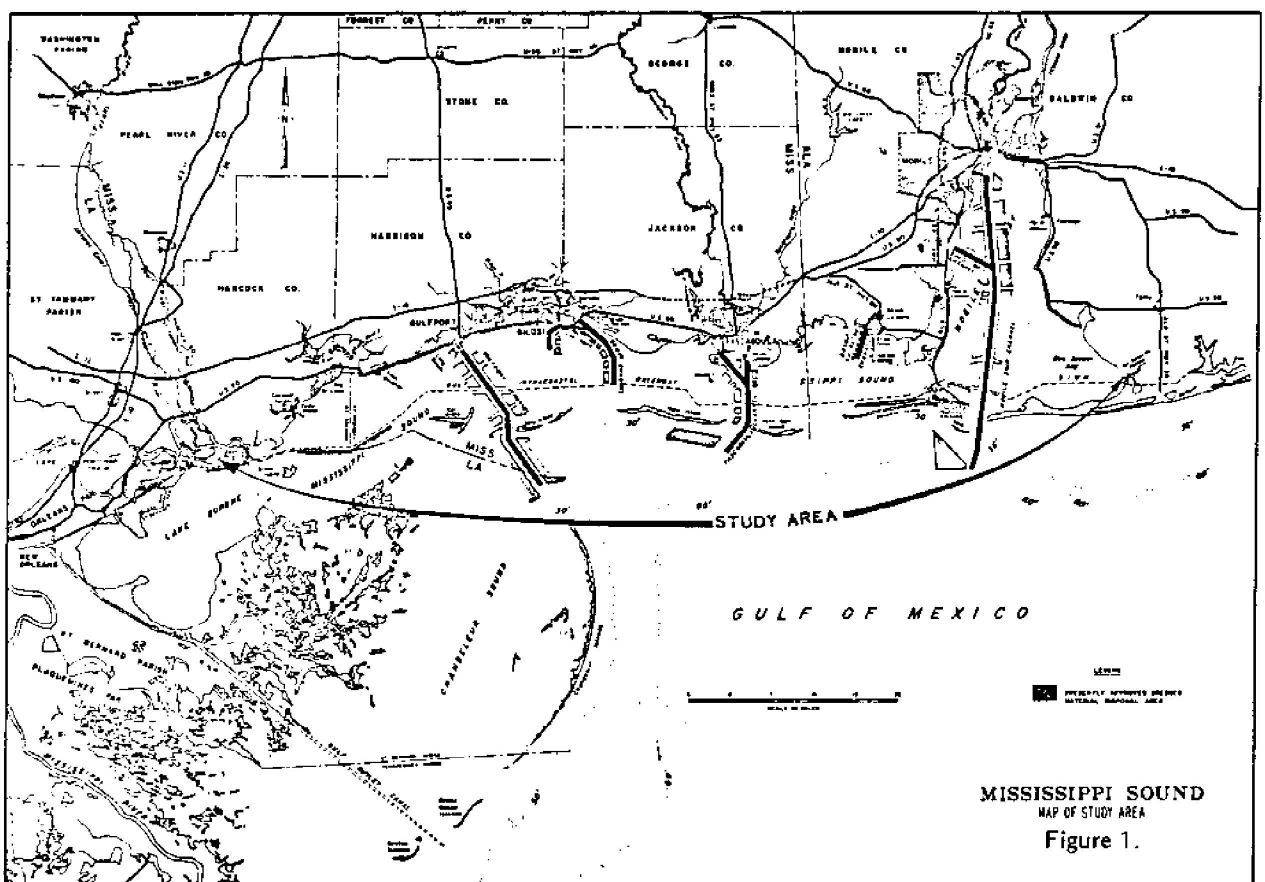
Two, maintenance dredging is necessary and extremely expensive. In 1979, the estimated cost to taxpayers alone was about $6 million annually.

Three, questions have been raised concerning the effects of dredging activities on the ecology of the area.

STUDY AREA AND PURPOSE

The area being studied encompasses portions of Alabama and Mississippi from Lake Borgne on the west to the eastern shore of Mobile Bay. The area extends south to the 120-foot depth contour of the Gulf of Mexico and approximates Interstate Highway 10 on the north (Figure 1). A three-stage study program was developed with four purposes in mind:

(1) to provide an overview of the resources and economy of the area;
(2) to investigate existing dredging and dredged material disposal practices;



MISSISSIPPI SOUND
MAP OF STUDY AREA
Figure 1.

(3) to analyze the effect of these practices on the resources and economy; and
(4) to determine if these practices should be modified.

Stage I

The Stage I reconnaissance level study was completed in 1979. The reconnaissance report provided a detailed summary of the study area's environmental , social and economic resources. It analyzed dredging activities being practiced and those proposed, described dredge equipment, and outlined the hydrodynamic modeling to be used for the Mississippi Sound and adjacent water bodies.

The work performed during the reconnaissance study relied primarily on existing data and information gained through a series of public involvement activities, also documented in the report. The Stage I work effort established the water resource needs to be addressed and planning objectives to be met, and finally, provided the scope and schedule of work for Stage II studies.

The reconnaissance report was compiled into a main report and five appendices:

A. Resources Inventory
B. Problem Identification and Public Involvement
C. Dredging Activities
D. Dredging Equipment and Dredged Material Transportation and Disposal
E. Mathematical Modeling

All six volumes are available for public review.

The public involvement program conducted as part of Stage I resulted in the identification of 93 needs that were later generalized into 12 categories including such areas as protection and enhancement of critical habitat areas and marine organisms, water quality and sedimentation, shoreline erosion, navigational safety hazards, dredging policy, and recreational opportunities. These needs and concerns were then translated into 16 provisional planning objectives which, for the most part, would dictate the direction for Stage II planning. These objectives are:

1. Provide for more economically efficient water transportation at the ports of Mobile, Pascagoula, Gulfport, and Biloxi.
2. Minimize the operating costs of commercial and recreational shallow-draft vessels.
3. Reduce the costs of dredging all navigation channels, both private and public.
4. Increase the production of marketable oysters.
5. Increase the productivity of wetlands and water bottoms.
6. Protect existing critical habitats and provide, where possible, additional wetlands and other prime fish and wildlife areas.
7. Maintain or improve present water quality levels.
8. Improve dissolved oxygen levels in Mobile Bay to reduce fish kills and improve environmental quality.
9. Reduce hurricane and other storm damages.
10. Restore eroded shorelines.
11. Maintain the shorelines of barrier islands in their natural erosion and deposition patterns.
12. Maintain the long-term natural sediment movement, deposition, and shoaling patterns of Mississippi Sound and Mobile Bay.
13. Protect lives and property from water safety hazards such as abandoned dredge equipment.
14. Provide additional recreational use areas.
15. Prevent losses of historical, archeological, and paleontological sites of particular significance.
16. Reduce the costs of land and fill materials for urban, industrial, and port development.

These objectives respond to the most important problems identified and thereby provide the basis for plan formulation. Since plan formulation involves developing different resource management alternatives to address the planning objectives, each objective was examined and measures were identified to meet them. During the identification process, it was recognized that a number of alternatives meeting planning objectives did not fall within the traditional authority of the Corps of Engineers to implement; therefore, other agencies and interest will be depended upon for development of those alternatives.

Initially, the list of alternatives numbered over 40. These will be evaluated, refined, and placed within comprehensive management plans during further study. However, five major concepts did evolve:

1. Channel and harbor dredging
2. New dredging equipment
3. Disposal of dredged material
4. Nonstructural alternatives
5. Other alternatives

The first four categories are being investigated by the Corps, whereas "other alternatives" will be developed by non-Corps entities.

Stage II

Stage II development of intermediate plans was initiated in the summer of 1979. This study phase is designed to examine potential alternative solutions to previously identified problems in sufficient detail to enable the study team to determine which alternatives should be rejected and which should be developed further.

Since Stage II work efforts will provide the needed technical data in formulating and evaluating alternatives, several types of investigations are being conducted. These include: assembly of available data; collection of field data; development of numerical modeling techniques; creation of a data storage and retrieval system; and formation of special committees.

Ecosystem Interdisciplinary Methodology

The planning process for the entire study is structured by the Corps of Engineers' regulations which respond to the Principles and Standards for Planning Water and Related Land Resources (P&S) formulated by the Water Resource Council and to the National Environmental Policy Act (NEPA) guidelines. The P&S regulations require an interdisciplinary approach, as opposed to a multidisciplinary one, to the planning process. This approach is being followed in the Mississippi Sound and Adjacent Areas Study (MSAAS).

In the MSAAS the entire study area is being investigated as a single unit--the ecosystem. In doing so, the elements by which it is composed are first defined thereby establishing base conditions, which will be used to predict the changes that could and most probably would take place during the planning period when any of a number of the elements are altered either as a result of no action being taken or implementation of each alternative. This will eventually enable us to determine with a high degree of validity which potential alternatives are feasible solutions and which should be rejected.

The MSAAS study team is composed of a diverse group of professionals whose combined expertise incorporates all areas of our investigations, such as hydrology, physiography, chemistry, economics engineering, planning, and biology. In addition to our own personnel, we have nonstaff support personnel comprising special committees to work with us throughout the study and selected contractors known for their excellence in a variety of fields.

GEOGRAPHICAL INFORMATION SYSTEM

At the onset of Stage II it became apparent that it would be necessary to establish some mechanism for managing the vast amount of data to be collected. Based on our need to access data in various forms and the time constraints in evaluating a broad range of alternatives, it was concluded that a computerized system would be necessary.

The study team outlined their data management needs which resulted in a system that would store data files, contain statistical and graphical manipulation programs, interface with computerized models and predictive programs, have various output capabilities, and allow for interactive use.

A geographical information system has been conceptually identified and essential components have been developed. Specific computer programs on the system will perform a series of statistical analysis, data manipulation and geographical display tasks.

All field collection data are being submitted to use on magnetic tapes in a predetermined format tailored for input to the geographical information system. The hydrologic/physical data collected by the Gulf Coast Research Laboratory has been entered on the system. A standard format is being used for all data using longitude and latitude as location identifiers.

Ultimately, we expect the system to be able to manipulate the data in a number of ways to perform various analyses which will answer questions relative to plan development, impact assessment and evaluation of alternative plans.

DATA GAPS

As a result of several literature searches performed as part of the reconnaissance study and during the initial months of Stage II, a number of data gaps were identified. These data gaps related to water circulation, sediment transport, properties of dredged material, location of critical environmental areas, values of submerged bottoms, nontraditional dredge equipment, and benefits of maintaining channels. The initial efforts of Stage II have been aimed at filling these data gaps and developing or adapting numerical models to aid in understanding the ecosystem and predicting future conditions. Some of the extensive data collection efforts conducted were designed to provide a valid data set for calibration and verification of these models.

Field Data Collection

Field data collection began in the summer of 1979. Several factors influenced the kind of data to be gathered and the conduct of the collection. These factors are:

1. Information gaps identified by prior literature searches
2. Capabilities of models
3. Probable alternatives to be investigated resulting from Stage I public involvement activities.

Hydrological/Physical

Raytheon, Inc., of East Providence, Rhode Island, was contracted to perform a number of hydrological and physical field data collection operations. They began in April 1980 by installing collection stations in portions of Mobile Bay, Mississippi Sound, Chandeleur Sound, Lake Borgne, and the Gulf of Mexico. Data were collected synoptically for 180 days. Synoptic data included meteorological, bottom pressure, current and conductivity/temperature readings.

Meteorological stations were located at five sites around the periphery of Mississippi Sound (Fig. 2, M1-5) to simultaneously record wind speed and direction, air temperature, and barometric pressure at 10 minute intervals.

Bottom pressure measurements were taken at three stations in the Gulf at five minute intervals. Stations were placed within 25 feet of latitude 29°53' at prescribed sites to maintain continuity of data recorded (Fig. 2, 22-24).

Forty current meters and 12 conductivity/temperature gages were distributed among 21 stations. All data were recorded at 30 minute intervals. Prior to operation, water depths were measured to verify data on navigation charts used in site specifications (Figure 2).

All of the above synoptic data have been furnished to the U.S. Army Corps of Engineers Waterways Experiment Station (WES) Hydraulic Laboratory for further analyses. A draft report on this effort including hard copy graphs and tables of all meter recordings and a description of all aspects of the work has been prepared by Raytheon, Inc. and a final report will be available for distribution about January 1982.

After the initial 180-day synoptic data collection period, Raytheon was requested to conduct three additional 45-day collections. This effort was begun in November 1980, with the methodology essentially the same as the previous collection effort, the distinction being that the additional sampling will take place in the Gulf of Mexico as opposed to Mississippi Sound.

The three pressure gages deployed initially were continued. In addition, 16 current meters and 16 conductivity/temperature meters were dispersed among eight stations, each recording at 30 minute intervals. The first 45-day collection was completed in January 1981, the second commenced in March and was completed the end of April. The third completed in September, 1981.

This set of data is being interpreted, with the assistance of Dr. William Schroeder of the Dauphin Island Sea Lab, to determine circulation patterns of the near northern Gulf and possible causes for these patterns.

A report is being prepared by Dr. Schroeder for each 45-day collection period which will present circulation patterns for the entire collection area; circulation patterns for the surface and bottom at each data station and the relationship to spatial patterns; the predominant driving forces causing these patterns; and the influence of thermoclines, pycnoclines, and haloclines, if present. This information will be extremely beneficial in that circulation patterns in the Gulf of Mexico have not been previously defined. It will also provide verification data to a model of the Gulf described later, which will ultimately allow us to calculate water movement at any given time.

Also, as part of their contract, hydrographic surveys were conducted by Raytheon at 11 locations within the study area (Fig. 3). These areas included the entrance to Mobile Bay, Grants Pass/Pass Aux Herons, Petit Bois Pass, Horn Island Pass, Dog Keys Pass, Ship Island Pass, Cat Island Channel, St. Joseph Pass to Le Petit Pass, St. Louis Bay, Biloxi Bay, and Ship Island Channel.

Three sampling transects were delineated across each pass. Soundings were recorded at generally 100-foot

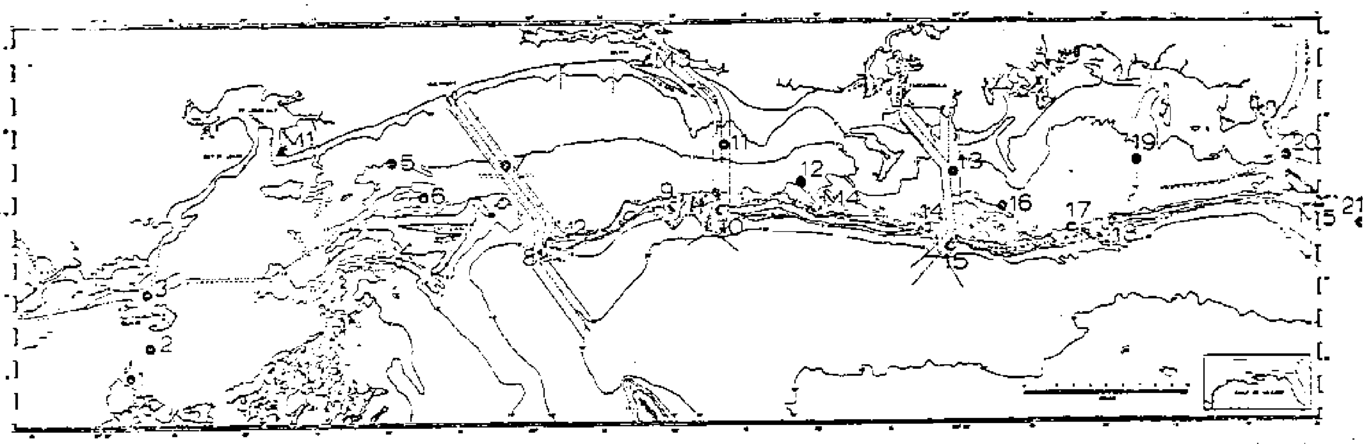


Figure 2. Station locations - Mississippi Sound and Gulf of Mexico.

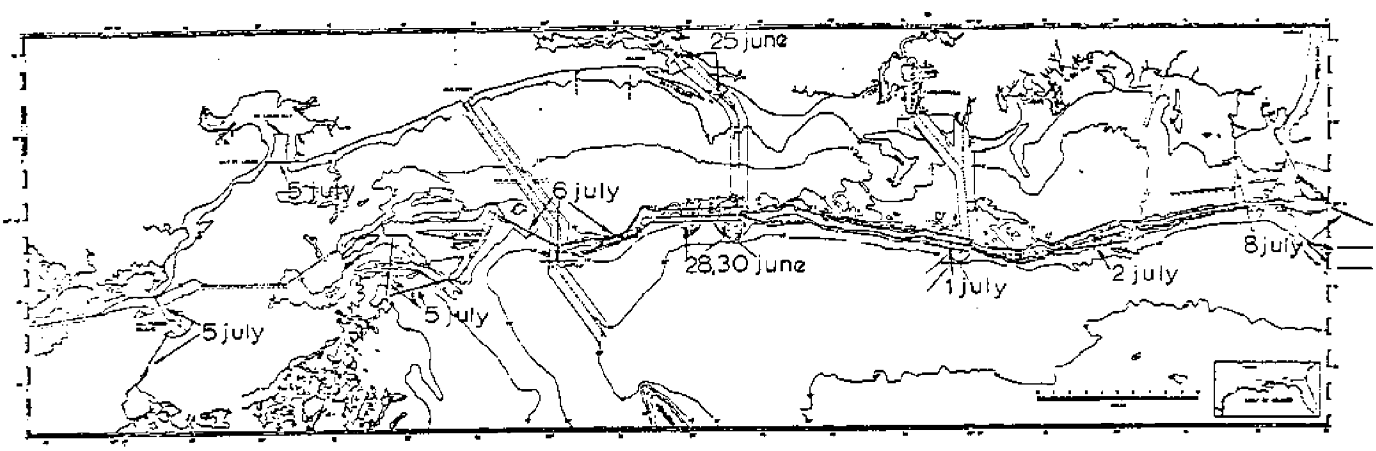


Figure 3. Bathymetric survey transect locations.

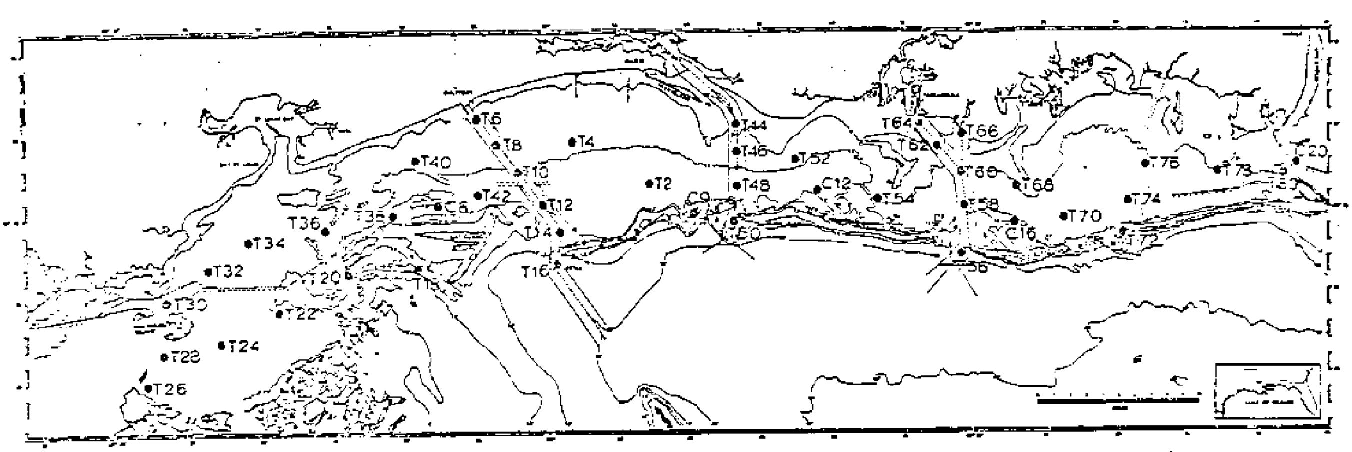


Figure 4. Conductivity/temperature profiling station locations.

intervals except within 200 feet of either side of the center line of any pass or channel, in which case, depths were recorded at 50-foot intervals. Each transect was referenced to the nearest tide gage and convereted to MLW or NGVD. Over 22,000 bathymetric data points were recorded in the 11 survey days.

Conductivity and temperature data were recorded along a zig-zag transect in Mississippi Sound at five mile intervals along the transect and within the specified navigation channels (Fig. 4). This procedure was repeated every three weeks for the entire 180-day period. Readings were taken just below the water surface, one foot above water bottom, and at five foot increments between. Samples were taken on subsequent transects to within 0.25 miles of the initial station sampled.

Suspended sediment sampling was performed in Mississippi Sound between 2 September and 28 September 1980. The sampling occurred during four periods, each three days long, corresponding to times when the Coastal Zone Color Scanner (CZCS) aboard the Nimbus G Satellite was providing imagery of the survey area. Sampling stations consisted of the 40 conductivity and temperature stations (T2-T80) normally sampled on a three week basis, and current meter stations 3, 6, 9, 12, 16, and 20 (Fig. 4). Stations T2-T80 and current meter stations were sampled for total suspended solids during each of the four time periods. In addition, the current meter stations, and station T22 were sampled during the second and fourth periods, for total organic carbon (TOC), chlorophyll-a, settling velocity, particle size, and moisutre content.

Surface and bottom samples were taken at each location. Surface samples were taken at one-half of the light extinction depth, as determined by a secchi disc, while bottom samples were taken two feet above the bottom.

Continuous and discrete point suspended solid (nephelometric) measurements were taken along the cruise track during each of the four sampling periods as well as volumetric suspended solids measurements.

Four wave gages were installed in the survey area for two periods during the month of September. Gages were installed from 29 August to 7 September and 18 September to 1 October, 1980.

These data will be linked to the Nimbus G satellite imagery. Once base conditions for suspended solids are established, future imagery will aid in determining cause-effect relationships between suspended solids, turbidity, and hydrologic processes. The Naval Ocean Research and Development Activity group are combining the field data and satellite imagery into maps depicting suspended solids for the entire study area.

The company of Biddy Chappin and Associates of Florida was selected to collect tide data from 21 stations (Fig. 5) for a period of 180 days coinciding with the initial efforts of Raytheon. Gages continuously recorded tide elevations at six minute intervals on punch-paper tapes for periods of 30 days for the duration of the 180-day collection period.

The National Ocean Survey reduced the collected data and compiled it on magnetic tapes for WES. WES in turn performed harmonic analysis on these data for calibration of a math model of the entire study area.

Biological

A study to characterize the benthic macroinfauna communities within the study area was contracted to Barry A. Vittor & Associates. The objective of this study was to develop data to characterize physical/benthic habitats on the basis of the presence of observed benthic community assemblages. This information will be a great asset in identifying areas for disposal of materials and determining impacts from the removal and placement of dredged materials in the Mississippi Sound and adjacent water bodies.

In addition to review of available, pertinent literature, the contract called for two field surveys – a fall collection and a spring collection. The fall survey was conducted in October and November, 1980 and the spring survey was completed in April 1981. Ninety-six stations were sampled

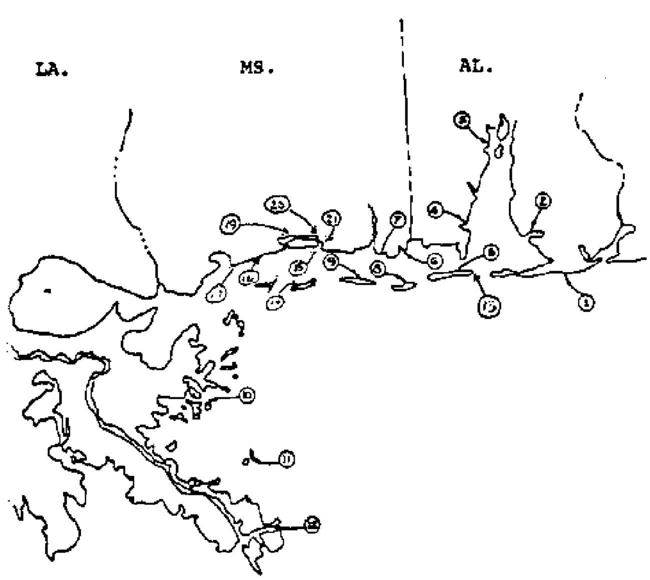


Figure 5. Location of tide gages.

KEY

Location	Nos No.
1. Gulf Shores	873-1269
2. Bon Secour	873-1952
3. Mobile State Docks	873-7048
4. Fowl River	873-5523
5. Dauphin Island(Aloe Bay)	873-5587
6. Grand Batteur Island	874-0199
7. Pascagoula Point	874-1196
8. Petit Bois Island	874-0405
9. Horn Island	874-2221
10. Comfort Island	876-0742
11. Breton Island	876-0595
12. North Pass	876-0412
13. Dauphin Island	876-5184
14. Ship Island	874-4756
15. Cadet Point	874-3735
16. Broadwater Marina	874-4586
17. Pass Christian	874-6819
18. Bay Waveland	874-7437
19. Popps Ferry Bridge	874-4671
20. Old Fort Bayou	874-3495
21. Davis Bayou	874-3081

during each of the 30-day collection periods, 56 in the Sound and 40 in the Gulf of Mexico out to the 20 fathom contour (Fig. 6).

Eight replicate box cores were taken at each station. From each, four subsamples were extracted for sediment analysis. Of the remaining, only the top 15 cm of the core sample was used for macroinfauna statistical analysis, except in those instances where sediment penetration was less than 15 cm. WES Environmental Laboratory has completed a preliminary analysis of the adequacy of replication in the benthic program to determine statistically how many replicates are necessary to describe species composition in difference sedimentary habitats.

Sediment analyses were performed on samples from the fall cruise to determine total organic carbon concentrations; particle size distribution; percentage of sand, silt, and clay present; and sedimentation rate (settling velocity). Macroinfauna analyses determined major taxonomic groups, biomass for each major taxonomic group, average size and biomass estimates of dominant species, and species identification and enumeration. Results of this survey are available.

Analyses of the recently completed spring collection were conducted in the same manner as that for the fall collection. However, 6 stations were relocated from Mississippi Sound to southeastern Mobile Bay. The final data analysis will emphasize statistical parameters that show whether a close correlation does exist between sediment size, total organic carbon, depth, and/or salinity and the identified benthic community assemblages.

The WES Environmental Laboratory began a trophic characterization study in November 1980. Primarily, the study consists of two literature reviews. One is a review of information regarding food preferences and feeding habits of demersal fishes. The other focuses on the community structure and productivity of macrobenthic invertebrates. Among the data being studied are fish gut analyses (conducted by B.A. Vittor & Associates) and records of fish trawls including those conducted by WES and by the National Marine Fisheries Service.

The information derived from this study will provide volume calculations regarding the amount of material consumed as opposed to the amount of material available. This will be used in conjunction with the Benthic Macroinfauna Community Characterization study to determine how much the benthos contribute as food matter to finfish within the study area. This should prove invaluable in calculating the effects dredging and disposal activities would have on the finfish population. Completion of this study is expected in early 1982.

RECENTLY INITIATED AND PLANNED STUDIES

Because of funding and manpower constraints, initiation of several study efforts has been delayed until this year. However, scopes of work have been developed or are in the process of being finalized and should be well underway by June 1981.

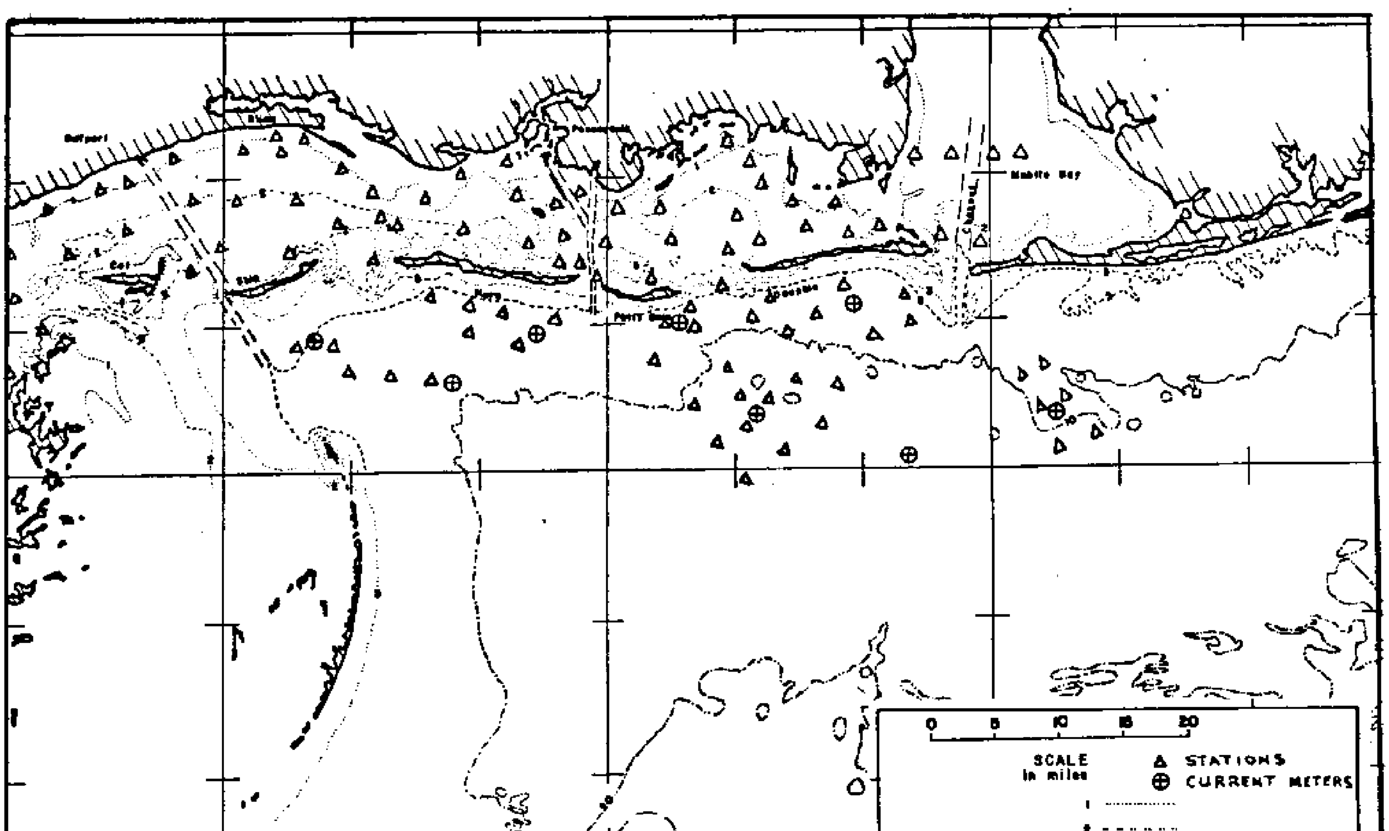


Figure 6. Benthic community characterization stations.

The firm of Reynolds, Smith and Hills has been contracted to review available data on dredging operations by the Corps of Engineers, permit applications and studies related to sediment movement and develop a plan of action to address the movement of dredged material, dredge operations and the cause-effect relationships between the two and other environmental parameters. As part of their contract they will compile historical data from the files of Mobile District on dredge production, quantities dredged, use of disposal locations, properties of materials dredged and non-Federal dredging permits. All data will be entered on the computer and analyzed.

Additional studies of existing dredged material disposal areas are also planned to provide data on material actually present, when they were placed there and processes affecting them. This effort along with others will be scoped by Reynolds, Smith and Hills but other contractors will be used.

A study to delineate upland disposal areas has been defined. This study would examine the upland areas of Alabama and Mississippi, and through a process called attractiveness modeling would identify areas of 1,000 acres or more which would meet certain environmental, socioeconomic, engineering and cultural criteria and therefore be possible upland disposal areas. Computerized base maps would be prepared for each set of criteria.

A study to identify productive uses of dredged material is also to be initiated this fall. This study would utilize data from the Reynolds, Smith and Hills investigation to show economically or environmentally productive uses of the various types of materials to be dredged from these channels.

SPECIAL COMMITTEES

During Stage I two special committees were formed for the purposes of providing guidance on the data to be collected relative to specific areas and to review data that are obtained in order that they may provide input on alternatives and the significance of their impacts. It was determined that during Stage II three additional committees would be formed.

The Modeling Committee composed of four members well versed in modeling techniques has provided invaluable assistance in the evaluation of various models under consideration in the study. The committee made its recommendations and continues to observe the modeling and data collection efforts taking place.

The 13 member Biology Committee provides a consortium of technical expertise from Alabama and Mississippi. The committee, formed by Sea Grant Advisory Services, has formally met three times during the course of Stage II to comment on ongoing and proposed work, discuss progress, and make recommendations relative to the study's direction. Members are provided scope of work drafts for review and comments prior to advertising for contractors and aid in the actual selection process. In addition, they review documents and monitor environmental studies for the duration of the study.

A Fishing Interests Committee, Environmental Quality Committee, and Dredging Interests Committee will each be established in the near future. Concerns and desires expressed during the Stage I's public involvement and program demonstrate the need for public input prior to plan formulation and perhaps to an even greater extend during the development and assessment of alternatives.

Delineation of Nursery Areas, Spawning Areas, and Migratory Routes for Selected Finfish and Shellfish

The U.S. Fish and Wildlife Service's National Coastal Ecosystems Team (NCET) is performing a study of nursery areas, spawning areas, and migratory routes utilized by 41 selected species of finfish and shellfish within the study area. Species selected for study were previously identified as being either numerically abundant or considered important for their sport or commercial value. Ultimately, the report will define the dependence of the selected species on specific areas and aid in determining impacts of removal and placement of dredged material.

The work effort for the NCET study involves an extensive literature search and review of all published and non-published reports, technical papers, and any other possible sources of information pertaining to the topic. Contacts are being made with appropriate government agencies and universities having access to this type of data to identify all related studies.

Thirty-one parameters have been established for investigation of the life history for each species. Once the literature collection has been completed and thoroughly analyzed, maps will be created depicting spawning areas, nursery areas, and migratory routes for each species. Areas will be ranked as to their relative importance to one another and the overall study area. In addition, a summary map will identify overall important areas for the combined species. All data will be entered on the computer.

To date, preliminary investigation has been completed on five species. A workshop was held the end of April 1981 to review these data and to attempt to clarify any discrepancies should any exist. All work was completed by July 1981.

MODELING TOOLS

Various numerical models were conceived in Stage I studies to be necessary for predicting likely future conditions of the study area. Early efforts in Stage II included development or adaptation of numerical models to the study area.

WES, at Mobile District's request, has contracted with Professor R.O. Reid of Texas A&M University to develop a mathematical model to predict tidal fluctuations at several locations in the Gulf of Mexico. Presently, tide data for many locations in the Gulf are interpolated. This is not only difficult, but can be very inaccurate in that even slight errors in calculating water surface levels can significantly alter water velocity calculations in the estuaries.

The model has been completed, test data have been run, and efforts are currently underway to interface this model with the one of the study area. The model utilizes a 15 minute grid scheme applied to the entire Gulf of Mexico.

Testing of the model was made by applying the model to a seiche in a closed system with simple solutions. Tests of natural modes of oscillation were compared with observed tidal data. The model was calibrated for five tidal constituents.

Final amplitudes and phases of major diurnal and semidiurnal tidal amplitudes and currents at all grid points are stored on tape. The model can be run for any climatic condition considered.

The second model selected for application to the Mississippi Sound is the WES Implicit Flood Model (WIFM). This model, a computer code for predicting long period wave behavior, will be capable of simulating velocity fields and salinity distribution throughout the Sound and adjacent waters. The model has been used at other geographical locations, however, new features including consideration of the horizontal salinity gradient, an embedded fine mesh grid and linkage to the Gulf tide model are being added.

A global grid has been schematized for the study area including definition of shorelines and barrier islands. Current and tidal output from the model has been formatted similar to the data sets collected by Biddy Chappin and Raytheon. A preliminary time step routine has been run to test the model operation. At present the salinity algorithm is being coded.

Model output is expected in December 1981 and a final report in January 1982.

The ARAP Sediment Transport Model is being adapted and modified under contract to WES by Dr. Peter Sheng of Aeronautical Research Associates of Princeton, Inc. (ARAP) independent of this study. However, our study data are being used in calibrating the model which will have some capabilities that we are interested in. The model will provide three-dimensional data on currents and sediment dispersion for the study area. It will estimate suspended sediment levels, changes in bottom topography, and water direction and magnitude at any point vertically for each grid cell. For calibration and verification the model will use the current, tidal and meteorological data collected by Raytheon initially, the suspended sediment, wave,and bottom sediment data collected during September and the Nimbus G Imagery results provided by NORDA. The model will be linked directly to the WIFM model described above. Results of this effort are not expected until June 1982.

A wave hindcast model is being adapted to Mississippi Sound and the Gulf of Mexico by Dr. Reccio at the WES Hydraulic Laboratory. This model is capable of providing relationships of wave height vs. wind field and wave height vs. frequency based on 20 years of historical data. The output will be available on a coordinate system compatible to the WIFM model grid. Historical wind data from Keesler AFB, Biloxi, Mississippi, and Bates Field, Mobile, Alabama, are being used along with the meteorological data collected in our study. Results of this model are expected in January 1982.

SUMMARY

This paper was prepared to provide a status report on activities now underway or to begin in 1981 which are being conducted as part of the MSAAS. The paper was not prepared to provide details concerning the data collection efforts or to describe future activities which will utilize the data collected or generated in developing dredged material disposal plans. Other papers are being prepared for these purposes. The main purpose of this paper is to bring together a description of these activities to illustrate the comprehensiveness of the study. In addition to the efforts described herein, the study team has been reviewing additional data generated by other agencies, institutions and individuals and preparing to include these data in our data base. Actual procurement of these data will not begin until the geographical information system for this study is finalized. All data collected or utilized from other sources will be documented in reports as the study progresses.

DESCRIPTION OF THE OCEANIC DATA COLLECTION EFFORT FOR THE MISSISSIPPI SOUND AND ADJACENT AREAS OF STUDY

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INTRODUCTION

The Mobile District is conducting the study of Mississippi Sound to define spatial and temporal current and salinity patterns, and to develop predictive capabilities, in the form of mathematical models. The work is part of a study to determine whether present and proposed dredging activities in the area could be modified to increase economic efficiency and promote environment quality. Raytheon Ocean Systems Company collected synoptic oceanographic data in Mississippi Sound between April and October, 1980, as part of the Mobile District's multidisciplinary Mississippi Sound and Adjacent Areas Study.

Data were collected during the period 23 April through 20 October, 1980, utilizing a complement of approximately 40 current meters and 18 conductivity and temperature sensors distributed among 20 oceanographic moorings within Mississippi Sound (Figure 1). Meteorological data, consisting of wind speed and direction, air temperature, and air pressure measurements, were collected at 5 sites around the periphery of the Sound. Bottom pressure measurements, from which tidal height data can be extracted, were recorded at three oceanographic morrings in the Gulf of Mexico, south of Mississippi Sound.

Additionally, suspended sediment data were collected throughout Mississippi Sound during the month of September. Bathymetric soundings through the passes leading into Mississippi Sound were collected in late June and early July. Conductivity and temperature profiles were determined for forty stations in Mississippi Sound on a three-week basis during the study period.

The Waterways Experiment Station will use physical data collected during this study to calibrate and verify their Implicit Flooding Model (WIFM), which is an implicit finite difference scheme to numerically solve the two-dimensional, vertically integrated, shallow water wave equations. The model will also be capable of representing spatial and temporal salinity values.

The following paragraphs describe the instrumentation and mooring systems utilized during the data collection program.

CURRENT MEASUREMENTS

Endeco Type 105 Current Meters were used to collect current speed and direction data. The 105 is designed to accurately measure currents in a wave field. The meter is adjusted for neutral buoyancy and is tethered to a taut subsurface mooring.

Current speed is sensed by a rotor magnetically coupled to an opaque drum with a transparent helix. The spiral is back-illuminated by a L.E.D. light source and is viewed through a slit by the camera lens.

Data are recorded on 16mm film in the form of an analog bar graph in which the length of the bar is proportional to the number of rotor revolutions.

For the data collection effort, the current meters recorded one reading every 30 minutes, providing a full scale current speed of 3.5 knots.

The compass in the current meter consists of a back-illuminated opaque card with a transparent spiral. Alnico V magnets are utilized to sense magnetic north.

The illuminating L.E.D. is on continuously during the recording period, producing a film image representing all positions of the compass during the recording interval. During data reduction, the maximum intensity of the film is recorded to represent the peak of the histogram of direction information during the recording period.

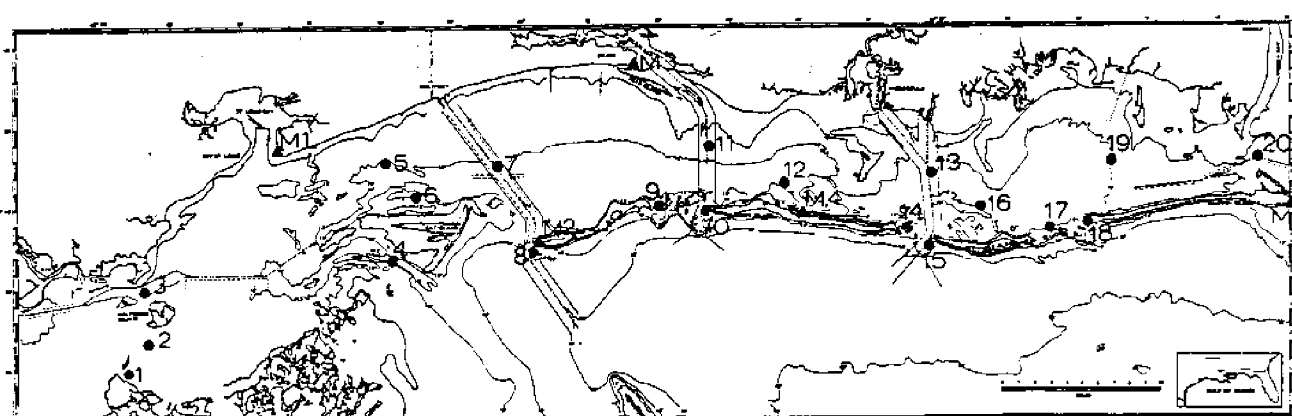

Figure 1. Location of in-situ instrumentation - Mississippi Sound data collection program.

Conductivity/Temperature Sensors

Aanderaa RTM Recording Conductivity and Temperature Meters wer used to collect salinity and temperature data. The RTM represents a modification to the Aanderaa RCM-4 recording current meter. The savonius rotor assembly, compass, and associated electronics were removed from the sensors, leaving only the temperature sensor (thermistor) and the conductivity sensor (inductive cell) and signal processing electronics.

Temperature and conductivity data were recorded in situ on 0.25 inch magnetic tape. During data processing, temperature and conductivity measurements are converted to salinity based on the Bennett Equation (*Deep-Sea Research*, 1976, Vol. 23, pp 157 to 165).

Bottom Pressure

Bottom pressure measurements at three stations within the Gulf of Mexico were obtained using Aanderaa WLR-5 water level recorders.

The WLR-5 employs a quartz crystal pressure sensor and averages the pressure over a specified integration time to eleminate effects due to waves. During the Mississippi Sound Study, an integration time of 54 seconds and a sampling interval of 5 minutes were used. The data were recorded on 0.25 inch magnetic tape.

Meteorological Stations

Aanderaa Automatic Weather Stations were used to collect meterorological data. Data recording equipment consisted of an Aanderaa DL-1 data logger, a Model 2371 connector board for accepting inputs from up to 10 different sensors, and a Model 2614 Block Numerator which serves as a record counter. Meteorological data were sampled at a 10-minute interval and recorded on 0.25 inch magnetic tape.

Wind speed was measured using a Model 2593 Wind Speed Sensor. The sensor is a three cup anemometer design, and measures average and maximum wind speed during the sampling interval. The maximum wind speed is the highest speed that has occurred over a two-second period at any time during the sampling interval.

Wind direction was sensed with a Model 2053 Wind Direction Sensor. The sensor consists of a light weight wind vane which is magnetically coupled to a compass with a potentiometer setting. Damping fluid in the van unit opposes rapid wind changes, but will permit light wind alignment. The sensor was aligned to magnetic north upon installation.

A Model 1289 Temperature Sensor with a Model 4011 radiation screen was used to acquire air temperature data. The sensor is of the platinum resistor type.

Air pressure data was obtained using a Model 2056 Air Pressure Sensor. The sensor is a CIC Model 7000 aneroid pressure transducer which as been modified to be compatible with the DL-1.

Salinity and Temperature Transect Data

Salinity and temperature profiles, obtained on a three-week basis during the data collection effort, were acquired using a Beckman RS5-3 Portable Salinometer. The unit uses a thermistor to sense temperature and a torroid inductive cell to sense conductivity.

Instrument Platform Description

Mooring systems used in the data collection effort are divided into three categories, based on depth of water. The three categories, Type A, Type B-C, and Type D, are discussed in the following sections.

Type A Moorings

The mooring system configuration for Type A moorings is illustrated in Figure 2. These moorings were used in water depths varying from 9 to 12 feet and were designed for one current meter per station. Surface float mooring lines had a scope twice the water depth to provide energy absorption of loading. The lighted buoy mooring consisted of chain with a swivel installed just above the bottom for minimum tension and thus free swivel operation. The potfloat buoy mooring was line buoyed at various points to provide energy absorption of wave motions. Bottom tether lines were interconnected to anchors with lengths twice the water depth plus 15 feet. This provided sufficient line to prevent surface lines from entangling with the subsurface instruments.

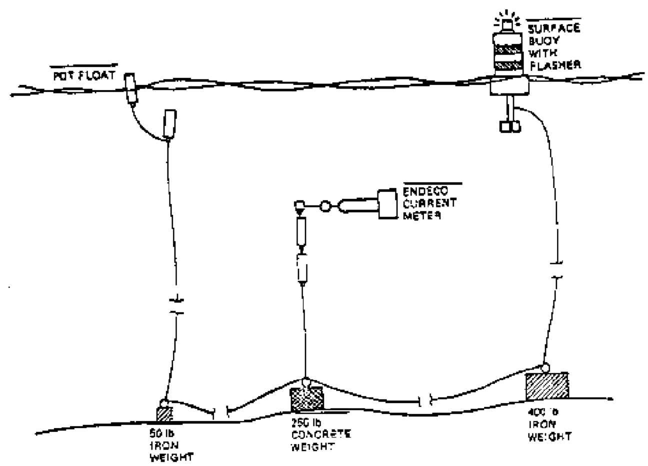

Figure 2. Station configuration - type A mooring.

Type B-C Mooorings

The mooring system configuration for a Type B-C mooring is shown in Figure 3. These moorings had either two (Type B) or three (Type C) current meters per string, and up to two conductivity/temperature gauges per string.

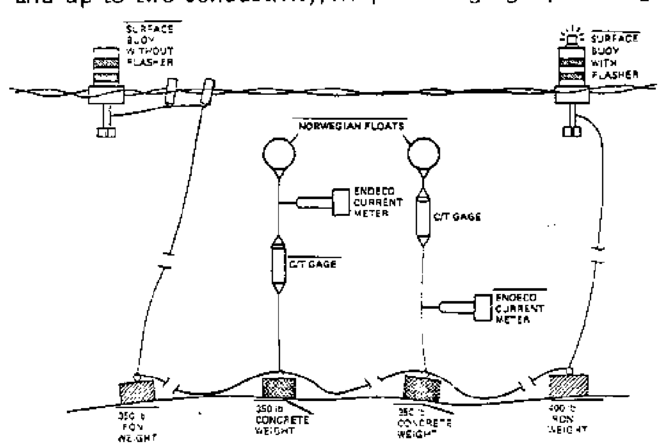

Figure 3. Station configuration - type B-C mooring.

These moorings were used in water depths of 13 to 35 feet. Two subsurface moorings were used in Type B-C moorings. One of the surface buoys was lighted. The surface buoy used as pick-up buoy was smaller than the main surface buoy and moored with chain, which was buoyed with small line floats to prevent chafing on the bottom. All surface lines had a scope of twice the water depth to absorb wave energy. The length of bottom tethers, which interconnected the anchors, were also twice the water depth. A urethane coating was applied to all line terminations to reduce wear.

Type D Mooring

The mooring system configuration for Type D moorings is illustrated in Figure 4. These moorings were designed for one pressure recorder mounted in a bottom platform/anchor, and were deployed in water depths of approximately 108 feet. The length of tethers for surface buoy moorings was 1.5 times the water depth plus 15 feet. One surface buoy was a 3-foot diameter steel buoy which included radar reflectors and a three-mile range incandescent light, equipped with a sun switch and lamp changer, and was chain-moored to an anchor. The smaller pick-up buoy for this system was equipped with an incandescent flasher and was moored with synthetic line to facilitate handling during servicing. The length of bottom tether lines connecting the anchors and instrument packages was 1.5 times the water depth plus 35 feet. The pressure recorder anchor was a flat concrete disc weighing approximately 350 lbs. in air with a lifting point above the instrument and centered at the axis of the cylinder. The pressure recorder anchor was designed not to increase flow velocities at its perimeter. This minimized scouring under the anchor and, therefore, minimized settling of the anchor during the deployment period.

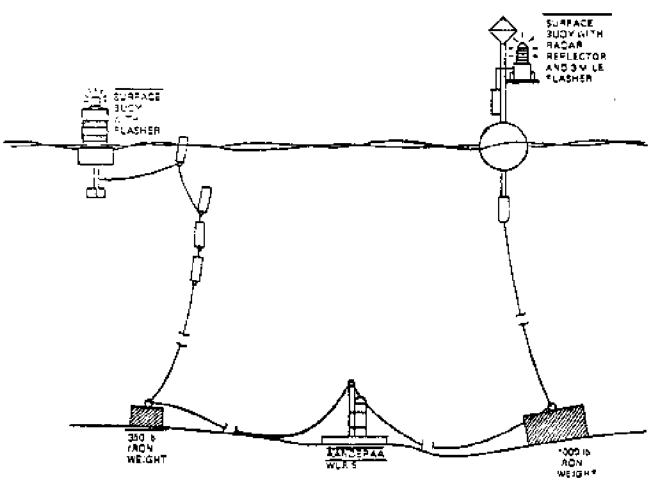

Figure 4. Station configuration - type D mooring.

Meteorological Towers

Meterological towers selected for this application were standard Rohn Model 25-G heavy duty communications tower. Towers were erected such that the sensors were located 10 meters above water level. The tower base pads were made from concrete and towers were guyed with 3/16 inch cable, anchored in concrete blocks several feet below ground level. Tower configuration and foundation details are illustrated in Figure 5.

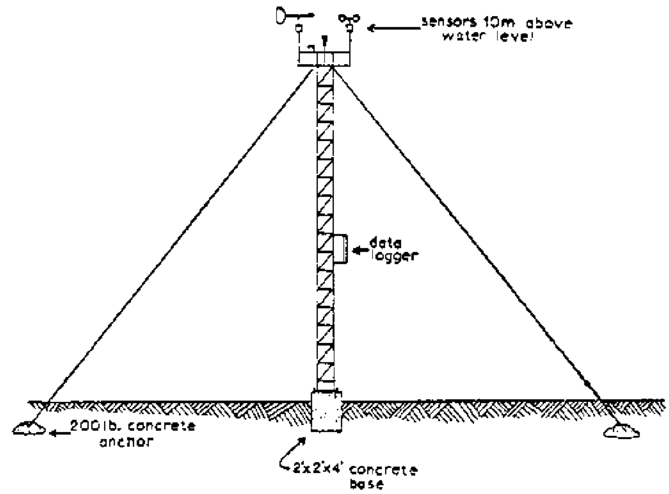

Figure 5. Station configuration - meteorological stations.

Instrument Servicing

Field operations for the data collection effort were based on a three-week cycle. Instrumentation was serviced on a 21-day schedule, with Conductivity/Temperature transects run after completion of instrument servicing.

Replacement of in-situ instrumentation took place on alternating days at the beginning of each 21-day cycle, with intervening days used to service and prepare instrumentation for the following day. Using this technique, it was possible to service and thoroughly check out each instrument in the laboratory prior to redeployment. This procedure resulted in the detection and rectification of problems which may have caused a loss of data during the subsequent deployment period.

Bathymetric Surveys

Bathymetric surveys of the following locations were conducted during the period 23 June through 11 July 1980:

Locations	Track Miles Surveyed
St. Joe's Pass to Le Petit Pass	4.5
Cat Island Channel	9.5
St. Louis Bay	2.0
Ship Island Pass & Camille Cut	7.0
Dog Keys/Little Dog Key Pass	16.3
Biloxi Bay	3.5
Ship Island Channel	1.3
Horn Island Pass	8.3
Petit Bois Pass	21.2
Grants Pass/Pass Aux Herons	2.0
Mobile Bay Entrance	11.0
Total Track Miles	86.6

The Mobile Mapping and Data Logger System utilized for these surveys is illustrated in Figure 6.

The system incorporates a Hewlett Packard 9825 Computer, a 6904B multi-programmer, and a 9872B bed plotter. A Raytheon Precision Depth Digitizer (PDD) and a DE719 Fathometer[R] were interfaced with the system to provide bathymetric data. A Motorola Miniranger III Navigation system was employed to collect horizontal positioning information.

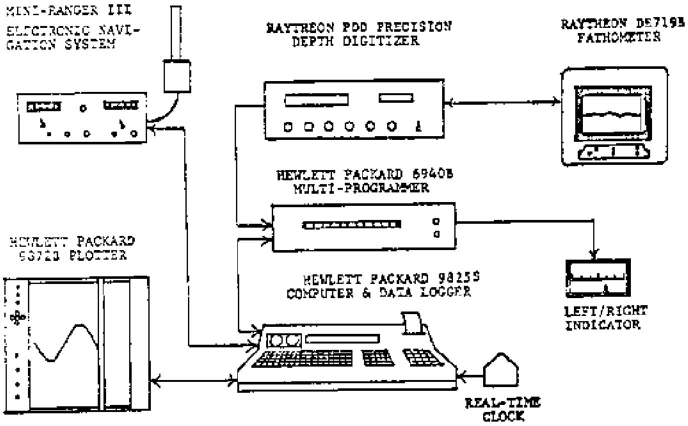

Figure 6. Mobile mapping and data logger system.

One navigation point from the horizontal control system and one depth value were collected every two seconds at a speed of 7 knots. This converts to approximately one data point every 23 feet. The depth value reflects the average of four (4) data points collected during a 0.5 second period centered around each two (2) second navigational fix. Data was then recorded on cassette in the microprocessor unit.

Pre-plotting of survey tracklines as well as real-time on-board printouts and processing of bathymetric and navigation data allowed control of survey lines and permitted on-board review of actual track lines to ensure complete coverage.

The precision of the pre-plotted track lines was achieved through use of a "left/right" rudder indicator. This unit displays actual boat position relative to the pre-plotted track line, thus enabling the helmsman piloting the survey boat to hold a course to the pre-plotted track line.

SURVEY RESULTS

During the survey period, approximately 24 instrument years of data were collected from in-situ instrumentation. Ten sets of conductivity and temperature transect measurements covering Mississippi sound were obtained.

Data from the instrumentation has been compiled on magnetic tape and transmitted to the Waterways Experiment Station. Graphic displays of in-situ data, tabulations of transect data, and bathymetric charts were submitted to the Mobile District of the U. S. Army Corps of Engineers.

A DECISION MODEL FOR THE TRADE-OFF BETWEEN THE BENEFITS OF ECONOMIC GROWTH AND ITS ENVIRONMENTAL COST

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In recent years there has been a growing awareness on the part of the public as well as the private sector of the limitations of our natural resources. It was made clear by those concerned that economic growth irreparably damages the environment. They call for an end or at least sharp curtailment of such growth. On the other hand, economists, in general, perceive growth as an essential requirement of our social welfare. The restoration and protection of the environment envisioned by ecologist require reduction in living standards which could seriously endanger the political well-being of the American society.

From all indications, the world, especially the western democracies and Japan, is destined and committed to a policy of economic growth. It then becomes necessary for policy-makers to devise positions and enforce polices where a trade-off between the benefits of growth and its environmental costs can be calculated in a quantifiable manner.

Such objective analysis could identify some projects as not being beneficial on environmental grounds though justifiable on economic grounds. It can also identify projects or programs that induce growth and simultaneously require minimal ecologic trade-off.

Among the most promising empirical models available at the present to evaluate the economic-ecologic trade-off is the "Materials Balance Approach" for the entire economy. The principle states that resources taken from the environment for use in production and services must be returned to the environment as waste residuals in equal mass. In describing this approach Allen Kneese [3] says:

> The inputs of the system are fuel, foods, and raw materials which are partly converted into final goods, and partly become residuals. Except for increases in inventory, final goods also ultimately enter the residuals stream. Thus, goods which are "consumed" really only render certain services. Their material substance remains in existance and must be either reused or discharged to the natural environment.

A comprehensive review of models in which the extension of input-output analysis includes environmental externalities as material flows into and out of the economic sector shows there is basically a handful of comparable approaches. Among the most prominent are the Ayers-Kneese model [1], the Daly model [2], the Isard model [5], the Leontief model [7], the Victor model [15] and the Hite-Laurant model [4].

The approach followed in this study is in essence a modification of the Hite-Laurant model as was applied in their study of the Charleston metropolitan region [6]. It is practical and easy to operate and recognizes data problems. The model includes waste residuals from the economy to the environment. This allows the extension of the accounting framework of the input-output table to the environmental sector by specifying the outputs of a number of chemical and biological effluents to air and water and of solid wastes as exports of production by-products. It consists of three phases as follows:

(1) Development of an input-output accounting of the region. It is the flow of goods and services in dollars usually during a year period. The economic activities of the region are depicted in terms of sectors composed of industries. The elements of the transactions among these sectors are displayed in the "Transaction Matrix." These elements are inter-industry flow in the sense that goods are transferred from some sectors as output to be used by others as input. An exogenous sector defined as Final Demand which includes households, government, and exports absorbs the remainder of output. Output and employment multipliers can be calculated.

(2) Development of an inventory of water and air pollutants as well as solid wastes that were produced as consequences of economic activities of the diverse producing sectors including households. This is the residual stream of the material substances which are discharged to the natural environment.

(3) The economic-ecologic trade-off is then accomplished through the incorporation of the results obtained in (1) and (2) as follows:

Let:

E = A matrix of outflows of residuals to the environment.

$(I-A)^{-1}$ = The Leontief inverse. It is the inverse of the input-output model.

U = A matrix of the direct and indirect environmental impact of each economic sector.

Then:

$$E(I-A)^{-1} = U$$

The multiplication of these matrices provides the necessary linkage between the economy and the environment. The analysis is carried further by obtaining the environmental-output multipliers and environmental-income multipliers. These multipliers are obtained by dividing the output and employment multipliers calculated from the input-output matrix by the economic-ecologic matrix.

These multipliers in the form of matrices in a sense show the impacts of economic growth on the ecologic system. They can provide valuable information regarding the trade-off between the benefits of economic growth and its environmental costs.

Such information is potentially valuable in decision-making. It is an empirical assessment of benefit-cost between economic growth and environmental integrity.

An actual application of this model was implemented for the Coastal Region of Mississippi. This region consists of three counties with a total population in excess of 270,000, and it is the fastest economically growing area in the State. An outline of this empirical study which is based on work reported in [9], [10], and [11] is presented.*

THE ECONOMIC MODEL

The input-output model is arranged with 29 endogenous sectors. It is constructed by using regionalization techniques of the 83 sectors national input-output tables for 1971 [16]. The aggregation scheme for grouping common sectors is based on the Standard Industrial Classification (SIC) code developed by the Department of Commerce.

An essential component of the economic model is the Transaction Matrix given in Table 1. It illustrates the structure of the economy in an accounting format in the sense that sales by a sector to other sectors equal the purchases of the particular sector from other sectors and value added (households as payment for labor, federal government as payment of taxes, and inputs). The horizontal rows are sales and the vertical columns are the purchases. Inputs comprise the residuals necessary to make sales (output) equal to purchases (input) and reflect purchases of labor, materials and input outside the study region. They also include items such as profit and depreciation.

Useful economic measures as consequences of input-output analysis are the output and income multipliers which are given in Table 2. Output multipliers measure the effects of changes in the final demand for output of each sector and the impulse it generates throughout the economy. Income multipliers express the total change in income due to change in sales of a particular sector to Final Demand.

When households sector is included among the endogenous sectors, the multipliers are called Type II. Otherwise, they are called Type I. It can be shown that multipliers of Type II are larger than of Type I.

THE ENVIRONMENTAL MODEL

The environmental model consists of an inventory of water and air pollution as well as solid wastes. These are the physical magnitudes generated through the economic activities of the coastal region of Mississippi.

Water effluent information was based primarily upon actual data provided by the Mississippi Air and Water Pollution Control Commission [8] obtained as part of their monitoring of producing establishments. Other vehicles for collecting data had to be used such as secondary sources published by the Environmental Protection Agency or by incorporating findings of other similar studies. Some information was collected by phone or by personal contact with engineers and experts in this field.

Quantities of air pollutants were derived from national data from studies of similar areas because localized data were unavailable. For estimation purposes the 30 economic sectors of the Mississippi Coastal model were divided into non-household and household categories to best utilize available data within time and budgetary constraints. The household category consisting of Sector 30 was estimated with emission factors published by the Environmental Protection Agency [13 and 14]. The non-household category includes sectors 1-29 and was estimated by adopting air pollution coefficients based on a pioneering study by Peter Victor [15].

Solid waste was estimated primarily from per-capita solid waste factors. The factors were obtained from the published detailed engineering study by Salvato [12].

The basic structure of the environmental matrix for the coastal region of Mississippi is illustrated in Table 3. It contains 29 rows representing the endogenous sectors, that is, the economic producing sectors of the region. Households, the last row, is the exogenous sector representing pollutants by non-producers. It also contains thirty columns. The first column headed Waste Water is water partially treated or nontreated which is dumped into the environment as a consequence of the economic process. The other 29 columns are net unpriced loadings of water effluents, air emission, and solid waste from the area's economy into the environment. The coefficients in the table represent values estimated for the year 1977.

THE ECONOMIC-ENVIRONMENTAL LINKAGE

The economic model and the environmental model are then linked to show the interdependence between economic activities and waste generation. It will emphasize that changes in the economy will accompany changes in the environment. Estimates in the form of pollution produced per dollar of output, employment and income can be obtained. Furthermore, environmental-economic multipliers can be calculated for each combination of environmental category and economic sector.

Tables 4 and 5 are the results of the immediate application of the linkage. In each of these tables, the rows indicate the pollutants and the columns numbered 1 through 30 are the economic sectors of the region.

Table 4 shows the environmental effects resulting from the inter-industry sales and purchases. Every entry in this table represents the total export of pollution to the environment. That is, a $1,000 increase in economic activity of a certain sector will cause increases in production in all other sectors due to the multiplier effect. Through their economic activities to meet the demands of that sector, they in turn will contribute to the pollution. For example, Sector 8, the Food Processing, when increasing its output by $1,000 will cause a total discharge to the environment of .108 (MGY) of waste water, .003 tons of nitrogen, .006 tons of BOD, .013 tons of suspended solids, .005 tons of settleable solids, .003 tons of oil and grease, .003 tons of nitrogen oxides, .03 tons of sulfur oxide, .02 tons of carbon monoxide, .006 tons of particulates, .002 tons of hydrocarbons, and .78 tons of solid waste.

*Due to their lengths, only parts of the tables are presented for illustration. For more technical discussion and details, see [9], [10] and [11].

It can be observed from Table 4 that though some of the sectors were not contributing to pollution directly through their production process, nevertheless, indirectly they cause other sectors to do so through their supporting activities. The construction industry, Sector 7, does not produce BOD directly, yet through the round of economic activities by the supporting industries .002 tons of BOD is produced for each $1,000 increase in construction.

The trade-off between income and the environment is given in the matrix illustrated in Table 5. The entries represent the physical quantities of pollutants generated through $1,000 increase in income of the various sectors. Looking at this from another view point, the limitations in environmental pollution by the quantities listed for each sector will necessarily cause a $1,000 decrease in income.

The values computed in Tables 4 and 5 are obtained by allowing the Households sector to be included among the producing sectors. Therefore, these tables give the direct, indirect, and induced effects of the economic-environmental interdependencies.

A PRACTICAL EXAMPLE

The model discussed can be used in a variety of useful ways depending on the nature of inquiry as regards to the interplay between the economy and the environment. As an example, environmental requirements due to attracting new industries will be discussed.

The attraction of a new industry to a region would have a multiple effect over the other producing sectors. First, through economic interrelationships, all sectors in the region will expand their outputs to meet the new demands.

Assume that a comparison of economic-ecologic trade-off is desired between a new Food Processing industry and a new Chemical-Petroleum industry. Further assume that the anticipated potential for both industries is of a magnitude of a million dollars per year. Anticipated sales of all the economic sectors can be calculated using the information from Table 1. These estimated values are given in Table 6.

In order to obtain estimates of pollution factors that will be caused by all sectors, Columns 8 and 13 of Table 4 can be used as the basis of calculation. The resulting detailed environmental pollutions to be contributed by each sector in the region are portrayed in Tables 7 and 8 for the Food Processing and the Chemical-Petroleum. Hence, information provided can be used for the purpose of deciding on the merits of each plan regarding the benefits of economic growth and its environmental cost.

Information currently available does not permit measuring the impact of the pollutants on the environment in dollar values. Some wastes (by products) have a positive economic effect; and some, negative. In other words discards from some sectors may enhance economic output of other sectors while other residuals may reduce productivity of other industires. For example, BOD discharges from the household and other sectors may harm the environment and thus reduce output of the fishery sector. Research to facilitate measuring such effects is needed.

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Table 1. Transactions matrix - Mississippi Coastal Region, 1972.

Input (Purchases) / Output (Sales)	Fisheries 1	Construction 7	Food Processing 8	Chemical/Petro/ Other 13
1 Fisheries	150	0	7235	0
2 Forestry	0	0	0	881
3 Livestock Products	0	0	2235	0
4 Crops & Agricultural	0	0	1135	23
5 Ag Forestry, Fish Svc	219	352	0	0
6 Mining	0	1245	0	301
7 Construction	0	48	461	3056
8 Food Processing	0	0	8335	172
9 Apparel & Finished	0	0	0	0
10 Lumber & Wood	0	5008	29	156
11 Paper & Allied	0	111	483	894
12 Printing/Publishing	0	41	163	34
13 Chemical/Petro/Other	11	111	73	1528
14 Stone, Clay & Glass	1	4296	512	447
15 Primary/Fab Metals	54	3858	172	151
16 Transportation Equip	3024	2	2	0
17 Miscellaneous Mfg	36	917	140	586
29 State/Local Gov't	3	139	175	500
ENDOGENOUS TOTALS	4167	34670	30400	39702
30 Households	2795	51352	26854	56807
31 Federal Gov't	336	4017	2176	7170
32 Imports	4602	29361	40408	107549
TOTAL PURCHASES	11900	119400	99838	221228

Table 2. Type I and type II multipliers.

Sector	Type I Output	Type I Income	Type II Output	Type II Income
1 Fisheries	1.40	1.49	2.22	1.99
2 Forestry	1.14	1.19	1.79	1.58
3 Livestock Products	1.72	1.88	2.75	2.50
4 Crops & Agricultural	1.42	1.56	2.27	2.07
5 Ag Forestry, Fish Svc	1.09	1.12	1.70	1.48
6 Mining	1.30	1.79	1.78	2.38
7 Construction	1.38	1.28	2.66	1.70
8 Food Processing	1.42	1.45	2.33	1.92
9 Apparel & Finished	1.27	1.31	2.09	1.74
10 Lumber & Wood	1.50	1.51	2.45	2.00
11 Paper & Allied	1.30	1.36	2.15	1.80
12 Printing/Publishing	1.32	1.38	2.18	1.83
13 Chemical/Petro/Other	1.24	1.29	2.05	1.72
14 Stone, Clay & Glass	1.37	1.45	2.28	1.93
15 Primary/Fab Metals	1.35	1.45	2.26	1.93
16 Transportation Equip	1.08	1.09	1.76	1.44
17 Miscellaneous Mfg	1.27	1.33	2.10	1.76
18 Water Transportation	1.52	1.46	3.00	1.93
19 Other Transp/Whse	1.41	1.35	2.79	1.80
20 Communication/Pu Utl	1.10	1.38	1.35	1.84
21 Eating & Drinking	1.35	1.29	2.50	1.72
22 Service Stations	1.31	1.27	2.44	1.69
23 Wholesale/Retail	1.20	1.15	2.23	1.53
24 Finance/Ins./Real Est	1.28	1.42	1.97	1.88
25 Hotel, Motel, Lodging	1.30	1.21	2.53	1.61
26 Medical Services	1.25	1.16	2.44	1.55
27 Educational Services	1.26	1.17	2.45	1.55
28 Other Services	1.24	1.16	2.42	1.54
29 State/Local Gov't	1.62	1.59	3.04	2.12
TOTAL	38.41	39.54	66.00	52.53
AVERAGE	1.32	1.36	2.28	1.81

Table 3. Physical quantities of water effluents, air pollution, and solid waste, Mississippi Coastal Region, 1977.

Sector Number	Sector Name	Waste Water (MGY) 1	Chlorine (Tons/yr) 2	Nitrogen (Tons/yr) 3	Sulfides (Tons/yr) 4	Flouride (Tons/yr) 5
1	Fisheries					
2	Forestry					
3	Livestock Products					
4	Crops & Agricultural	175.634				
5	Ag, Forestry, Fish Svc					
6	Mining	633.600				
7	Construction	759.000				
8	Food Processing	7,534.839	4.372	245.560		
9	Apparel & Finish	328.634	.135	2.246		
10	Lumber & Wood	311.268		12.949		
11	Paper & Allied	7,245.000				
12	Printing & Publishing	6.495				
13	Chemical/Petro/Other	12,874.239		153.936	1.811	256.363
14	Stone, Clay & Glass	3,240.408	.010			
15	Primary/Fab Metals	1,458.868	.777	17.983		
16	Transportation Equip	324,804.460	1.586			
17	Miscellaneous Mfg	86.848	.028	.919		
29	State & Local Gov't	29.910	.053	.749		
30	Households	5,205.740	8.943	136.383		
TOTAL		369,127.735	23.539	680.523	1.811	256.363

MGY = Million gallons per year.

Table 4. Type II environmental-output interdependence matrix (tons) (environmental change per $1,000 change in finan demand) Mississippi Coastal Region, 1977.

	Fisheries 1	Construction 7	Food Processing 8	Chemical/Petro/ Other 13
1 Waste Water*	.169131	.030262	.107967	.070990
2 Chlorine	.000009	.000018	.000059	.000010
3 Nitrogen	.000152	.000339	.002879	.000902
4 Sulfides	.000000	.000000	.000000	.000009
5 Fluoride	.000002	.000002	.000002	.001223
6 Phosphate	.000001	.000005	.000001	.000000
7 Heavy Metals	.000000	.000000	.000000	.000062
8 Zinc	.000001	.000001	.000000	.000000
9 Cadmium	.000000	.000001	.000000	.000003
10 Iron	.000001	.000002	.000001	.000222
11 Chromium	.000000	.000000	.000000	.000003
12 Aluminum	.000000	.000005	.000001	.000000
13 Cooper	.000000	.000001	.000000	.000000
14 Nickel·	.000000	.000001	.000000	.000000
15 Lead	.000000	.000000	.000000	.000000
16 Fecal Colifm	.000000	.000000	.000000	.000000
17 BOD	.000675	.001519	.005995	.001868
29 Hydrocarbons	.002165	.004571	.002291	.004235
30 Solid Waste	.149270	.258157	.778712	.213749

*Million gallons per year (MGY).

Table 5. Type II environmental-income interdependence matrix (tons) (environmental change per $1,000 change in income) Mississippi Coastal Region, 1977.

	Fisheries 1	Construction 7	Food Processing 8	Chemical/Petro/ Other 13
1 Waste Water*	.362757	.041293	.208602	.153765
2 Chlorine	.000020	.000024	.000114	.000021
3 Nitrogen	.000326	.000463	.005563	.001953
4 Sulfides	.000000	.000000	.000000	.000019
5 Fluoride	.000004	.000003	.000003	.002649
6 Phosphate	.000003	.000006	.000001	.000001
7 Heavy Metals	.000000	.000000	.000000	.000135
8 Zinc	.000003	.000001	.000000	.000000
9 Cadmium	.000001	.000001	.000000	.000006
10 Iron	.000002	.000003	.000001	.000481
11 Chromium	.000001	.000001	.000000	.000007
12 Aluminum	.000003	.000007	.000001	.000001
13 Copper	.000000	.000001	.000000	.000000
14 Nickel	.000001	.000002	.000000	.000000
15 Lead	.000000	.000000	.000000	.000000
16 Fecal Colifm	.000000	.000000	.000000	.000000
29 Hydrocarbons	.004644	.006237	.004427	.009173
30 Solid Waste	.320158	.352262	1.504537	.462984

*Million gallons per year (MGY)

Table 6. Inputs required for a million dollar new industry in the food processing and chemical-petroleum sectors, Mississippi Coastal Region (thousands of 1972 dollars).

	Sales To Food Processing	Sales To Chemicals-Petroleum
1 Fisheries	72470	
2 Forestry		4170
3 Livestock	22390	
4 Crops	11370	110
5 Ag, Forestry, Fish Svc		
6 Mining		1430
7 Construction	4620	14470
8 Food Processing	83490	810
9 Apparel & Finished		
10 Lumber & Wood	290	740
11 Paper and Allied	4840	4230
12 Printing & Publishing	1630	160
13 Chemicals & Petroleum	730	7230
14 Stone, Clay & Glass	5130	2120
15 Primary & Fab Metals	1720	710
16 Transportation Equip	20	
17 Miscellaneous Mfg.	1400	2770
18 Water Transportation	8830	16920
19 Other Trans/Warehousing	6460	32750
20 Communication/Pu Util	13700	29030
21 Eating/Drinking Places	4110	2410
22 Service Stations		780
23 Wholesale & Retail Trade	31610	18530
24 Finance, Insu., Real Estate	9980	27110
25 Hotels, Motels & Lodging	1290	1180
26 Medical Services	90	150
27 Educational Services	100	170
28 Other Services	16480	1760
29 State & Local Gov't	1750	2370
30 Households	268980	268940

Table 7. Induced environmental impact attributable to a million dollar expansion in the food processing industry, Mississippi Coastal Region (tons per year).

Environmental Factors	Fisheries 1	Construction 7	Food Processing 8	Chemical/Petro/ Other 13
1 Waste Water*	7824.151	498.794	9013.914	78.814
2 Chlorine	4.276	.273	4.926	.043
3 Nitrogen	208.641	13.301	240.368	2.102
4 Sulfides				
5 Fluorides				
6 Phosphate				
7 Heavy Metals				
8 Zinc				
9 Cadmium				
10 Iron	.072	.005	.083	.001
11 Chromium				
12 Aluminum	.072	.005	.083	.001
13 Copper				
14 Nickel				
15 Lead				
16 Fecal Coliform				
17 BOD	434.458	27.697	500.523	4.376
29 Hydrocarbons	166.029	10.584	191.276	1.672
30 Solid Waste	56433.259	3597.649	65014.665	568.460

*Million gallons per year (MGY)

Table 8. Induced environmental impact attributable to a million dollar expansion in the chemicals-petroleum industry, industry sectors.

Environmental Factors*	Fisheries 1	Construction 7	Food Processing 8	Chemical/Petro/ Other 13
1 Waste Water		1027.110	57.495	513.200
2 Chlorine		.145	.008	.072
3 Nitrogen		13.052	.731	6.521
4 Sulfides				
5 Fluoride				
6 Phosphate				
7 Heavy Metals		.897	.050	.448
8 Zinc				
9 Cadmium		.043	.002	.022
10 Iron		3.212	.180	1.605
11 Chromium		.043	.002	.022
12 Aluminum				
13 Copper				
14 Nickel				
15 Lead				
16 Fecal Coliform				
17 BOD		27.030	1.513	13.506
29 Hydrocarbons		61.280	3.430	30.619
30 Solid Waste		3092.948	173.137	1545.405

*Environmental factors are represented in tons per year, except for Waste Water which is represented in million gallons per year.

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THE MISSISSIPPI COASTAL PROGRAM RESOURCE MANAGEMENT ON THE MISSISSIPPI COAST

By
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INTRODUCTION

The Mississippi coastal area,[1] with its environmentally fragile estuaries, is part of a complex ecosystem which contains nutrient rich waters and many diverse and unique wildlife habitats. Mississippi's coastal waters abound with fish, shellfish and other marine life. Over the years, the natural resources in and around the Mississippi Sound have provided the basis for one of the highest rates of economic development and growth in the State of Mississippi. The coastal area has attracted a great number of skilled workers and has become one of the most heavily urbanized and industrialized areas of the state. Defense and energy related industries and on-shore fish processing facilities are located all along the Mississippi coast. The waters of the Mississippi Sound are also extremely important to the state for recreational purposes, providing opportunities for fishing, boating and sailing.

Only recently have we begun to appreciate that the resources of the Mississippi Sound are finite. The expanding availability of detailed scientific and technical information about the Sound has increased our understanding of the complex natural relationships between man's activities and the fragile coastal environment. This increased knowledge has been accompanied by concerns about the impact of man's activities on the coastal area.

The purpose of this symposium is to synthesize the scientific and technical material available on the Sound with a view toward raising the level of public discussion on critical issues and closing informational gaps. Effective management for environmental quality will require more scientific knowledge, but it is also important to address the set of questions that must be resolved if effective action is to be taken. These questions involve choices among policy options and alternatives and require the implementation of an institutional framework which simplifies the identification and articulation of these choices.

With the recent federal approval of the Mississippi Coastal Program ("MCP"), Mississippi has taken a big step toward implementation of an institutional framework for managing its coastal resources. The MCP is designed to protect sensitive coastal resources and to control and manage industrial development in the coastal area.

This paper provides a brief overview of the MCP, with emphasis on the wetlands permitting process, which is likely to be the arena where battles between proponents and opponents of the program will be fought.[2] The paper includes general comments on the ability of the MCP to provide a framework for management of Mississippi's coastal resources. This critical evaluation must of necessity be general in nature because the program is less than six months old and has not yet been fully implemented. Evaluation of the program should be a continuous process, however, particularly in this time of high uncertainty.[3] Continuous evaluation provides information and feedback which will allow coastal managers to identify and refine aspects of the program which are working effectively. In this era of fiscal restraint and increasing public skepticism about government, it is important that effective government programs which are providing longterm benefits be saved from the budgetary axe.

THE MISSISSIPPI COASTAL PROGRAM

Federal Incentives – State Action

Increasing and often conflicting demands upon the coastal zone of the United States and the resulting loss of living marine resources and permanent adverse changes to coastal ecological systems were the impetus behind Congress' passage of the Coastal Zone Management Act of 1972 (CZMS).[4] Congress passed the CZMA to encourage effective management of coastal resources, and it is primarily a mandate to coastal states to develop and manage their own coastal resources through the use of coastal management plans that are consistent with federal guidelines. CZMA encourages coastal states to plan the development of their coastal areas through defining permissible land and water uses and by instituting regulatory mechanisms to control those uses.[5]

The CZMA establishes a two-stage federal grant program whereby coastal states can receive federal monies for both the development and implementation of an approved plan.[6] Additional money is available for states with approved programs through the Coastal Energy Impact Program (CEIP).[7] CEIP helps coastal states and their local governments meet needs that result from activities relating to energy development in their coastal areas. Another incentive for coastal states to develop their own coastal programs is the federal consistency provision of the CZMA which states that any federal activity within the state's coastal zone must, to the maximum extent practicable, be conducted in a manner consistent with the state's approved coastal plan.[8]

On September 29, 1980, Mississippi's coastal management program was approved by the federal office of Coastal Zone Management. Approval of the Mississippi Coastal Program (MCP) was the culmination of many years of hard work by a group of people concerned with the wise use and management of Mississippi's coastal resources.[9]

The MCP is based, in large part, on the Coastal Wetlands Protection Law of 1973,[10] which was the Mississippi Legislature's initial response to passage of the CZMA. The law addresses management and use of coastal resources in the three coastal counties, all adjacent coastal waters found within the three mile limit seaward of the coastline and the Mississippi barrier islands. The Wetlands Protection Law provides the statutory basis for the regulatory program which is implemented by the MCP.

The state agency with primary responsibility for implementation and enforcement of the MCP is the Mississippi Commission on Wildlife Conservation, through its Bureau of Marine Resources. The Commission must insure that certain goals established by the state legislature are met. Among these goals are: (1) reasonable industrial expansion on the coast with special consideration given to water dependent industries; (2) coordinated state, local and federal planning and; (3) one-stop permitting to coordinate the processing and issuance of a variety of permits in the coastal area.[11] All state agencies are required to comply with the coastal program and to consider wetlands protection as a factor in their decisionmaking processes.

Program Highlights

The MCP is too lengthy and complex to be examined fully in this paper. The wetlands permit system, which is the backbone of the program, is described in detail in the next section, however, and other important aspects of the program are summarized below.

(1) **Fisheries Management.** While the primary concern of the program is with structural development within the wetlands, it also deals with the problem of managing the state's fisheries resources. The fisheries management section reflects concern with the long term stability of Mississippi's fisheries. Its major objective is to provide for the maintenance of the "optimum sustainable yield" of the fisheries; i.e., that the resources will be fished within the reproductive capacity of a species while at the same time deriving the greatest public benefit. The planners envision this being accomplished through the effective use of ordinances, licensing, the protection of natural habitats, educational, research and development projects, and the use of future technological advances. Primary authority for fisheries management will continue to be vested in the Mississippi Commission on Wildlife Conservation and the Bureau of Marine Resources.

(2) **Special Management Areas.** Three areas have been identified as ones needing special management because of their economic and recreational importance. These are: (a) port and industrial areas, (b) urban waterfronts, and (c) shorefront access areas. (Specific sites are identified in the program.) Designation of these areas does not impose new regulatory authority, but it is hoped that development of specific, environmentally sound plans for these areas will reduce the need for regulation while simultaneously providing coastal resources with the greatest amount of protection.

(3) **Affirmative Management Activities.** The coastal program identifies certain activities which require affirmative management to complement the regulatory provisions of the program. Among these activities are energy facility siting, shoreline erosion and mitigation, construction of public facilities such as sewer, water and drainage systems, marine fisheries research, designation of areas for preservation and restoration, the preservation of scenic qualities of an area, and public information and education regarding coastal resources.

(4) **A-95 Clearinghouse System.** The A-95 Clearinghouse system serves as a statewide notification and review system for federal assistance programs in Mississippi. To assist in the coordination and approval of projects affecting coastal areas, A-95 has been extended to include review of both state and federal actions. A weekly log of proposed projects is compiled by A-95 and distributed to interested agencies who may then submit comments on the project. Any interested person may receive copies of the weekly log upon request. The A-95 Clearinghouse system is an important step in the interagency policy coordination procedure and should help the Bureau of Marine Resources insure that all federal and state actions which affect the coastal area are consistent with the MCP.

(5) **Pollution Control.** The requirements of the federal Clean Water and Clean Air Acts and the Mississippi Air and Water Pollution Control Law are incorporated by reference into the coastal program. As a result, air and water quality standards and permitting requirements affecting the coast will continue to be administered by the Bureau of Pollution Control which is required to carry out its responsibilities in compliance with the coastal program.

Wetlands Permitting System

The public policy expressed in the Mississippi Coastal Wetlands Protection Law is that wetlands should be preserved unless there is an overriding public interest inherent in a proposed activity affecting the wetlands.[12] To carry out this policy, a permitting and compliance review procedure is authorized by law, described fully in the MCP and administered by the Bureau of Marine Resources (BMR).

Any activity which affects coastal wetlands is a "regulated activity" and cannot be conducted without a permit from BMR. Since some activities carried on outside the wetlands area may affect the wetlands, a permit may be needed for activities beyond the three county coastal area. The five (5) classes of regulated activities which require a permit are: (1) dredging or removing of any material from wetlands; (2) filling wetlands by direct or indirect means; (3) killing or materially harming any wetland plant or animal; (4) building any structure that materially affects the ebb and flow of the tide, and (5) erection of structures on sites suitable for water dependent industry.[13]

The applicable coastal wetlands use plan, which is a document designating the types of activities allowed in specific coastal wetlands areas, should also be consulted before planning activity in the coastal zone. No permits will be granted for activities that are inconsistent with an applicable use plan. The MCP provides for a petition procedure to obtain revisions of use plans.

If a proposed activity requires a permit, and is allowed by the use plan, a permit application must be filed with BMR. The application must include, among other things, the names and addresses of the applicant and all adjacent land owners, an estimate of the cost of the project, a detailed description of the proposed activity with a map, a statement of its purpose and of its intended and possible unintended effects, a description of the public benefits to be gained from the project, and an estimated completion date. The application should include an environmental assessment of the proposed activity. The applicant must also certify that all other required permits have been applied for, or that no other permits are required.[14]

When BMR receives an application, copies are forwarded to certain public officials[15] and a public notice is published stating the date by which written objections to the application must be filed.[16] This notice is published once a week for 3 consecutive weeks with the final publication appearing at least 7 days before the deadline for filing written objections. Any interested persons may file a written objection to the permit application.

If an objection is made, or upon the applicant's request, a public hearing must be held within 20 days of the deadline for filing written objections. The applicant and each person who filed a written objection is informed by mail of the date, time and place of the hearing. All others receive notice of the hearing by publication. Adjacent landowners are given written notice of the public hearing, but do not receive notice of the time for filing written objections except in the newspaper.[17]

The authority to grant or deny a permit is specifically given to the Mississippi Commission on Wildlife Conservation (MCWC), but it is not clear who is responsible for conducting public hearings on permit applications. While the MCP specifically states that the MCWC "shall base all of its decisions generally on the rules, guidelines and procedures. . . .and on the findings and recommendations of BMR", it doesn't state who will hold the required hearings.

The MCP provides guidelines which must be used in evaluating proposed activities against the public policy of wetlands protection. The factors which must be considered include: (1) the public interest as seen by the courts and the legislature; (2) the detailed guidelines for regulated activities; (3) cumulative impacts of similar development; (4) ecological concerns; and (5) the extent of alternative sites available to reduce unavoidable impacts.

BMR must follow the guidelines in recommending decisions on permit applications unless a variance is requested and specifically justified. A variance is required for regulated activities conducted in a manner inconsistent with the guidelines. MCWC may, in its discretion, grant a variance if it determines that: (1) the impacts on coastal wetlands will be no more detrimental than if the guidelines were followed; (2) the variance will be temporary; (3) there are no feasible alternative construction techniques or sites; or (4) the project requires a waterfront site. MCWC is required to specifically state the grounds for granting or denying a permit or a variance.

In issuing a permit, the MCWC may provide for such conditions as are necessary to insure compliance with the MCP. For example, it may require mitigation as a means of minimizing net adverse impacts. Any variation from the permit conditions will constitute a violation of the Coastal Wetlands Protection Law and will subject the applicants to enforcement actions.

A controversial issue throughout the development of the MCP involved the extent of the program's coverage. A number of activities and agencies are specifically excluded or exempted from the wetlands permit requirements.[18] Among the "excluded" activities are hunting, fishing, swimming, hiking, boating, and the regular maintenance and repair of bulkheads, piers, roads and highways. Among the excluded entities are the Biloxi Bridge and Park Commission, Biloxi Port Commission, Long Beach Port Commission, and any municipal or local port authorities. A more limited "exemption" is extended to 2 classes of activities: (1) construction by a water dependent industry on a site suitable for water dependent industry; and (2) construction by an individual on his own property.

BMR must be notified of every excluded or exempt activity. The notice must state the specific basis for the request for an exclusion or exemption. Within 30 days of receiving notification, BMR will prepare a set of findings and send them to the notifying party. Based upon these findings, BMR may grant the request for an exclusion or exemption, require a permit to be obtained, or may find that the activity is not in compliance with the public policy of wetlands protection.

Even though an excluded or exempt activity may be conducted without a permit, it must be conducted in a manner consistent with the public policy expressed in the Coastal Wetlands Protection Law, and all state agencies must carry out their responsibilities in the coastal area in compliance with the MCP.[19] To insure compliance, the MCP includes policy coordination procedures governing state agencies.

When BMR publishes notice of a date for filing written objections to a permit application, BMR also notifies all other state agencies through the A-95 clearinghouse. All other agencies are given the opportunity to comment on proposed actions related to their respective statutory responsibilities. "Coastal program agencies," which include BMR, the Bureau of Pollution Control, the Bureau of Land and Water Resources and the Department of Archives and History, must insure that all other agency activities are consistent with the MCP. If a coastal program agency objects to a proposed action, the action cannot go forward. Enforcement procedures are provided if an agency proceeds in a manner contrary to the MCP.

WILL IT WORK? – AN ANALYSIS

Program Evaluation

The MCP provides a framework for resource management to protect Mississippi's coastal wetlands, promote marine recreation, site major facilities, and comprehensively manage shoreline and coastal regions. The program represents years of work by competent professionals and concerned citizens and is the "best" program deemed possible in the prevailing political climate. While the ultimate success of the MCP cannot yet be measured, it is possible to identify certain characteristics of successful resource management programs and to assess the likely success of the MCP in terms of how closely the program adheres to these characteristics. Ongoing evaluation of this sort is important, because successes can be identified and problems can be avoided. It assists the regulators in making necessary refinements and adjustment to the program to insure maximum success.

The order in which this discussion proceeds is not intended to imply a "ranking" of these "fundamental characteristics" in terms of their importance to the success of the MCP. The factors which are identified as relevant to the success of the program are certainly not exclusive. There are many factors, some yet unknown, which will determine whether the MCP becomes an effective tool for coastal resource management or falls victim to public indifference and bureaucratic neglect.

Necessary Ingredients

There are certain characteristics which seem to be fundamental to the development of successful resource management programs. Programs which exhibit these characteristics enable resource managers to carry out their work consistently with the values, goals and objectives which stimulated the formation of the programs.

(1) Accountability. First, it is important for individuals responsible for resource policy and management to represent the interests and reflect the preferences of those directly effected by their decisions. The most desirable means of accomplishing this objective is through direct election of representatives to the policy-making authority. If the governing authority is politically accountable to a constituency which includes the entire affected area, the public will be assured of full participation in the decision-making process. This will in turn insure that all of the issues relevant to a particular policy decision are fully articulated. A politically sensitive regulatory agency is more likely to prove viable because its elected officials respond to changes in the interests and values of the electorate.

The regulatory agency primarily responsible for implementation of the Mississippi Coastal Program is the Mississippi Commission on Wildlife Conservation (the "Commission"). The Commission is a five person body whose members are appointed by the Governor to serve five year terms.[20] One person is appointed from each of the state's congressional districts. One of the commissioners must "be knowledgeable and experienced in marine fisheries management and shall have at least a bachelor's degree in marine technology ...".[21] The Commission is given authority and responsibility for formulating policy regarding wildlife, adopting necessary rules and regulations and applying for, receiving and spending state and federal funds.[22] As noted earlier, the Commission will apparently make decisions on wetlands permit applications, although necessary hearings will be conducted by the Bureau of Marine Resources.[23]

The Bureau of Marine Resources (the "Bureau") is the administrative agency responsible for administering the state's marine policies and will be responsible for day-to-day oversight of the MCP. The Bureau's staff consists of numerous experts trained in various aspects of marine affairs, and the staff's influence will undoubtedly extend beyond mere administration. The Commission will rely heavily upon the Bureau staff to identify and articulate policy options. On the operational level, the Commission will not often disagree with the Bureau's recommendations on permit applications.

Concerned environmentalists should find comfort in the fact that the MCP will basically be administered by trained professionals who understand the consequences of uncontrolled development in the coastal area. But the influence these professionals will have in the setting of policy is uncertain, and neither the Director of the Bureau of Marine Resources nor the members of the Commission on Wildlife Conservation are elected officials. Whether the Commission and the Bureau can or will respond to public sentiment and build a following among coastal residents remains to be seen. The real test will come when the first major dispute involving the MCP focuses public attention on the program.

(2) Authority. In addition to public support, a regulatory authority needs sufficient power to implement its decisions and to influence the behavior of individuals, industry and governments. This should include power to adopt and enforce new rules and regulations and require compliance with existing ones.

The Commission has been delegated apparently broad power by the Mississippi Legislature, including power to "adopt, amend and repeal such regulations and rules as may be necessary ..." and power to "discharge such other duties, responsibilities and powers as are necessary..."[24] The problem is that the seemingly broad powers of the Commission are severely limited by the Coastal Wetland Protection Law[25] which authorized the wetlands permit procedure implemented in the MCP. There are so many agencies and activities exempted and excluded from the permit requirements that there is a real chance that environmentally harmful projects will proceed without the scrutiny of the regulatory authorities.[26] All activities in the coastal zone must, however, be conducted in a manner consistent with the policies and goals of the MCP, even exempt activities,[27] so the real extent of the Commission's powers will depend upon how committed the Bureau staff is to truly regulating development in the coastal area.

The concept of power also includes geographic and time dimensions. The regulatory body must have responsibility and authority over the entire area where problems exist. The wetlands permit program incorporated in the MCP is limited to areas below the watermark of ordinary high tide, except in two situations: where upland activities are filling into coastal wetlands, and where structures are being erected on suitable sites for water dependent industry.[28] Again, sufficient authority exists to control most activities which could affect the wetlands, even those outside the three county coastal area, but the Bureau can exercise a great deal of discretion in exercising that authority.

(3) Funding. The responsible regulatory should have a long range perspective and not be merely limited to pursuing immediate solutions to critical problems. This requires assurance of continued funding sufficient to provide technical and administrative support. The funding issue is the biggest question clouding the MCP's future.[29] If federal support is reduced or terminated, will the Mississippi Legislature provide sufficient funds to the Bureau to enforce the MCP? The answer to that question depends to a great extent upon how the MCP is received by the public during its crucial first year.

(4) Coordination. Another important characteristic of successful regulatory programs is clear definition of authority and relationships with other institutions and programs. What the responsible agency can and can't do needs careful delineation or existing agencies will attempt to absorb elements of the new program into their exisitng structure. This careful circumscribing of authority is necessary at both the policy-making and operational level and both within the regulatory authority itself and within the overall regulatory framework.

The MCP includes a review and policy coordination procedure governing all state agencies. This procedure is designed to insure that all state agencies carry out their responsibilities in the coastal area in complicance with the MCP. In addition to the Bureau of Marine Resources, the Bureau of Pollution Control, the Bureau of Land and Water Resources and the Department of Archives and History are designated "coastal agencies" and are required to review state agency action in the coastal area to insure complicance with various aspects of the MCP. The review authority and responsibility of each agency is defined in the MCP in broad terms and with reference to various state and federal statutes. This could lead to disputes among the "coastal agencies," but the important thing to note is that no proposed agency action can be conducted if a coastal agency finds it inconsistent with the MCP.

Lack of cooperation among government entities has always been a problem in Mississippi, particularly in the coastal area. The extensive governmental reorganization of 1978 was designed to eliminate the problem,[30] but it is not clear how effective it will be. For example, in 1980 the Legislature created the Mississippi Gulf Coast Regional Wastewater Authority to "promote the development and operation of adequate wastwater collection and treatment facilities"[31] on the coast, but local governments and wastewater authorities are resisting what they believe to be unjustified usurpation of their powers.[32] If local and state entities are overly protective and jealous of their powers under the MCP, the inevitable disputes and controversies which follow will seriously affect public support of the program and limit its effectiveness.

(5) **Public support.** Finally, it seems evident that regulatory programs have a greater chance for success if they are viewed as emerging from the initiative of the locally affected area rather than being imposed by some "outside" authority. If the intensity of interest at the local level is not adequate to generate the development of a regulatory program, it is not likely to be effective.

Certainly there are those who view the MCP as being mandated by the federal government.[33] Through the CZMA, the federal government provided funds for development and implementation of the program, funds to offset impacts of offshore energy activities and the substantial enticement of the "consistency" provision.[34] In return, the federal government required that the state program meet federal guidelines. But the MCP was developed and approved only after substantial public involvement and reflects as much as possible the attitudes and interests of coastal residents. If the persons responsible for administration of the program remain attuned to the desires of coastal residents and to the legitimate interests of all of the state's citizens, the "federal" aspect of the MCP should not prevent the program from gaining wide public acceptance and from being an effective resource management tool.

CONCLUSION

As we increase our knowledge concerning the nature of key pollutants, their effects, their sources, their rates of accumulation, the routes along which they travel and their final reservoirs, we must deal with the question of how to apply our knowledge constructively to cope with existing problems. The Mississippi Coastal Program provides an institutional and regulatory framework for applying our knowledge and understanding of the Mississippi Sound and the surrounding coastal area toward effective resource management. Whether or not the program is successful will depend largely upon the vigor and diligence of the individuals responsible for its implementation and enforcement. Continual evaluation of the program and its effectiveness is an important aspect of the overall management scheme and will provide information for necessary refinements and changes in the program.

FOOTNOTES

[1]For purposes of this paper, the "Mississippi coastal area" includes Harrison, Hancock and Jackson Counties, the Mississippi barrier islands and the waters of the Mississippi Sound.

[2]This symposium focuses upon the Mississippi Sound and is designed to bring attention to bear on the problems of management of the waters of the Sound as contrasted with the more commonly emphasized coastal land use management problems. There is no question, however, that the problems are related and that solutions to water quality problems in the Sound will depend upon the effectiveness of programs designed to control development around the Sound.

[3]Congress is currently debating the future of federal support for coastal programs. See Coastal Zone Management, Vol. 12, No. 12, March 25, 1981. If federal support for coastal programs, including the coastal zone management program and the National Sea Grant College Program, is eliminated or substantially reduced, states will have to determine whether their programs are worthy of their full financial support.

[4]16 U.S. C. § § 1451-1464.

[5]It is important to note that the CZMA is not the only federal statute which is relevant to development in and around the Mississippi Sound. A comprehensive review of all federal marine laws is beyond the scope of this paper, but the following statutes should be noted: The Rivers and Harbors Act of 1899, The Fish and Wildlife Coordination Act (as amended), The Federal WAter Pollution Control Act (as mended), the Ports and Waterways Safety Act (as mended), and the Marine Protection, Research and Sanctuaries Act of 1972.

[6]Mississippi received development grants in various amounts for several years and received $800,000 to implement the approved plan this year. Continued federal funding for development of coastal programs is doubtful at this time. See n. 3 *supra.*

[7]16 U.S.C. § 1456 (a).

[8]16 U.S.C. § 1456.

[9]The entire program including statutes, rules, guidelines and supporting material has been printed in a single document by the Bureau of Marine Resources, Mississippi Department of Wildlife Conservation (October 1, 1980). Further references to the "program" or to the "MCP" are to that document.

[10]MISS. CODE ANN. § 49-27-1 through § 49-27-69 (1980 Supp.).

[11]MISS. CODE ANN. § 57-15-6 (1980 Supp.).

[12]MISS. CODE ANN. §49-27-3 (1980 Supp.).

[13]Id., § 49-27-5(c).

[14]Id., § 49-27-11.

[15]Id., § 49-27-13.

[16]Id.

[17]Id., § 49-27-27. Since only those persons who filed written objections may be heard at the public hearing, the notice of hearing date to the landowner may be of no practical value.

[18]Id., § 49-27-7.

[19]MISS. CODE ANN. § 57-15-6(3) (1980 Supp.).

[20]MISS. CODE ANN. § 49-4-5 (1980 Supp.).

[21]Id.

[22]MISS. CODE ANN. § 49-4-9 (1980 Supp.).
[23]See text at n. 17, *supra.*
[24]MISS. CODE ANN. § 49-4-9 (1980 Supp.).
[25]MISS. CODE ANN. § 49-27-1 through 49-27-69 (1980 Supp.).
[26]Id., § 49-27-1.
[27]MISS. CODE ANN. § (1980 Supp.), § 57-15-6 (1980 Supp.).
[28]MISS. CODE ANN. § 49-27-5 (1980 Supp.), Mississippi Attorney General's Opinion (December 14, 1976).
[29]See n. 3, *supra.*
[30]The old Game and Fish Commission, Boat and Water Safety Commission, Marine Resources Council and Marine Conservation Commission were combined by the 1978 Legislature into one umbrella agency governed by the Mississippi Commission on Wildlife Conservation. See MISS. CODE ANN. §§ 49-4-1 through 49-4-23 (1980 Supp.).
[31]MISS. CODE ANN. § 49-17-303 (1980 Supp.).
[32]See e.g. *The Daily Herald,* Feb. 18, 1981, at p. B-2, col. 1; Feb. 21, 1981, at p. A-10, col. 1; March 3, 1981, at p. A-1, col. 1.
[33]See, e.g., S. Morse, "Unconstitutional, Unnecessary and Unwanted," in *The Water Log,* University of Mississippi Sea Grant Legal Program, Vol. I, No. 1, (March 1981).
[34]See text a n. 5-8, *supra.*

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SEISMIC SURVEY OF MISSISSIPPI SOUND, MISSISSIPPI, AND MOBILE BAY, ALABAMA

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Table of Contents

INTRODUCTION

Coastal Alabama (Figure 1) contains the second largest river drainage basin of the eastern United States (fourth largest of the entire country, behind the Mississippi, Yukon and Columbia) (Chermock, 1974). This basin, its associated river delta and the estuarine system of nearly 400,000 acres of open water enclosed by barrier islands, provide industry, recreation and commerce to the coastal counties of Alabama. The Port of Mobile ranks eleventh largest in the United States (1972) based on total tonnage, and is the site of possible future construction of a major deep-water facility. Geological exploration for oil and gas reserves in the sediments below Mobile Bay is in progress, and continuing drilling activities will probably increase in the near future. Southwest Alabama also continues to be the major oil and gas producing region, with statewide production for 1979 exceeding 10 million barrels of oil and 92 million tcf (thousand cubic feet) of gas (Masingill and McAnnally, 1980). New drilling activity by Mobil Oil Company at the entrance of Mobile Bay promises future production entirely within the bay waters. The rich natural resources of the Mobile Bay region nearly assures continued environmental impact of physical, biological and chemical means.

Biological and chemical environmental disturbances to Mobile Bay are caused primarily by the discharge of pollutants in municipal and industrial wastes exceeding 850 million gallons per day (Chermock, 1974). Pollutants include bacteria, organic chemicals, heavy metals and other toxic substances.

In addition to man-made disturbances, Mobile Bay is subject to the occasional passage of devastating storms, such as Hurricane Frederic in 1979, and the landfall of 24 such storms between 1901 and 1955 (Chermock, 1974). Effects of hurricanes include wind damage, storm surge, salinity changes and sediment redistribution. Some of the effects of Hurricane Frederic on the benthic fauna of Mobile Bay are currently under study by researchers at the Marine Environmental Sciences Consortium in Mobile.

JUSTIFICATION FOR INITIATION OF SEA GRANT RESEARCH

The increasing environmental pressures on Mobile Bay by oil exploration companies, the Army Corps of Engineers, bay management and advisory groups, and local fishermen make all the more important information on the geological structure of the bay bottom. Geological information is of great value in the areas of bottom structure stability, presence of faults and slumps, assessment of bottom disturbance, estimation of natural rates of sedimentation, and relationship to benthic organisms. Although the Alabama Highway Department and the Alabama Geological Survey have geological surveys and cored into the bay bottom in several areas (Theodore River Ship Channel, Dauphin Island Bridge Reconstruction, Interstate 10 crossing), this work is related only to specific construction projects. There have been few studies of the overall bay bottom, of a general nature, for assessment of gross geologic structure.

Previous geological research in Mobile Bay was concerned with detection and mapping of oyster reefs, both living and buried ones (Ryan, 1969; Ryan and Goodell, 1972; May, 1976), assessment of historical changes in sedimentation rate and topography of the bay bottom (Ryan, 1969; Ryan and Goodell, 1972; May, 1976), recognition of the underlying Miocene sediments (Isphording, 1976; Isphording, 1977), and formation and development of the barrier islands (Otvos, 1973).

The major physical impact of local development on Mobile Bay lies with continued dredging of the navigable ship channels (about 128 miles), with construction of the new Theodore River Ship Channel, and the disposition of dredge spoil materials from these activities along channel aprons. The disposition of the dredge spoil materials from these activities poses great concern to bay management and advisory groups such as the South Alabama Regional Planning Commission, and the Coastal Area Board of Mobile, Alabama. The problem of disposal of spoil materials and effects on water quality and living organisms is of great concern (Hard, 1975; Kirby et al., 1975; Sherk et al., 1975; Windom, 1975) with doubts by some researchers as to our ability to assess at present the long-term effects of marine dredging activities (Pequegnat, 1975).

In addition to the above areas of long-standing concern, new oil and gas exploration poses additional hazards for Mobile Bay. These include well-cutting disposal, well blowouts, and oil spills from wells and ships.

OVERALL PROGRAM OBJECTIVES

Because there is little overall geologic data in the public domain with which to compare certain future modifications and assist in bay management decisions, our original Sea Grant reserach program was directed at achieving the following objectives over a three year period:

1. Characterization of the shallow, sub-bottom seismic stratigraphy of Mobile Bay, Mississippi Sound, and near, offshore Gulf of Mexico along the Alabama barrier islands (Figure 1).
2. Coring of selected seismic locations in Mobile Bay to obtain a lithostratigraphy against which to correlate the seismic stratigraphy previously obtained. This would provide geologic confidence in the interpretation of the seismic records.
3. Chemical analysis of the deep cores for trace elements of importance in pollution, to establish a historical baseline level against which to compare man's recent and future influences.
4. Radiometric age-dating of upper sedimentary layers from the cores to establish sedimentation rates for comparison against estimates from other studies (Ryan and Goodell, 1972; May, 1976) and for future changes.

Results of First Year of Sea Grant Research

The initial seismic survey conducted in Mobile Bay and Mississippi Sound has provided heretofore unavailable information on the shallow subsurface geology of the coastal waters of Mississippi and Alabama. Boundaries between stratigraphic units are clearly discernable in the seismic record as relatively abrupt vertical changes in the nature of the seismic reflections. We have developed a synthetic seismic stratigraphy summarizing these units. A variety of geologic, biologic, and man-made features can also be described from the seismic record. The geologic features include unconformities, ancient river channels, and high angle, steeply dipping beds typically in the vicinity of barrier islands. The primary biologic features are ancient oyster reefs and shell deposits, which in many cases are located near modern oyster reefs. The man-made features evident in the seismic record are ship channels, spoil banks, and possible dispersed spoil. The possibility of widespread spoil distribution raises serious questions regarding the future of benthic communities in Mobile Bay, and hence, the ecological balance of the coastal environment of Alabama.

Generalized Seismic Stratigraphy

From a synthesis of the patterns of seismic reflections across the bottom of Mobile Bay and Mississippi Sound, we have drawn up an initial seismic stratigraphy incorporating most of the observed features (Figure 2). The actual seismic stratigraphic sequence at any specific location is not likely to match exactly our synthesis, as there is some variability in the distribution of the features we have seen. This synthesis will, of course, be subject to future modification as our research progresses, and lithostratigraphic information becomes available.

We have subdivided the upper 40 meters or so of sediment into four seismic stratigraphic units, separated by three interfaces or horizons. The basis for our subdivisions rests upon a relative homogeneity of properties within seismic stratigraphic units, and their relative abrupt change across horizons separating these units. Note that not all units are strictly homogeneous (Unit 3) as some vertical variability may be present.

We have not attempted to place time-stratigraphic significance to these units as we have no confirmatory evidence at our seismic stations. Such information would have to come from coring studies conducted exactly over some of our seismic stations to provide a correlation between an age-dated lithostratigraphy and our seismic stratigraphy. These studies are currently in progress.

A brief description of the characteristics of our seismic stratigraphic units begins with the sediment-water interface and the underlying few meters of most recent sediments. Horizontal seismic reflections, parallel with the sediment-water interface, are characteristic of the interior of Unit 1. The uppermost surface is obviously subject to existing processes such as recent sedimentation as well as erosion and scour. The unit extends into the sub-bottom about two to three meters.

The lower surface of Unit 1 (and upper surface of Unit 2) is called Horizon 1. This is clearly in some areas a seismic angular unconformity, as the uppermost seismic units of Unit 2 pinch out gently against the bottom of Unit 1. The geographic extent of this angular unconformity is widespread. In Mobile Bay, it appears to lie from the most shallow edges of the bay which we are able to explore (approximately the 2 meters depth contour) to perhaps 1/3 the distance towards the center of the bay. It may represent a geologically recent event when Mobile Bay was smaller in extent than it is today, with a portion of its bottom previously above water and subject to erosion. The thickness may be on the average about 10 to 15 meters.

Horizon 2 (the bottom of Unit 2 and top of Unit 3) is a highly eroded surface with moderate amounts of topographic relief. The depressions cut into the top of Unit 3 can range from less than a meter to 5 meters or more. The lateral extent of these depressions can vary from a few tens of meters to a few hundreds of meters in Mobile Bay, and in Mississippi Sound we found one extending for some 2000 meters.

The most common seismic characteristic of the bulk of Unit 3 is one of irregular "bedding", in that seismic reflectors are not continuous lines. This irregularity is not just one of the discontinuity of horizontal lines, but appears in some areas as confused or chaotic. Unit 3 extends to depths of 30 to 40 meters below the sediment-water interface.

Horizon 3, the surface between the bottom of Unit 3 and the top of Unit 4 is not well developed or clearly seen in all places. However, there is a noticeable change in the character of the seismic reflectors, in that the chaotic bedding of Unit 3 gives way to underlying even "bedding". Further, these deeper reflectors, about 30 to 50 meters below the sediment-water interface, are more widely spaced than those above, and posses a clear, regional dip, from the north or northeast to the south or southwest.

Subsurface Geologic Features

In most cases the geologic features seen in the seismic record are delineated on both the $7kH_2$ and minisparker records. Figures 3 and 4 are index maps indicating the locations in Mobile Bay and Mississippi Sound, respectively, of the features described below. Since the minisparker system provides greater detail and deeper penetration, it is the better record overall for recognizing unconformities. In Figure 5 (Location A, Figure 3) two uncomformities are evident. The youngest is Horizon 1 located at a depth of approximately 7 1/2 meters. The parallel, horizontal beds of Unit 1 lie above the unconformity, and the beds of Unit 2 are truncated by the beds of Unit 1. The second unconformity in Figure 5 is at a depth of approximately 16 meters (Horizon 2) and is deeply eroded and channeled. A third, older unconformity is suggested in Figure 6 (Location B, Figure 3) where at a depth of approximately 50 meters essentially horizontal beds appear to truncate gently dipping beds that extend further into the subsurface than the penetration capability of the minisparker system. Due in part to the irregular, chaotic bedding of Unit 3, the precise boundary between Units 3 and 4 (Horizon 3) is typically indistinct, but the presence of these gentle, regionally dipping beds is prevalent throughout the record at approximately the same depth below the sediment-water interface.

Ancient river channels are encountered in the seismic record throughout Mobile Bay and Mississippi Sound. The channels are cut into Horizon 2 and are most pronounced in near-shore areas adjacent to present fluvial outlets. Figure 7 is the 7 kH_2 record from Location C (Figure 3) offshore of Fish River and Weeks Bay, and exhibits a series of drainage paths of various sizes and shapes. Channel 1 is approximately 80 meters wide and 3 meters deep, while channel 2 is approximately 600 meters in width with a depth of 15 meters.

The characteristics of channel features in Mississippi Sound differ from those in Mobile Bay. At Location D (Figure 4) southeast of the present-day Jourdan River - St. Louis Bay outlet the 7 kH_2 record (Figure 8) indicates an extremely broad, realtively shallow river channel cut into Horizon 2. This channel is approximately 2000 meters wide, and its extreme width and smooth surface distinguish it from the channels in the subsurface of Mobile Bay. Another interesting channel feature in Mississippi Sound is at Location E (Figure 4). These scour features as seen on the 7 kH_2 seismic record (Figure 9) differ from those discussed previously in several ways. First, the channels have unusually smooth surfaces and are almost wave-like in appearance. Second, the two channels on the right do not appear to be cut into Horizon 2, but seem to have cut into sediments in Unit 2 above the unconformity. Last, the middle channel is superimposed onto the channels to its left and right, indicating that these scour features are multiple cut-and-fill channels.

The highly inclined bedding noted in the seismic record is encountered in the vicinity of barrier islands. Figure 10 is the minisparker record indicating the nature of these beds at Location F (Figure 3) offshore of Fort Morgan peninsula. The beds occur at a depth of approximately 4 meters below the sediment-water interface, range from 4 to 8 meters in thickness, and dip toward the Gulf of Mexico. Adjacent to barrier islands in Mobile Bay and Mississippi Sound these high angle beds dip toward the mainland shore. We were not able to conduct seismic profiling on the gulf side of these islands, and the orientation of bedding there is unknown. However, based on studies of the internal structure of barrier islands offshore of Texas (Dickinson, et al., 1972) and the presence of high angle seismic reflections on the gulf side of Fort Morgan peninsula, we suspect highly inclined beds to be draped on both the seaward and shoreward sides of the barrier islands of Mississippi and Alabama.

Another incidence of high angle bedding occurs on the flanks of Pistol Bank, a submerged sand bar in Mississippi Sound (Location G, Figure 4). Figure 11 is the 7 kH_2 record exhibiting the topographic outline of the sandbar and vaguely indicating horizontal bedding within the structure. Figure 12 is the minisparker record in the vicinity of Pistol Bank in which the steeply dipping beds are best seen on the left flank. The genetic relation of Pistol Bank to the processes involved in barrier island formation is not apparent from the seismic record, nor is it clear whether this structure is degrading, or migrating shoreward or seaward.

Subsurface Biologic Features

The primary biologic features encountered in the seismic record are ancient oyster reefs and buried shell deposits. The relationship between modern reefs and buried reef material is exhibited at Location C (Figure 3). Figure 13 is a detailed map (Kelley, 1971) of modern oyster reefs and buried shell material 2 to 3 meters below the sediment-water interface with the seismic trackline superimposed from shotpoints 343 to 346. (Shotpoints represent precisely determined locations about 1000 meters apart.) Figure 14 is the 7 KH record in the vicinity of shotpoints 344 and 345 in which the ancient oyster reefs are clearly evident as the darker reflections that extend upward.

These reefs appear to have grown off of Horizon 2 and continued to rise vertically as water level rose. Internal details of the reefs are masked due to the reflection of the seismic signal at the hard upper surface of these features. A shell dredge channel is evident at the sediment-water interface indicating the recent mining by Radcliff Materials, Inc. of the buried shell material several meters in the subsurface. The ancient oyster reef and buried shell deposits in the seismic record are typically located in the vicinity of ancient river channels as seen in Figure 15. This is consistent with the growth of modern reefs on the banks of present-day rivers. Figure 15 also exhibits a small channel that has been cut into a relatively flat, even shell deposit.

Dredge Spoil

Because minisparker and 7 kH_2 systems both detect the abrupt change from water to sediment, features of the sediment-water interface are clearly visible. The artifically dredged ship channels leading to port landing from outer bay regions are the most significant topographical alterations of the bottoms of Mobile Bay and Mississippi Sound. The dredged materials have, to the present time, in most instances been disposed of in specified regions along the ship channels. Where the spoil has been placed in mounds along the channels, spoil banks one meter above the natural bottom are formed. These banks in the northern portion of Mobile Bay have modified the natural circulation and flushing of the bay in the northwest quadrant, to the extent that some isolation of that area from the rest of the bay has occurred (Ryan and Goodell, 1972).

Although the spoil materials are deposited within contract disposal areas, some studies indicate its possible movement for some distance along the bay bottom upon exiting the end of the hydraulic pipe through which it flows from the disposal barge (May, 1974). The geographic extent of spoil within Mobile Bay is essentially unknown, as the previous studies indicate some movement at the time of disposal, and further dispersal by storm currents and tides is possible, but the effects of which are at present unknown. Our seismic survey has yielded a picture of a possible spoil-related phenomenon noted in other bays of the Gulf Coast region adjacent to man-made channels with open-water spoil disposal programs. If our hypothesis of this phenomenon is verified, we will have provided a means of identifying the presence, and ability to map the extent of, dredge spoil materials disposed of in open-water sites adjacent to channels.

A close examination of this feature can be seen in a transect across the contract disposal areas and ship channel in southern Mobile Bay (Figure 16). Our actual trackline positions determined every five minutes by LORAN-C provided fixed locations called shotpoints (Figure 17). These shotpoints are spaced about 1000 meters apart with the vessel moving approximately at 6 to 6.5 nautical miles per hour. The actual seismic output (analog) in the vicinity of shotpoint 618 is shown in Figure 18, and its interpretation in Figure 19. Our Horizon 'A' is the feature appearing in the vicinity of the channel crossings, while Horizon 'C' appears to be a sub-bottom geological surface. Notice in Figures 17, 20, 21, 22, and 23, the continuity of Horizon 'A' to the ship channel and beyond.

There are several characteristics of Horizon 'A' which lead us to believe that this feature is related to the presence of spoil on the bay bottom.

1. Horizon 'A' in lateral extent appears and disappears exceedingly abruptly (Figures 18, 19, 22, and 23). This is unlike geological horizons, which of course are bounded laterally, but frequently undergo lateral gradational changes in properties.
2. Horizon 'A' "masks" underlying geological structures. That is, little acoustic energy penetrates below, and returns to the surface through, Horizon 'A' (Figures 18 and 22). Similar absorption of acoustic energy is known to occur for gas-charged sediments, and probably can be due to many physical phenomena.
3. Horizon 'A' lies at or near the sediment-water interface, as indicated by the "masking" of all underlying geological features from a sub-bottom depth of approximately 1 meter (Figures 18 and 22).
meter (Figures 18 and 22).
4. Horizon 'A' appears to bend vertically along the slopes of the ship channel (Figures 20 and 21). Near surface geological horizons interrupted by channel construction would not be expected to change slope (as long as sediments were relatively consolidated and supported by surrounding sediments).
5. The geographic distribution closely parallels the contract spoil disposal areas along the main Mobile Bay ship channel, as seen in Figure 24.

The observations noted above are the facts of the occurrence of Horizon 'A', and do not by themselves uniquely identify dredge spoil materials as the source of this phenomenon. We cannot identify Horizon 'A' as due to spoil until we are able to sample these locations for near-surface sediment samples upon which laboratory analyses can be made to validate the above hypothesis.

It would not be unreasonable to suggest that the process of dredging natural sediments of the bay bottom through hydraulic suction pipes, its transport by barge, and the further movement of this material from barge to bay bottom again by pipe, would cause a change in physical properties related to acoustic impedances. Any difference between materials of different acoustic impedance will appear on seismic reflection output as a reflection surface. If the dredged sediment properties include changes towards decreasing bulk densities and possible increased amounts of gas, these changes may account for the great acoustic absorption seen for Horizon 'A'. The significance of the distribution (Figure 24) of Horizon 'A' under the hypothesis that it is a feature directly related to the presence of sound-absorbing spoil lies in the asymmetrical extent of Horizon 'A' on either side of the main ship channel. Notice in Figure 24 that Horizon 'A' lies relatively close to the western spoil apron, but on the east extends far beyond the contract disposal area towards the eastern shore. Possible redistribution of spoil outside the disposal areas might indicate net current or drift under conditions during which bottom surface sediments are resuspended and transported away from positions of origin. Hydrodynamic studies of current distribution and modeling are presently underway (Raney et al., 1980) and may suggest conditions under which transport might occur.

GEOLOGIC HISTORY

Our seismic study will probably add considerably to the inferred geologic history of the Moible Bay region suggested by previous authors (May, 1976; Otvos, 1973; May, 1973; Boone, 1973) by the abundance of detail due to fine stratigraphic resolution and the widespread geographic coverage of our seismic reflection profiles. We prefer to delay our geologic interpretations, however, in advance of future efforts in obtaining an analysis of lithologic cores for Mobile Bay and Mississippi Sound. We can at this time make only a few interpretations of our seismic profiles based upon available literature. The regional, gently dipping beds at 30 to 40 meters and below should be almost certainly Miocene in age (Isphording, 1976). And the highly channeled surface, Horizon 3, about 15 to 25 meters beneath the sediment-water interface, should be connected with a low stand of sea level exposing much of the periphery of Mobile Bay. Questions of the ages of this and other features will have to wait for further studies, detailed below.

ADDITIONAL RESEARCH EFFORTS

The initial seismic survey conducted in the summer of 1980 provides the base upon which further research efforts in Mobile Bay and Mississippi Sound might be built. The survey has produced valuable information about the shallow subsurface geology of these areas, including the distribution of buried oyster reefs, subsurface erosional channels, barrier island associated inclined bedding and possibly the extent of dredge spoil materials outside of contract disposal areas. However, there have been raised several questions which this study cannot answer.

Ages of various surfaces: Seismic reflection profiling produces, of course, no direct information of the various ages of the reflection surfaces. Horizons of particular interest for which approximate ages would be very interesting include the surface supporting the buried oyster reefs, the channeled and eroded surfaces, and the units of inclined bedding adjacent to present barrier islands. Absolute ages can only be obtained from radioactive series dating techniques, with indirect ages provided by biostratigraphic means. Our future efforts will incorporate analyses for Pb-210 (Holmes and Martin, 1978a; Holmes and Martin, 1978b), providing sedimentation rates over the past 100 to 150 years in the upper one-half meter or so, and C-14, with the capability of providing ages to 30,000 years or so. Beyond that, pollen and spore biostratigraphy, as well as macroinvertebrate Late Tertiary and Quaternary indicator species will be useful.

Barrier Islands: The inclined bedding we saw on our various approaches to the barrier island may be connected with island genesis and movement. Various studies suggest the formation of the northern Gulf barrier islands in essentially the same positions occupied today (Otvos, 1970a; Otvos, 1970b; Otvos, 1973), while others suggest migration of barrier islands in similar regimes (Kraft and Chacko, 1979).

The origin and evolution of non-emergent structures may be different from that of the barrier islands, and Pistol Bank may be representative of barrier islands in the process of formation, destruction, or equilibrium. Coring studies on Pistol Bank would be particularly helpful in deciphering the faint internal structure as seen on the seismic records.

To maximize these tentative interpretations of our seismic records, as well as providing material for future age-dating studies, we have programmed a series of lithologic cores, 10 meters in length, to be taken exactly on our seismic trackline and at stations within Mobile Bay and Mississippi Sound at which specific various features are seen. This lithostratigraphy will provide the means to identify lithologic features with specific seismic ones. With some common seismic features identified in these lithologic cores, we will have the means of correlating seismic horizons across the estuarine systems of Mobile Bay and Mississippi Sound, and a much more detailed understanding of the recent geologic history of this region.

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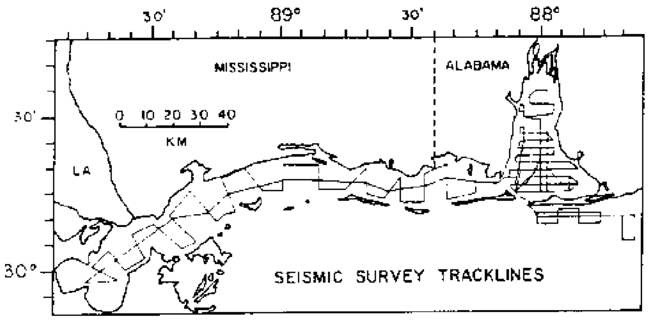

Figure 1 — Coastal Alabama and Mississippi. Approximately 875 kilometers of Mississippi Sound, Mobile Bay and the Gulf of Mexico were surveyed by seismic reflection profiling during 1980 Mississippi-Alabama Sea Grant program.

GENERALIZED SEISMIC STRATIGRAPHY OF MOBILE BAY, ALABAMA

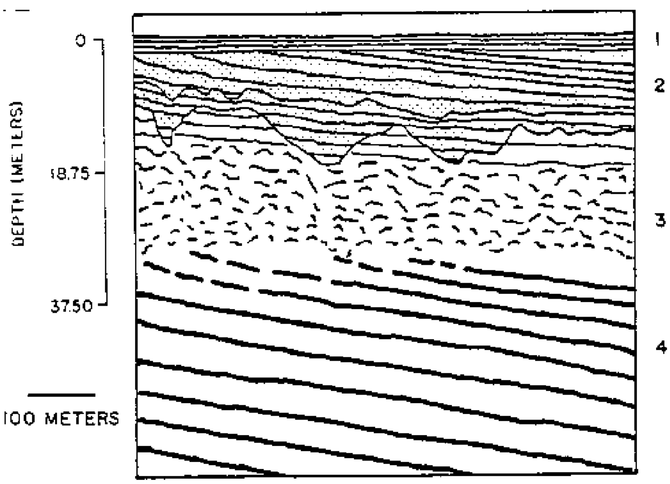

Figure 2 — Generalized seismic stratigraphy for the subsurface of Mobile Bay. Characterization of units explained in text.

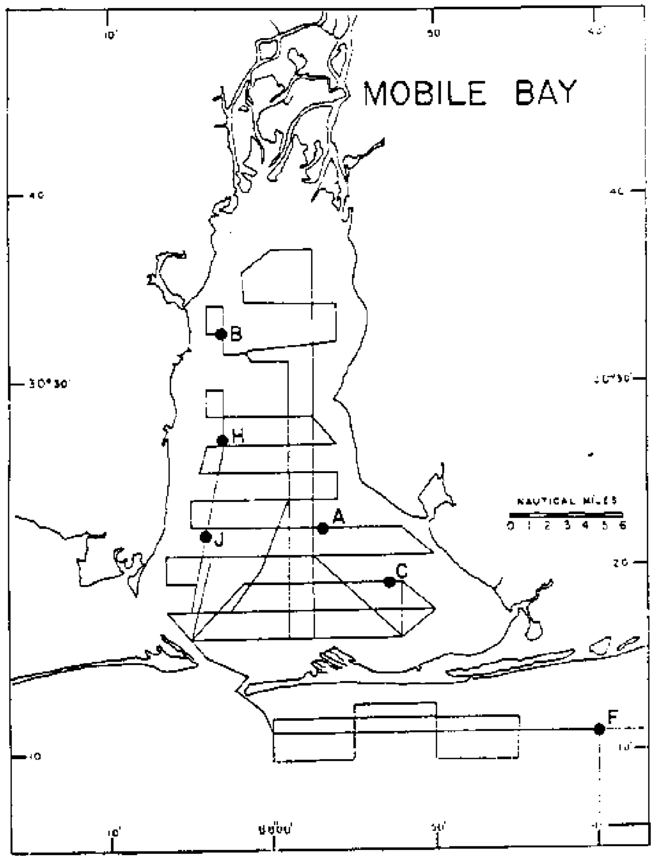

Figure 3 — Index map of Mobile Bay indicating seismic survey tracklines and locations of features found in Mobile Bay and offshore of Fort Morgan Peninsula. Discussion of features in text.

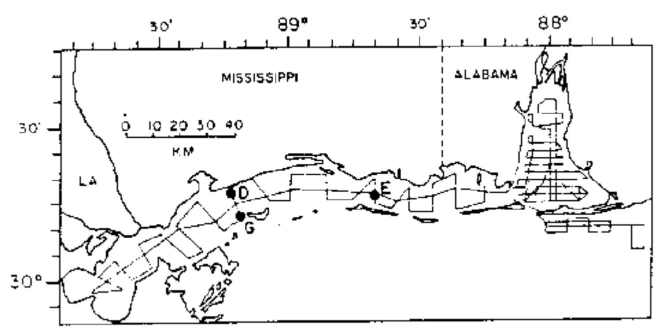

Figure 4 — Index map of Mobile Bay and Mississippi Sound indicating locations of features found in Mississippi Sound. Discussion of features in text.

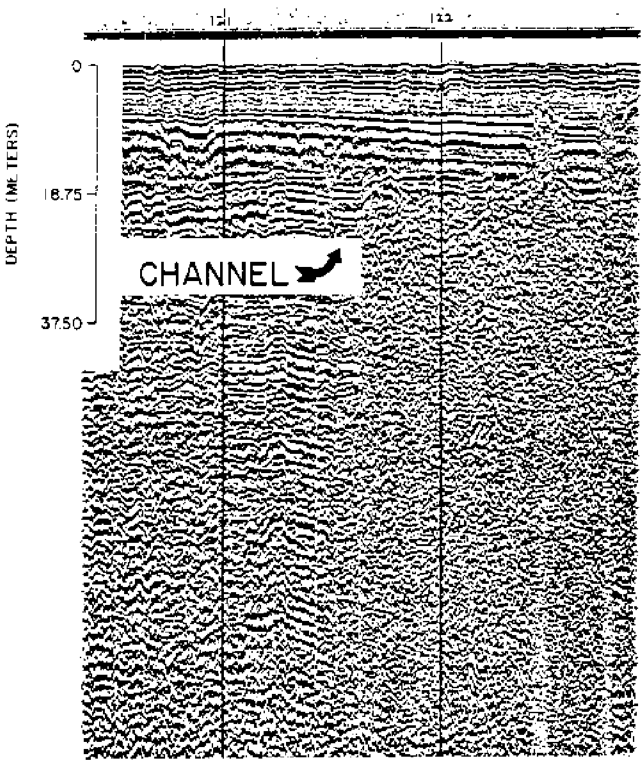

Figure 5 – Minisparker record indicating unconformities in Mobile Bay (Location A, Figure 3).

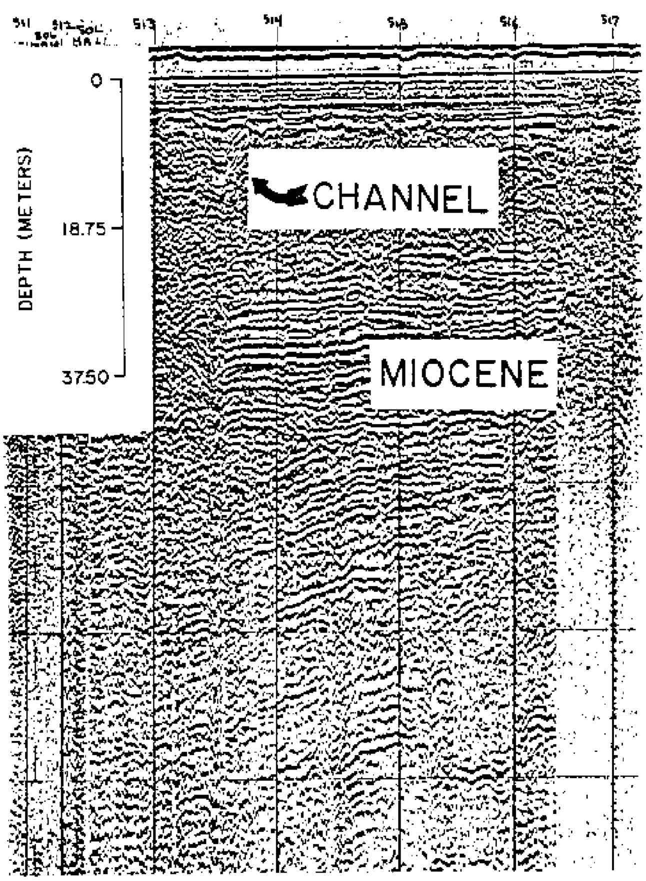

Figure 6 – Minisparker record indicating unconformity between units 3 and 4 (Location B, Figure 3).

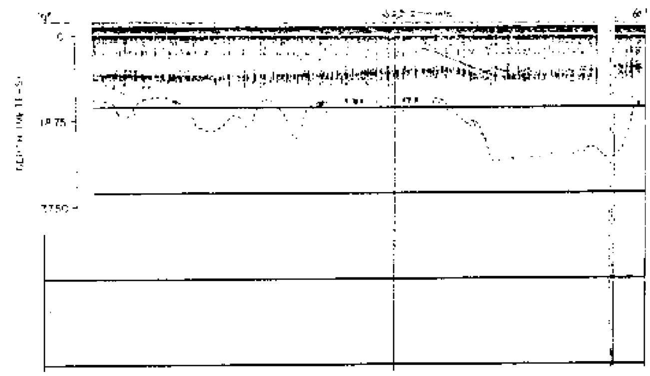

Figure 7 – 7 Kilohertz (kH_2) record exhibiting eroded, channeled surface at Horizon 2 in Mobile Bay (Location C, Figure 3).

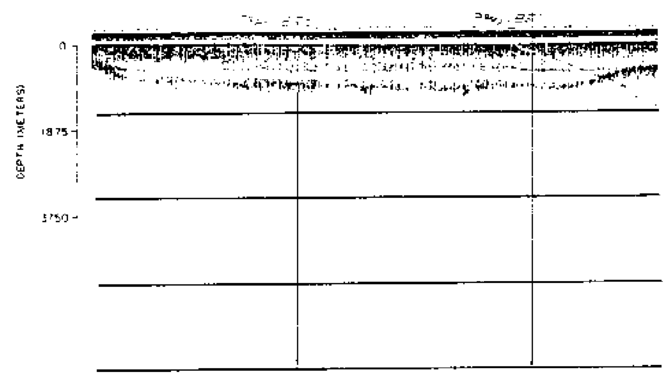

Figure 8 – 7 kH_2 record of channel in Mississippi Sound (Location D, Figure 4).

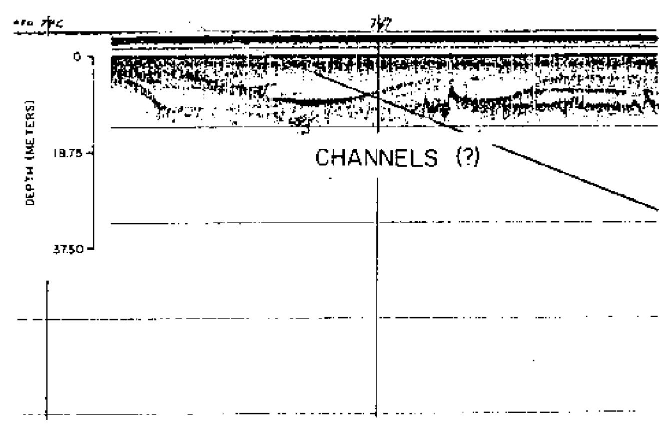

Figure 9 – 7 kH_2 record of multiple cut-and-fill channels in Mississippi Sound (Location E, Figure 4).

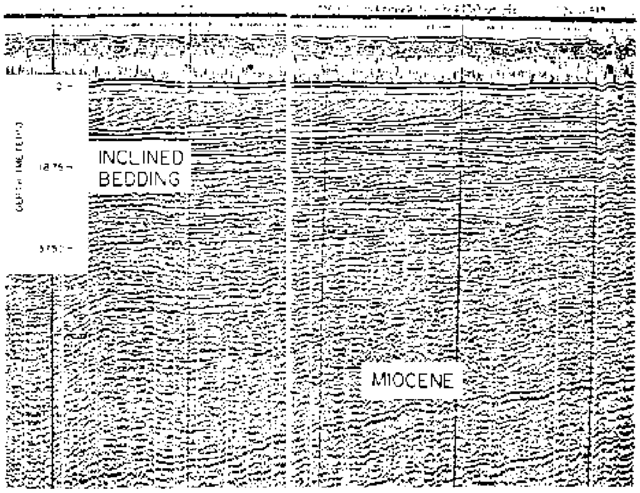

Figure 10 – Minisparker record of inclined bedding offshore of Fort Morgan Peninsula (Location F, Figure 4).

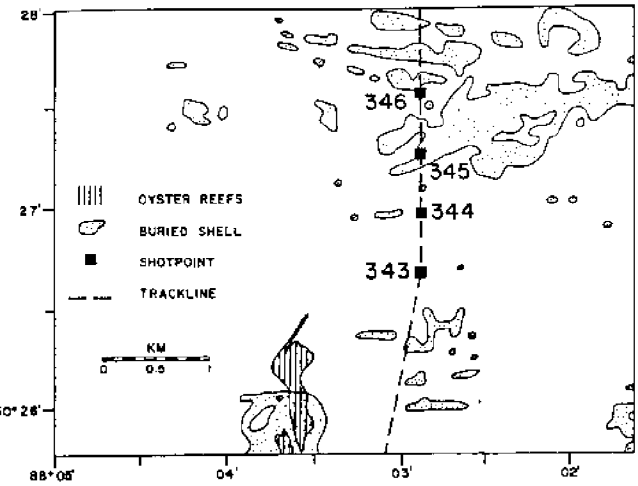

Figure 13 – Detailed map of oyster reefs and buried shell deposits in Mobile Bay (Location H, Figure 3).

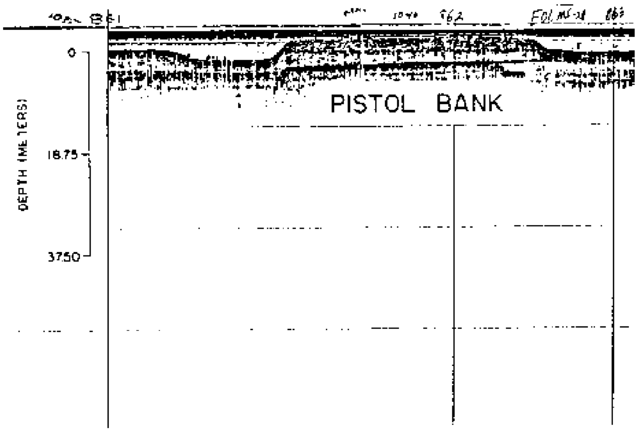

Figure 11 – 7 kH$_2$ record indicating submarine topographic relief of Pistol Bank, Mississippi Sound (Location G, Figure 4).

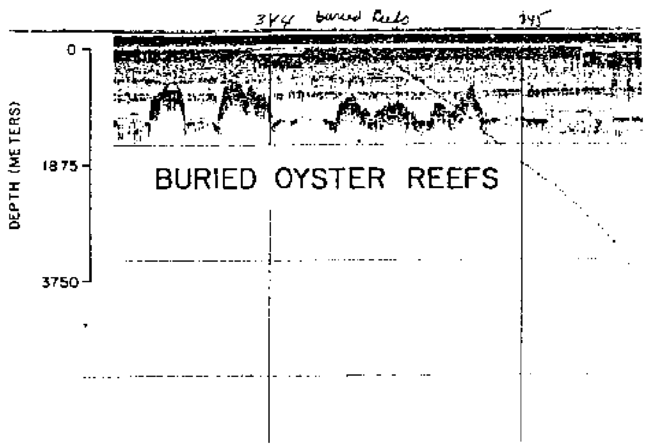

Figure 14 – 7 kH$_2$ record indicating buried oyster reefs in the vicinity of living reefs and shallow, buried shell deposits in Mobile Bay (Location H, Figure 3). Record taken along trackline of Figure 13.

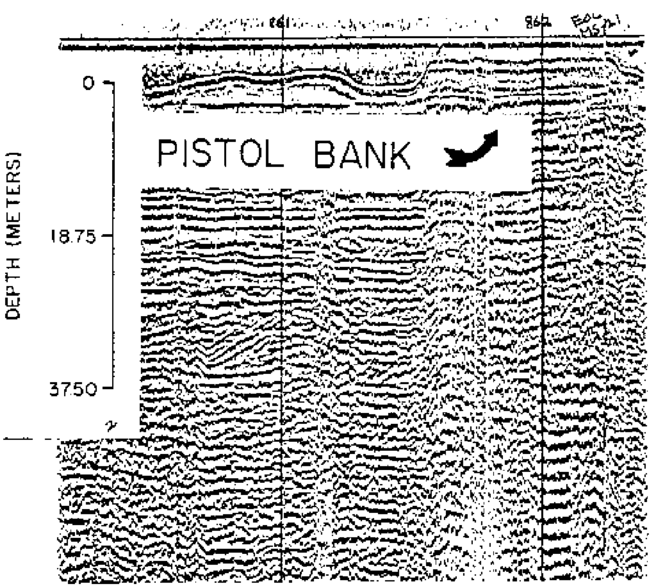

Figure 12 – Minisparker record indicating bedding features of Pistol Bank, Mississippi Sound (Location G, Figure 4).

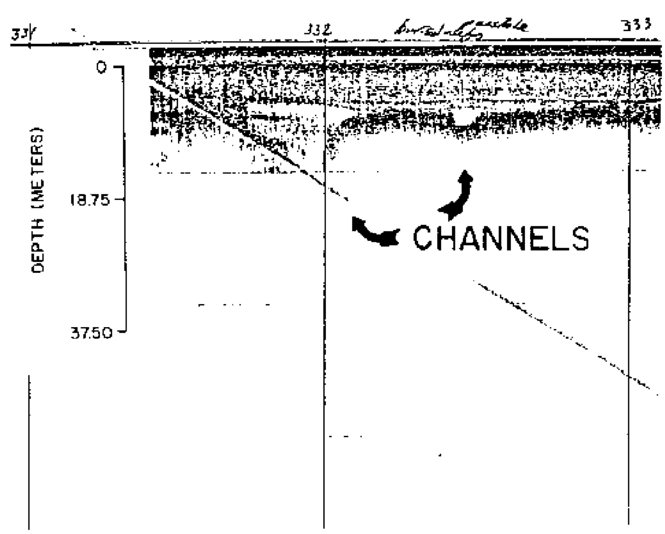

Figure 15 – 7 kH$_2$ record exhibiting relationship of buried oyster reefs and channels in Mobile Bay (Location J, Figure 3).

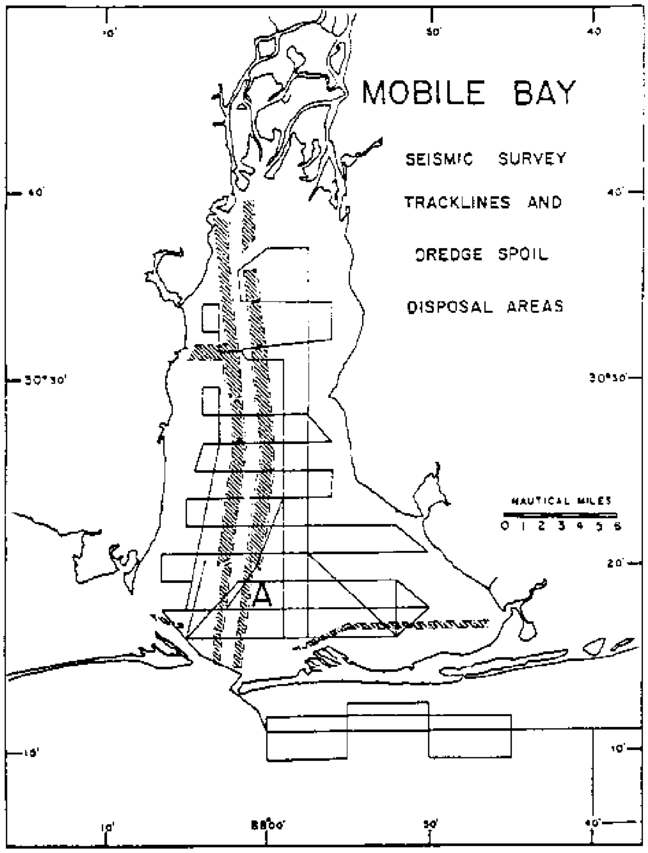

Figure 16 – Map of Mobile Bay indicating contract dredge spoil disposal areas along main ship channel and intra-coastal waterway.

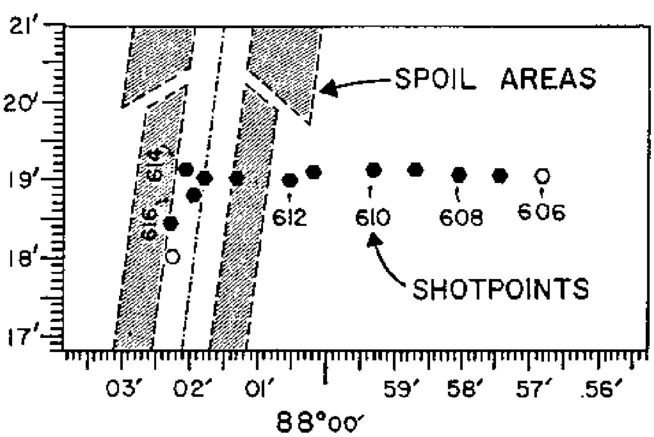

Figure 17 – Transect across main ship channel and dredge spoil disposal areas in southern Mobile Bay indicating extent of Horizon 'A'.

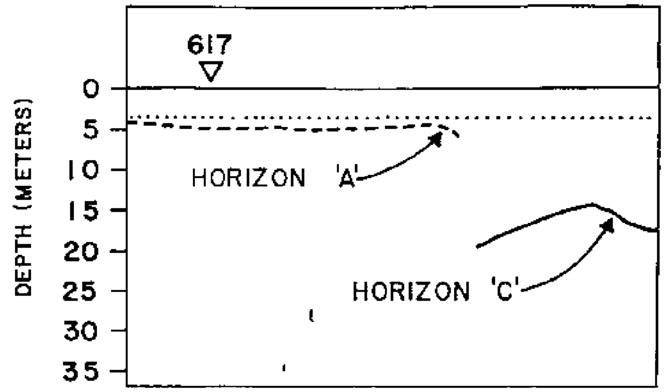

Figure 18 – 7 kH_2 record in vicinity of shotpoint 617.

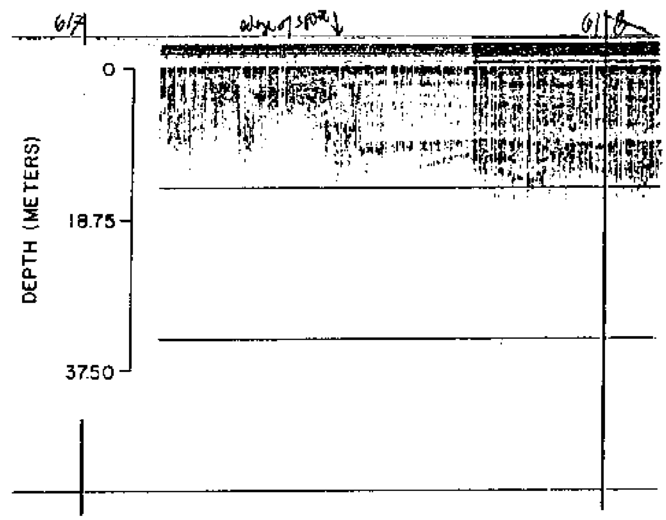

Figure 19 – Interpretation of seismic record of Figure 18.

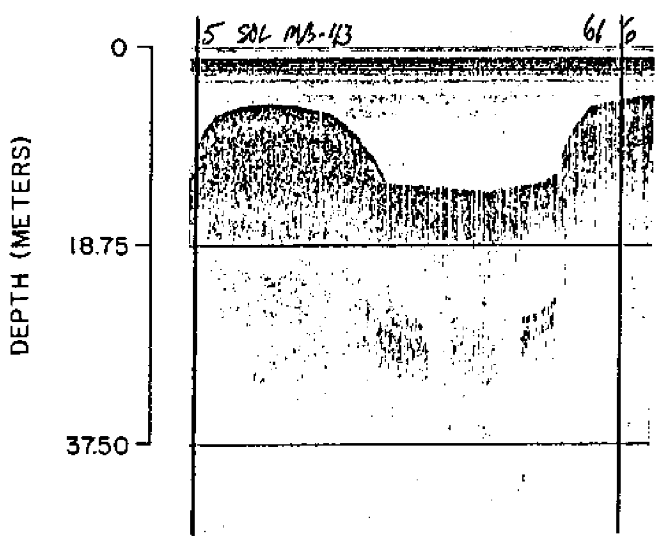

Figure 20 – 7 kH_2 record across main ship channel between shotpoints 615 and 616.

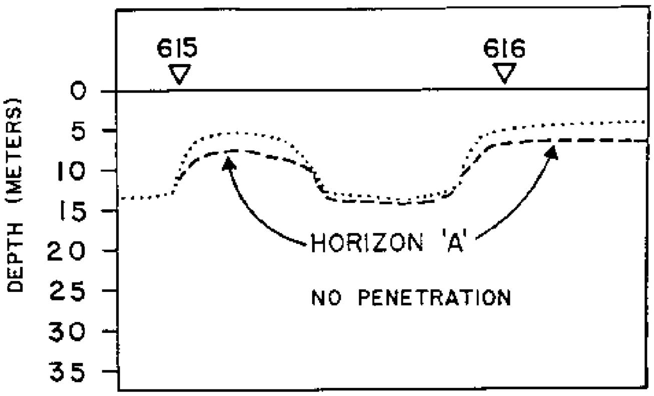

Figure 21 – Interpretation of seismic record of Figure 20.

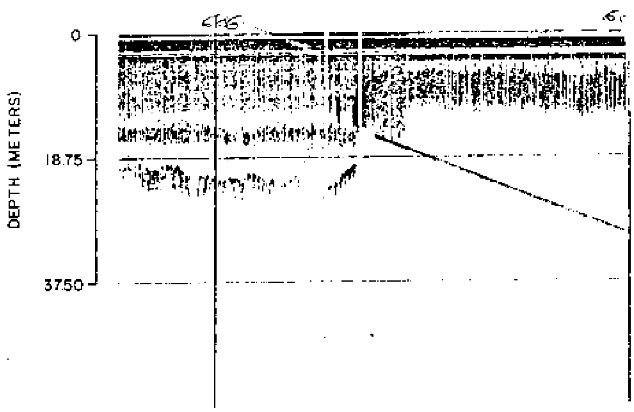

Figure 22 – 7 kH_2 record in vicinity of shotpoint 606.

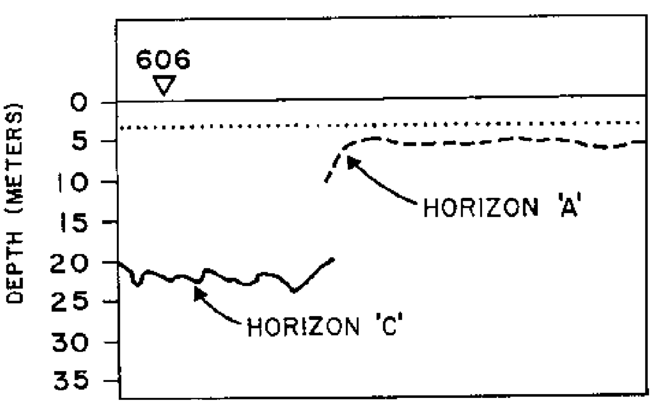

Figure 23 – Interpretation of seismic record of Figure 22.

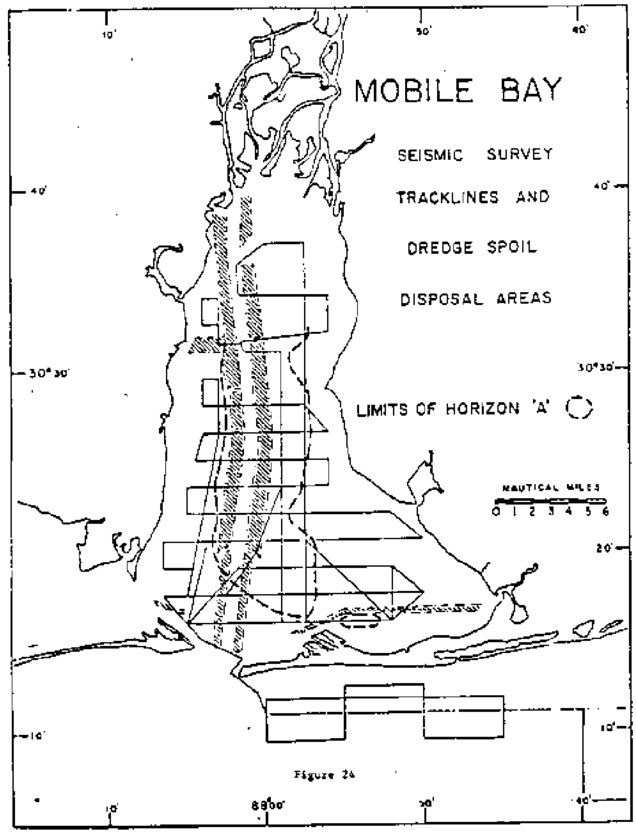

Figure 24 – Extent of Horizon 'A' in Mobile Bay, indicated from signal absorption.

MISSISSIPPI COASTAL RIDGES: ORIGIN AND ANALYSIS

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PURPOSE

The purpose of this study is to determine the origin of three linear and curvilinear, subparallel coastal features located in western Jackson and eastern Harrison Counties, Mississippi.

Previous investigators have ascribed the origins and the development of the features to different geologic processes such as resulting from: a fluvial-alluvial system (Otvos, 1972 and 1973); a stranplain-barrier-beach ridge system (Minshew et al., 1974); or an alluvial-fluvial and beach ridge system (Brown et al., 1944).

Two approaches were used in solving this dilemma of differing origins. The first, a sedimentologic approach, was based on statistical analysis of grain-size properties, measurement of sedimentary structure, mineralogy, and geostatistics.

The second approach involved analysis of topographic, maps and black and white aerial photographs in which these three topographic features were delineated and geomorphic interpretations made.

STUDY AREA

The study area and an arbitrarily defined rectangular unit are located on the coast of Mississippi in western Jackson and eastern Harrison Counties (Fig. 1). The boundaries are:

- North: approximately three miles north of Bayou Costapia (N30° 33')
- East: the eastern edge of the Vestry 15 minute and the Ocean Springs 7.5 minute Quadrangles (W88° 45')
- South: Old Fort Bayou and Back Bay of Biloxi (N30° 29')
- West: the confluence of the Biloxi and Tchoutacabouffa Rivers (W39° 59' 30")

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The Mississippi Sandhill Crane National Wildlife Refuge is located near the eastern part of the study area. The city of Biloxi is situated just south of the study area and Interstate Highway I-10 passes through the area.

PREVIOUS WORKS AND GEOLOGIC SETTING

Geologic studies of the coastal sections of Jackson and Harrison Counties appear to be limited to a few investigations which refer to this area in a general manner. The most important works are by Brown et al. (1944), Otvos (1972 and 1973), and Minshew et al. (1974).

The oldest geologic unit exposed in the study area is the Citronelle Formation. Brown et al. (1944) describe the Citronelle as Pleistocene Age distributary channel deposits. Carlston (1950) and Doering (1956) also assigned a Pleistocene age to the Citronelle sand and gravels. In contrast, Otvos (1973) described the Citronelle as Pliocene alluvial-fluvial sands and gravels. Minshew et al. (1974) described this unit as a submarine erosional-depositional surface superimposed on the Citronelle fluvial-deltaic depositional plain.

The "Post-Citronelle" surface units are given ages ranging from Early Pleistocene to Recent. Table 1 (Appendix) shows age and sea level stands of the surface units. These Pleistocene-Recent units are assigned different names and depositional environments. Brown et al. (1944) describe the southern portion of the study area as Pleistocene "Low Terrace Deposits" and Pamlico Sand. The "Low Terrace" tan to yellow sands are either dune-capped ridges associated with the Pamlico terrace or are correlative with Cooke's (1935) Talbot terrace, or even an older higher terrace now warped downward. The Pamlico Sands are beach sediments with thin interfingering lagoonal sediments. Conversely, Otvos (1973) indicates a continuation of alluvial-fluvial units southward (an Earlier Pleistocene unit and the Prairie Formation).

Minshew et al. (1974) indicate a strandplain-barrier-beach ridge system for those sediments west of the Pascagoula River, therefore including those sediments of the study area. Other workers (Rainwater, 1963 and Carlston, 1950) also ascribed beach ridge, back beach and marine terrace environments for sediments of the study area. A more recent work (Willetts et al., 1980) demonstrates a coastal marine process for the origin of the three ridges within the coastal counties of Jackson and Harrison.

Recent sediments are the fluvial and marsh sediments found along the rivers and streams and Back Bay of Biloxi areas.

Tectonic Activity

Major structural features of the region are the Lucedale-Wiggins Anticline situated approximately 30 miles north of the study area and the Gulf Coast Geosyncline approximately 50 miles south of the study area. Both features trend east-west (Murry, 1947).

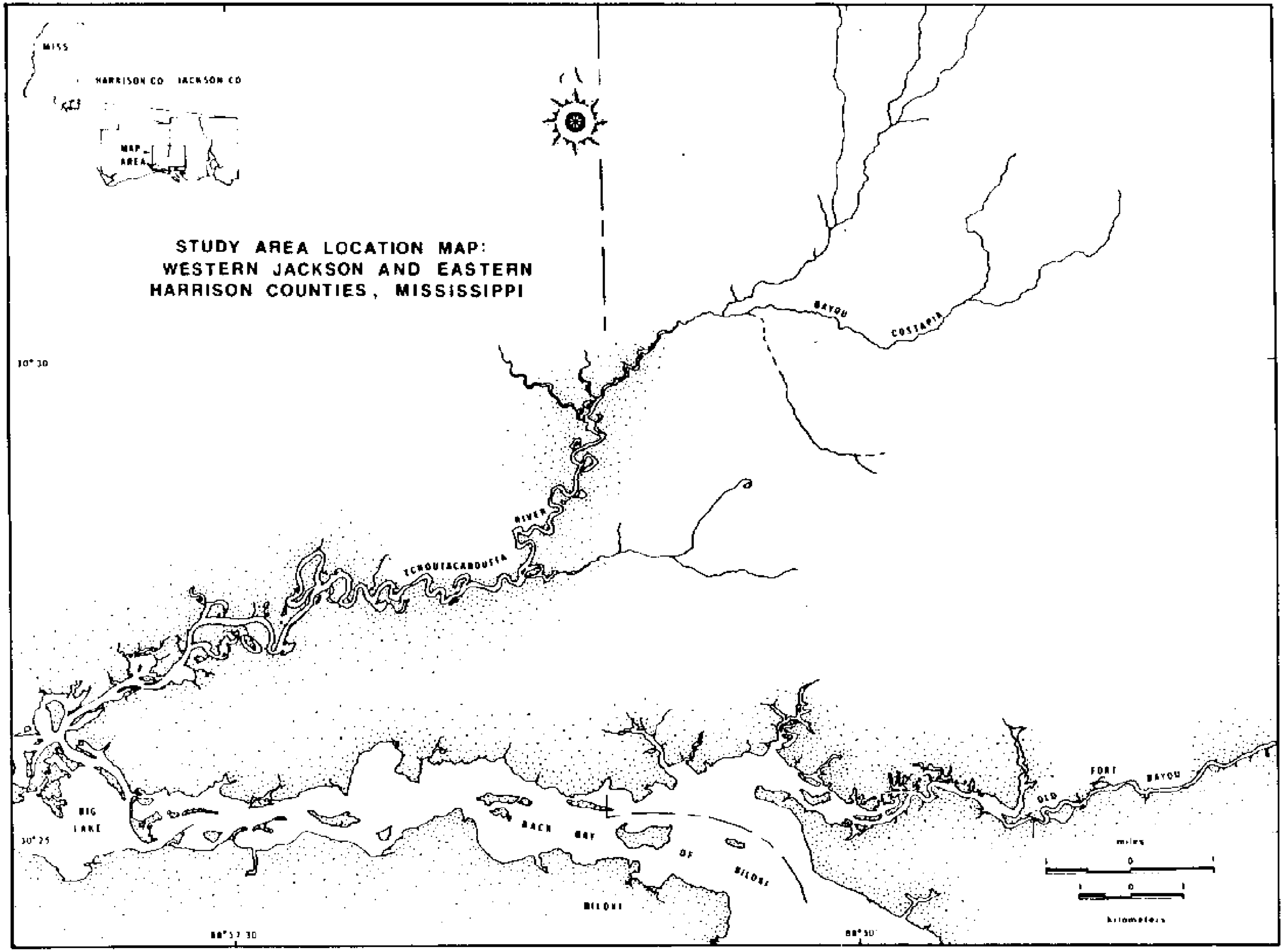


Figure 1. Study area location map.

Overall dip of the subsurface sediments is southward with an east-west strike; however, in western Harrison and Hancock Counties the sediments have an increasingly westward dip. This westward dip component is attributed to deltaic deposition and consequent subsidence of the area (Brown et al., 1944).

The southward dip component of the sediments is attributed to a continuous or an intermittent differential tectonic activity occurring throughout the Pleistocene Doering, 1956). A slow uplift occurred inland and subsidence or downwarping occurred gulfward and along the coastal margins (Brown et al., 1944; Carlston, 1950; Doering, 1956; and Bernard and LeBlanc, 1965).

Minshew et al. (1974) disagree with the tectonic interpretation for the southward dip of the subsurface sediments in Jackson County. These workers contend that the sediment dip modifications are in response to sediment loading during glaciation in the northern United States.

Pleistocene Sea Levels

Carlston (1950) describes the Plio-Pleistocene as a period of submergence with a sea level at 58 to 64 m. (190-210 feet) above present sea level. The Pleistocene ended with a sea level advance (Rainwater, 1963 and Bernard and LeBlanc, 1965). During the Pleistocene, however, a succession of lowering sea levels are documented for the Atlantic Coast. Colquhoun (1974) describes these as transgressive-regressive cycles.

Correlating the sea levels from the Atlantic Coast to the Gulf Coast is complicated because of the difference in tectonic activity; however, ridge complexes have been found and tentatively correlated with Talbot and Pamlico shorelines on the basis of elevation similarity.

Cooke (1935) describes the Talbot shoreline at an altitude of 12.8 m. (42 feet) and Pamlico at 7.6 m. (25 feet). Colquhoun (1974) found in South Carolina the Talbot shoreline at 12.1 m. (40 feet) and Pamlico at 7.6 m., whereas Hoyt and Hails (1974) working in Georgia and using the upper limit of *Callianassa* burrows place the Talbot shoreline at 12.1-13.7 m. (40-45 feet).

Winker and Howard (1977) described relict ridges in the Panhandle region of Florida at 10 m. (33 feet) (Escambia Sequence). These relict ridges were referred to as part of the Pamlico Shoreline. Brown et al. (1944) found mollusk bored pebbles at 12.8 m. (42 feet) and suggested a Penholoway sea stand or that the pebbles came from a dune-capped Pamlico shoreline ridge. Other coastal features, such as Big Ridge, were attributed by Brown et al. (1944) to be part of a Talbot shoreline. Further, correlations of Pamlico shorelines for the Gulf Coast include a barrier ridge complex at 7.6 m. (25 feet) in Harrison County, Mississippi (McAuliffe, et al., 1980) and ridges at 6 m. and 9 m. (20 and 30 feet) in Hancock County, Mississippi (Pellegrin, 1978).

METHODOLOGY

Sample Locations

Location of the sample sites was based on a deterministic traverse pattern. This enabled emphasis to be placed on sampling the three ridge features. Samples were also taken outside the study area for comparison and designated as undifferentiated non-ridge samples because of an unclear origin and apparent lack of distinctive features. Later analysis revealed the type of environment for some of these samples. A total of 79 sites were sampled in the field but, as indicated on Figure 2, only samples from 54 sites were related to the ridge complexes and shown on the sample location map (Fig. 2 and Table 2, Appendix) and analyzed in the laboratory.

Field Methods

A preliminary reconnaissance of the study area was conducted prior to sampling in order to determine accessibility of the sample sites, to obtain property owner's permission for sampling on private property, and to determine if any detrimental aspects of the location existed, such as a thick cover of fill dirt or underground cables.

During the reconnaissance, a section of the study area was found to lie within a National Wildlife Refuge. Therefore, a proposal of this study was submitted to and accepted by the Department of Interior for entry and sampling permission. Twelve sites were located in this area.

Several quarries and road cuts were substituted for some of the selected core locations. Measurements were made and sections described with emphasis on sedimentary structures (if present), stratigraphic relationships, and lithologic characteristics which could indicate possible depositional environment.

Shallow cores were chosen as the means for obtaining the remaining samples because this method would give relatively undisturbed samples. Shier and Oaks, Jr. (1966) described a coring method for wet and unconsolidated sediments and, as past work on the coast of Mississippi had revealed a sediment that was very wet and unconsolidated, their method appeared to be most suitable.

This method was successful in loose and wet sediments but difficulties occurred when encountering a dry or dense sediment. The types of problems encountered involved the coring pipe becoming stuck and having to be dug out and suction within the hole causing the stopper to "pop," consequently losing the vacuum and losing the core. It should be noted that any time such problems arose during the coring, care was always taken to insure that the core sample taken for analysis was without doubt a good and reliable sampling.

Field evidence indicated sediments of Big Ridge (the southern-most feature) were dry; therefore, another means of obtaining samples was needed. A (Sears) posthole digger (an augering type device) was utilized. Though limited in depth, samples collected were in proper stratigraphic sequence and only the bottom 7 to 10 cms. (3 to 4 inches).

In each case, care was taken to prevent sample contamination and to keep an accurate depth measurement.

Laboratory Methods

Samples of laboratory analysis were chosen at 43-48 cms. (17-19 inches) and 101-127 cms. (40-50 inches). The depth of 43 to 48 cms. (17-19 inches) was chosen for each sample site as the first sample below the surface topsoil and organic material layer. The depth of the second sample was based on apparent lithologic changes.

Approaches used in analyzing the samples are sand grain size analysis and mineralogic and textural analysis. Silt and clay size analysis was done for selected samples in order to

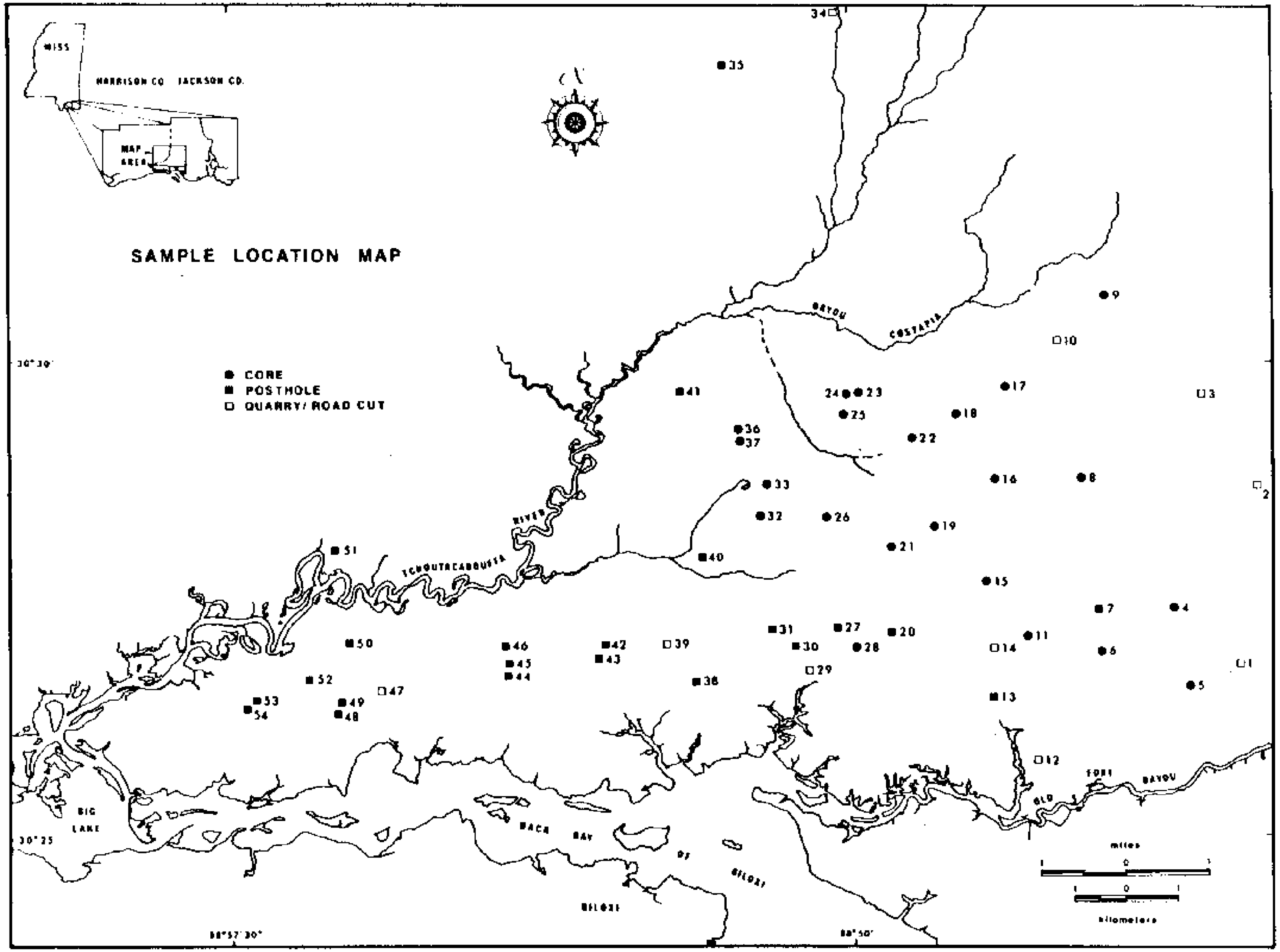


Figure 2. Map showing sample location and indication of type of sample collection.

check for sand-silt-clay percentage patterns. Also, selected samples were analyzed for heavy mineral percentages and mineralogy. Procedures used were based on Carver (1971) and Royse (1970).

Topographic Methodology

Winker and Howard (1977) used United States Geological Survey (U.S.G.S.) topographic maps of 1:24000 and 1:62500 scales to delineate relict beach ridges and to establish shoreline stands in the panhandle and west coast regions of Florida. McAuliffe, et al. (1980) also used 7.5 minute U.S.G.S. quadrangles to map relict barrier ridge complexes in Harrison County, Mississippi.

The 7.5 minute U.S.G.S. topographic quadrangles (Biloxi and Ocean Springs) and the Vestry 15 minute U.S.G.S. quadrangle were examined for any topographic features, trends, or patterns suggestive of relict ridges or shorelines. Based on past references to sea levels ranges of 20-30 feet (6-9 m.) and 40-50 feet (12-15 m.) (Cooke, 1935; Brown et al., 1944; MacNeil, 1949; Oaks and Dubar, 1974; Hoyt and Hails, 1974, and Pellegrin, 1978), contour intervals of these sea level ranges were inspected on the Biloxi, Ocean Springs and Vestry quadrangles. Twenty-five foot and fifty foot contour lines were found to show three coastal subparallel, linear and curvilinear trends, defined as Bayou Costapia Ridge, Desoto Ridge, and Big Ridge.

Black and White Aerial Photograph Methods

Black and white aerial photographs (1:20000) from the U.S. Department of Agriculture were used to delineate topographic features within the study area. The scale of the black and white aerial photographs allowed for discrimination of features within the area.

Photographs used were from the years 1952, 1953, and 1958 (Table 3). An advantage of these dates was that present day urbanization did not interfere with detection of the topographic features.

Initially, all the gray tones were examined using a U.S. Army stereoscope (model MS-1) and photographic stereo pairs. Distinction of the light gray tonal features was based on the continuous linear shape of the light gray tones and the relief exhibited by the light gray tones from the surrounding gray tones. The light gray tone patterns were traced on a base map in the form of a single line representing the axis of the topographic features. Figure 3 shows the linear and curvilinear patterns of the light gray tones (A - A'). Major topographic features were delineated on the basis of the length and continuity of the tones and on the position with comparison to topographic trends. The minor topographic features were those tones that were not associated with the continuity of the major topographic features. Some apparent topographic features were mapped; however, their presence was not readily discernable.

AERIAL PHOTOGRAPHIC INTERPRETATION

A linear east-west trending topographic ridge (Fig. 4) is defined by the 25 foot (7 m.) contour line. On the Gulf side and at the eastern end of this ridge at a series of ridge and small swale-like features. Toward the distal (western) end the ridges coalesce into one ridge complex called Big Ridge. Along the gulfward side of Big Ridge is a scarp-like feature which Otvos (1973) called a fault scarp. Also, at the distal or western end of Big Ridge there appears to be a recurved pull-out feature. Big Ridge appears to be a spit-like extension from the headland which is located in the northeast. Development may be in the manner of a linear ridge build-up and termination with a recurved pull-out followed by another linear ridge build-up reflecting fluctuating sea levels. In the same area, a westward extending linear feature is shown which may be due to the influence of the Tchoutacabouffa River or the continuation of a westward growth of Big Ridge (Fig. 4).

Two topographic ridge features are delineated by the 50 foot (15 m.) contour line (Fig. 5). The northermost topographic ridge (Bayou Costapia Ridge) appears as a curvilinear ridge trending out of the northeast toward the west extending out of the northeast toward the west estending from the Citronelle Uplands.

The second, more gulfward ridge (Desoto Ridge) trends northwest to southeast (Fig.5). This topographic ridge is a narrow, slightly arcuate feature with a cusp near the northwest. At the southeastern end, Desoto Ridge appears disjointed which is probably due to recent drainage. At the northwest end, Desoto Ridge widens and is oriented in a southwest-northeast manner. This appearance is probably due to the influence of the Tchoutacabouffa River.

Bayou Costapia Ridge extends from the Citronelle Uplands forming a pattern similar to that of a recurved spit. At this same time or shortly after, Desoto Ridge developed into a barrier ridge-like system in the southeastern end and into a tidal channel feature in the northwestern end.

A small area at 15 m. (50 feet) is located southwest of Desoto Ridge (Fig. 5) and is not associated with Desoto and Bayou Costapia Ridges. Later field and sedimentologic studies revealed this feature to consist of dune sand capping Big Ridge.

Northwest of Bayou Costapia Ridge and Desoto Ridge, the 25 foot (7 m.) and 50 foot (15 m.) contour lines reveal an upland area which terminates in an arcuate pattern broken by an estuary-like system (Figs. 4 and 5) where tributaries of the Tchoutacabouffa River now flow.

Several linear and curvilinear patterns were revealed from mapping continuous light gray tonal patterns on black and white aerial photographs (Fig. 6).

The area between Bayou Costapia and Perigal Creek contains a recurved spit-like feature. The main axis of the mapped tones is a slightly curved pattern with several northwesterly oriented pull-outs. This feature begins abruptly in the northeast and terminates in the recurved pull-out in the west and lies in the same position as the spit-like Bayou Costapia Ridge (Fig. 5).

A second more prominent feature is delineated between Perigal Creek and Cypress Creek. This feature extends from the northwest to the southeast in an arcuate pattern as depicted by the light gray tonal patterns on aerial photographs (Fig. 7, B - B'). In the northwest, the major features are long and continuous with smaller, subparallel features at the front of the main feature. At the southeast end, this feature breaks up into a multiple series of subparallel forms and follows the same orientation as Desoto Ridge.

South of Cypress Creek and Tchoutacabouffa River an east-west trend complex is delineated. In the eastern part, a series of subparallel, somewhat disjointed trends are

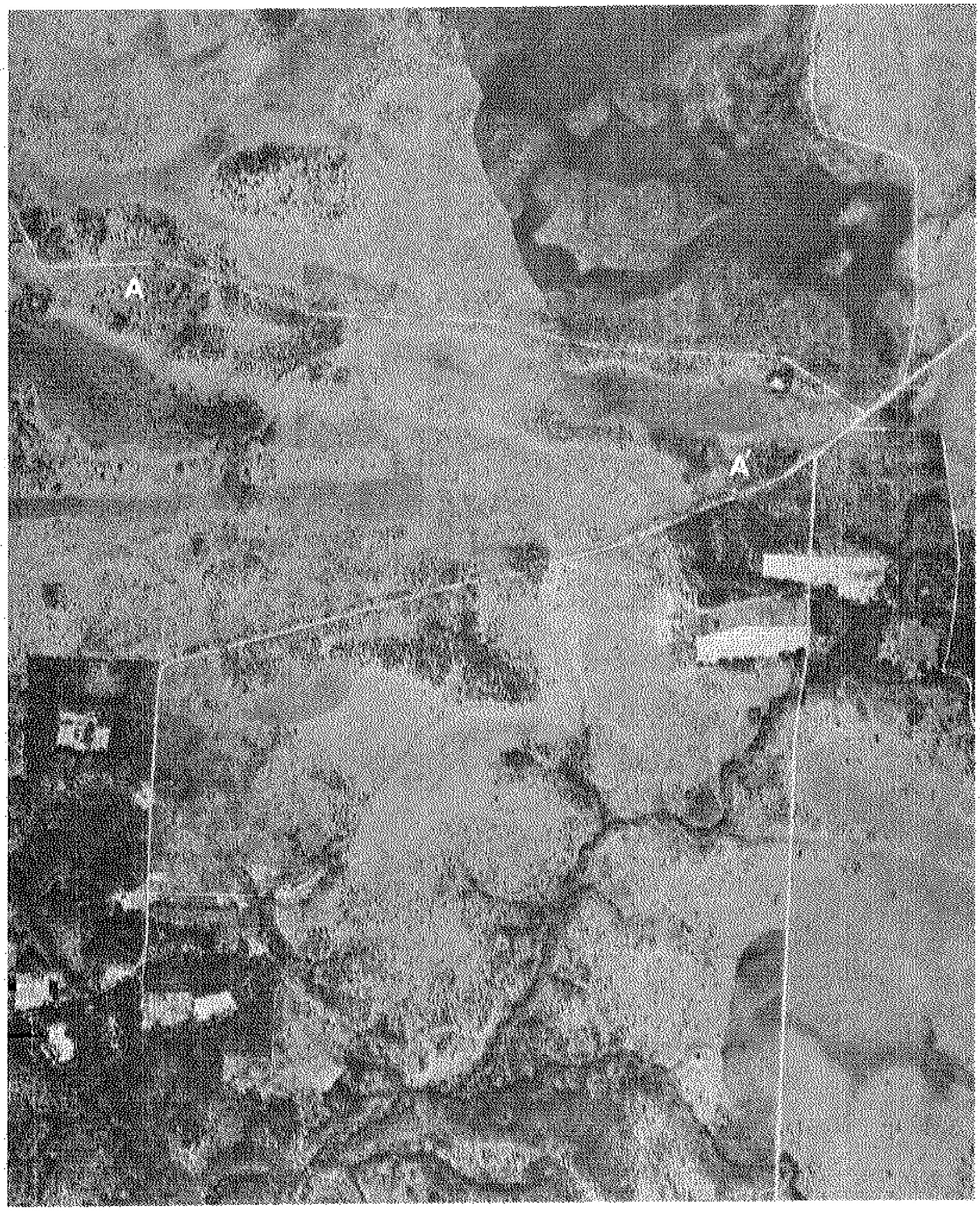


Figure 3. Black and white aerial photograph showing light gray tone, linear/curvilinear trend (A - A').

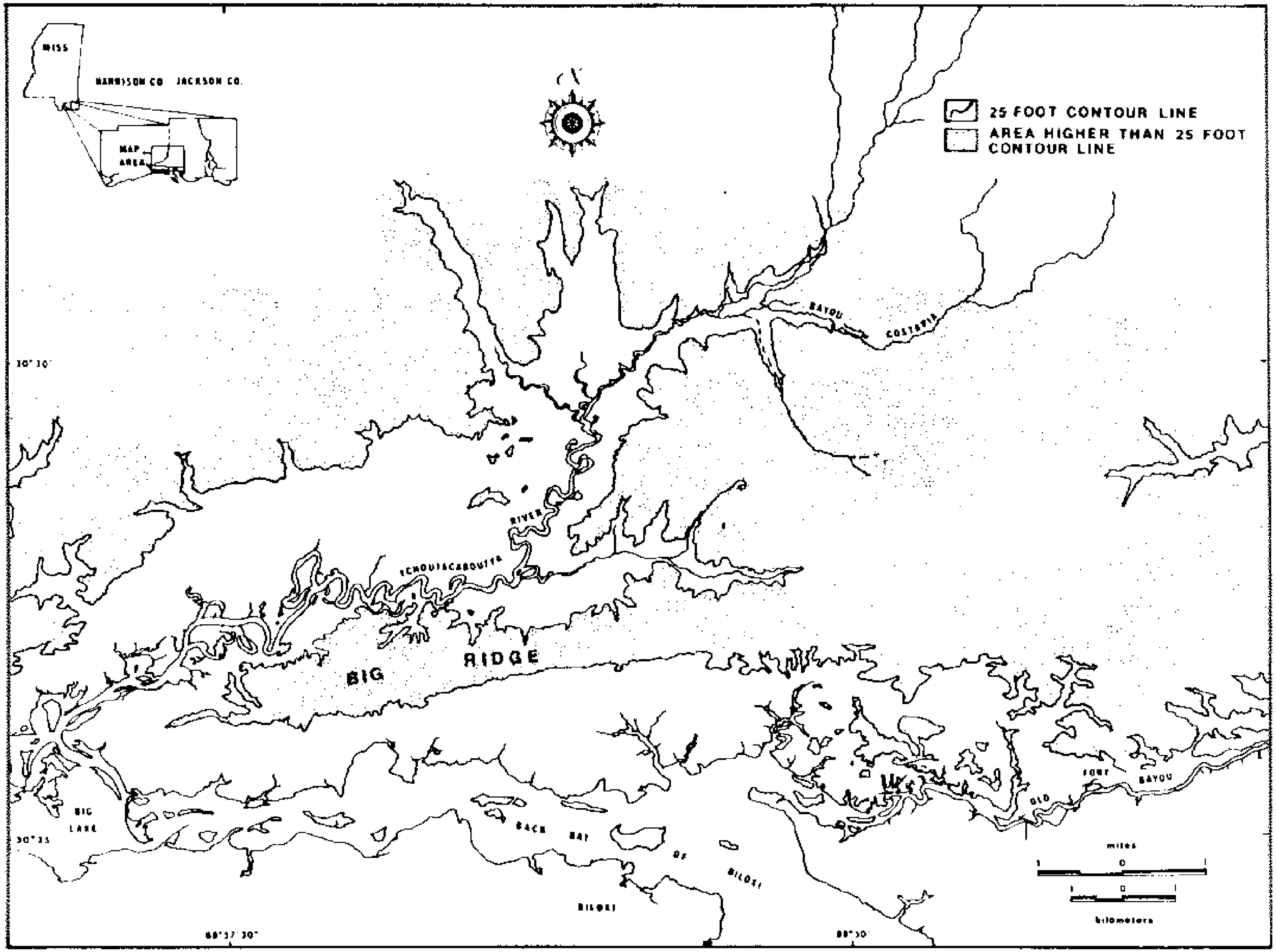


Figure 4. Twenty-five foot contour line delineating the east-west trending Big Ridge.

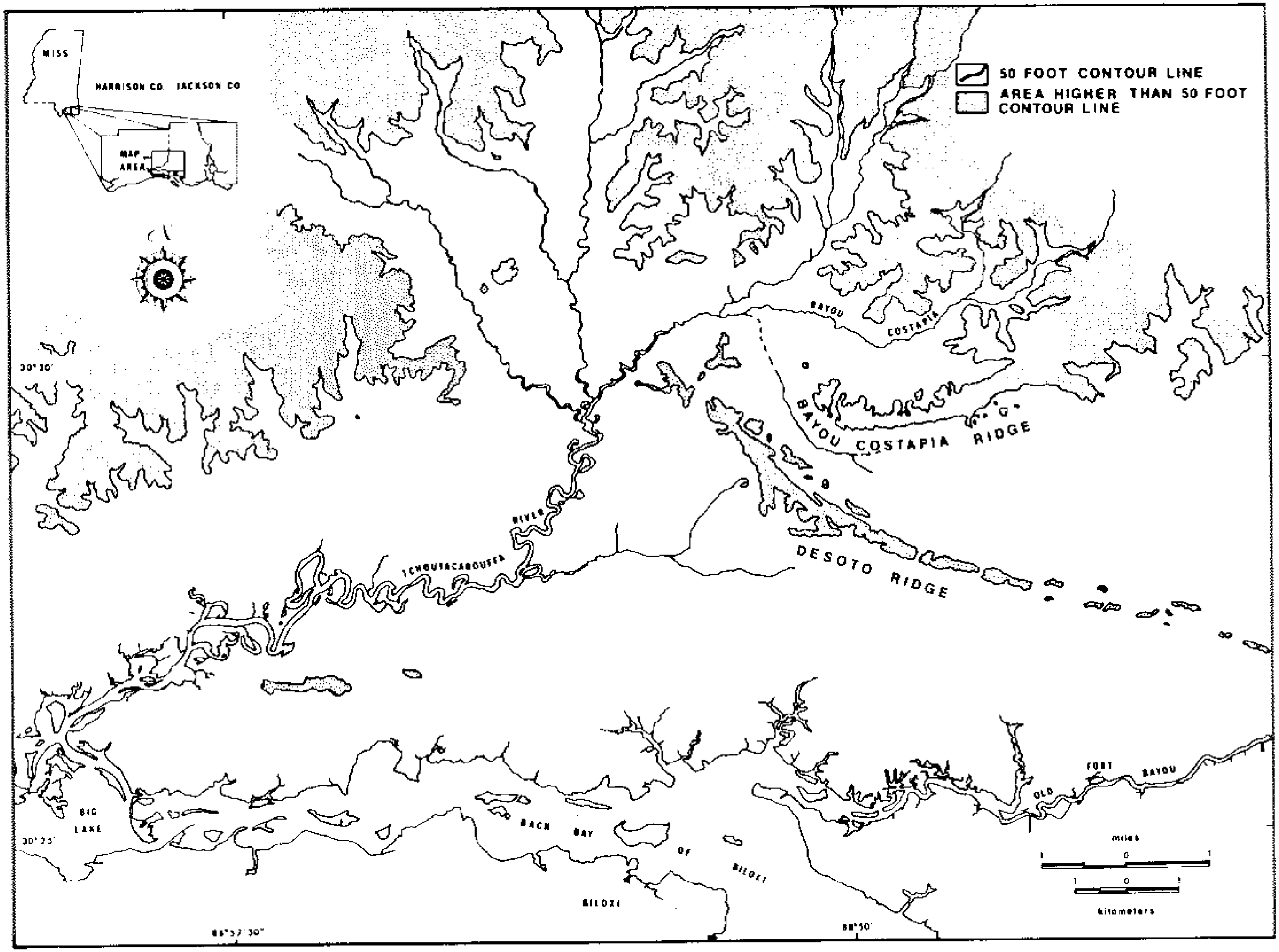


Figure 5. Fifty foot contour line delineation of Desoto and Bayou Costapia Ridges. Bayou Costapia Ridge appears as a recurved spit and Desoto Ridge appears as a barrier ridge.

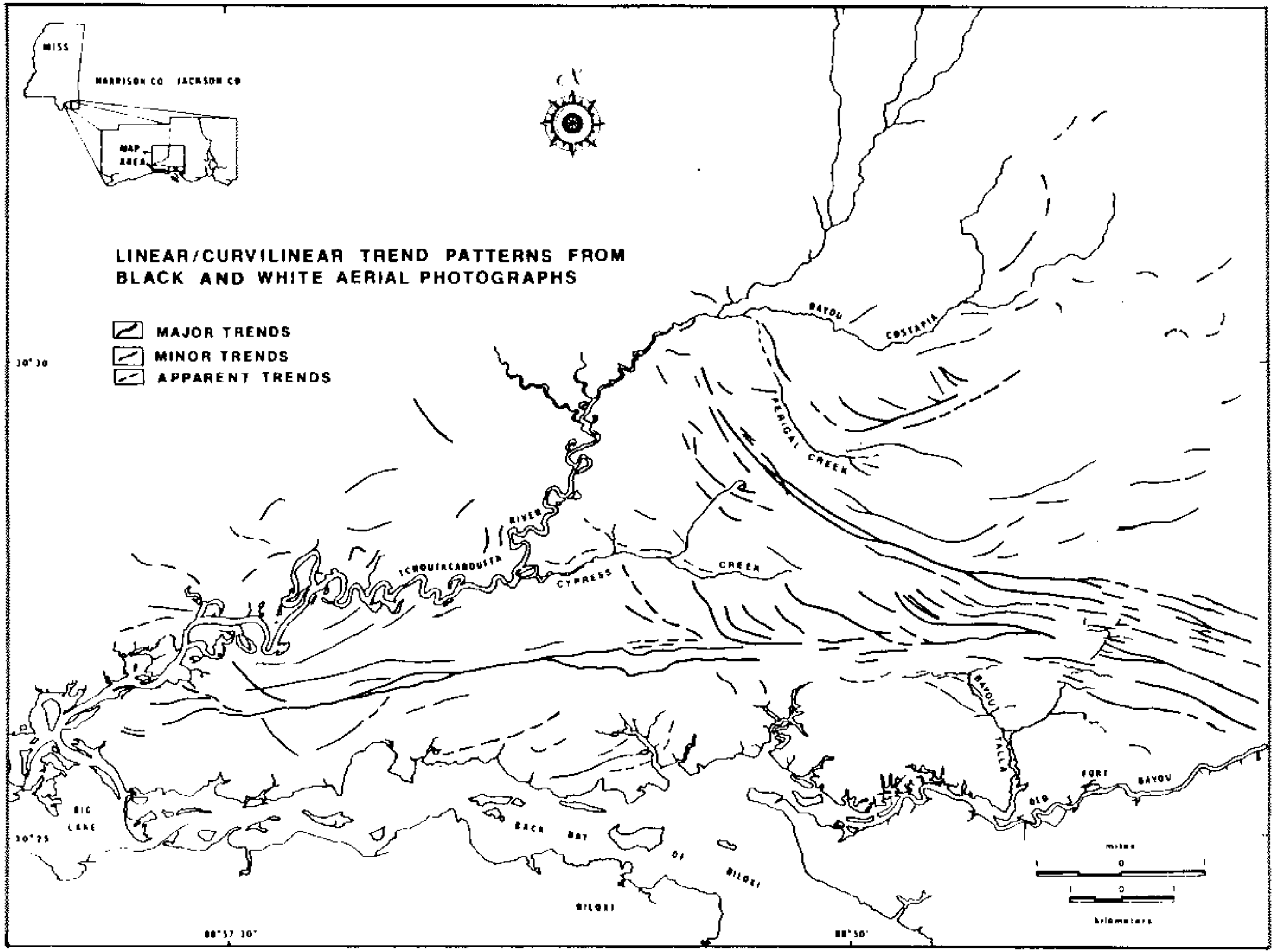


Figure 6. Trend map of axes of the light gray tones from black and white aerial photographs. Note the three different trend patterns.

Figure 7. Black and white aerial photograph showing the cirvilinear light gray tone trend of Desoto Ridge (B - B').

revealed. These are in conjunction with the Desoto Ridge trends. Proceeding westward the trends decrease in number and form a more linear and curved pull-out set of patterns. This linear pattern is featured as a narrow linear trending light gray tone on aerial photographs (Fig. 8, C - C'). Further west, the trend appears as a single linear feature terminating into a northward pull-out extension and a second apparent northward pull-out which appears to have been modified by the Tchoutacabouffa River. This trend complex also lies in the same position as one of the topographic ridges -Big Ridge (Fig. 4).

Drainage Patterns

Drainage patterns were mapped from 7.5 minute and 15 minute U.S.G.S. topographic maps and black and white aerial photographs. This combination of mapping was done in order to depict the overall drainage pattern of the study area and surrounding area to the north. Salt marshes, fresh water marshes, and swamps were mapped as wetlands (Fig. 9).

The Tchoutacabouffa River flows southward and abruptly changes to a westward direction until the river empties into Big Lake. Here another change of course occurs in which drainage of Back Bay of Biloxi is easterly.

The Tchoutacabouffa River exhibits well developed meander patterns beginning just north of Cypress Creek (Fig. 9) and continues till the river enters Big Lake. Oxbow lakes are prevalent in the western portions. Some of the wetland patterns along the river indicate relict meanders.

Tributaries of the Tchoutacabouffa River show a dendritic pattern as shown by the streams in the northwest. These tributaries also have a southward flow direction. In the northeast, the streams such as Bayou Costapia and Cypress Creek exhibit a drendritic pattern with a generally westward flow direction.

Cypress Creek flows westward into the Tchoutacabouffa River and has tributaries which flow in a northwestwardly direction, while streams just north of Back Bay of Biloxi flow due south into Back Bay of Biloxi or Old Fort Bayou (Fig. 9). These southward flowing streams have a trellis type of drainage pattern (Figs. 3 and 9). The headward area of these streams originates along an east-west axis in the central portion of Big Ridge – south of Cypress Creek and the Tchoutacabouffa River.

Perigal Creek and Cypress Creek are separated from each other by an apparent ridge. Perigal Creek turns northward rather than flowing southward into Cypress Creek via one of the streams near Perigal Creek.

The drainage patterns give evidence for ridges within this area such as the separation of Perigal and Cypress Cresks and the deflection of the Tchoutacabouffa River to the west. An indication of ridge and swale topography is revealed by the trellis drainage patterns of the streams in the southern portion of the area.

SEDIMENTOLOGIC ANALYSIS

Sediment Description

Overall surface (43-48 cms.) field characteristics of the sediments at the sample sites (Fig. 3) are yellow-brown silty sands. However, at some sample sites the surface sediments are dark gray (sample site 46) silty sands with yellow-brown streaks. Between Bayou Costapia Ridge and Desoto Ridge (sample sites 8, 16, and 19) the sediments are dark gray and yellow streaked sticky sandy silts.

Coloration changes from a lighter yellow-brown in the upper surface to a clean white sand with increasing depth. A zone of red iron-stained mottling occurs at various depths in some of the sediments in the eastern portion of the study area.

Pebble size ironstones were found at several sites but not in any appreciable quantity; however, at sample site 14, a layer of red ironstone occurs at 66 cms. (26 inches).

Ternary plots of selected samples show a tendency for the ridge samples to be sand to silty sand, whereas the undifferentiated non-ridge samples tend to be silty sand (Fig. 10). The one sample which lies within the central part of the ternary diagram is at site 9 which lies just northeast of Bayou Costapia Ridge. Values for the sand-silt-clay percentages are listed in table 4 (appendix).

Descriptive statistical treatment of sieve data based on moment measures (Friedman, 1961) (Table 5, appendix) indicate the dominant textural characteristic of the sediment to grade from a fine silty sand to a fine sand. Mean grain size for Bayou Costapia Ridge ranges from 2.377 phi (ϕ) to 3.866ϕ. The undifferentiated non-ridge sample means range from 2.264ϕ to 3.780ϕ. Big Ridge and Desoto Ridge have a mean size range of 1.986ϕ to 3.107ϕ and 2.212ϕ to 2.866ϕ, respectively. Tables 6 and 7 (appendix) contain the specific mean phi values for each of the samples which fall within the fine to very fine sand ranges.

Particle size sorting ranges using standard deviation values are: Bayou Costapia Ridge: 1.220ϕ to 2.868ϕ; undifferentiated non-ridge : .571ϕ to 1.888ϕ; Desoto Ridge: 0.569ϕ to 1.817ϕ; and Big Ridge: 0.528ϕ to 1.807ϕ (Tables 6 and 7, appendix). These values indicate the Bayou Costapia Ridge and the undifferentiated non-ridge sediments are poorly sorted, whereas Big Ridge and Desoto Ridges are moderately to moderately well sorted sediments (Friedman, 1962). The poorly sorted nature of the Bayou Costapia Ridge sediments are probably due to the closeness of a source area as well as decreasing energy of sorting.

Friedmen (1961) refers to the positive or negative aspect of the value of skewness as representative of the depositional environment. A positive skewness value is described for river or dune sands while a negative skewness value refers to beach sands. Eighty-three of the samples show a positive skewness (Tables 6 and 7, appendix). Value ranges are from 0.333ϕ to 2.184ϕ for Bayou Costapia Ridge; -0.015ϕ to 3.379ϕ for Desoto Ridge; -1.283ϕ to 3.848ϕ for Big Ridge; and -0.720ϕ to 2.439ϕ for the undifferentiated non-ridge sediments.

Kurtosis values for the samples vary widely and no obvious tendencies for differentiation between sample areas were noted. Bayou Costapia Ridge sediments tended to have a slightly smaller range of values (2.765ϕ to 8.749ϕ) while the other values from the three areas ranged from 2.090ϕ to 29.991ϕ.

Mineralogy and Texture

Selected samples representing the three ridges and undifferentiated non-ridge areas were examined using a binocular microscope for light and heavy mineral percentages, textures and mineralogy.

Figure 8. Black and white aerial photograph showing the linear light gray tone trend of Big Ridge (C - C').

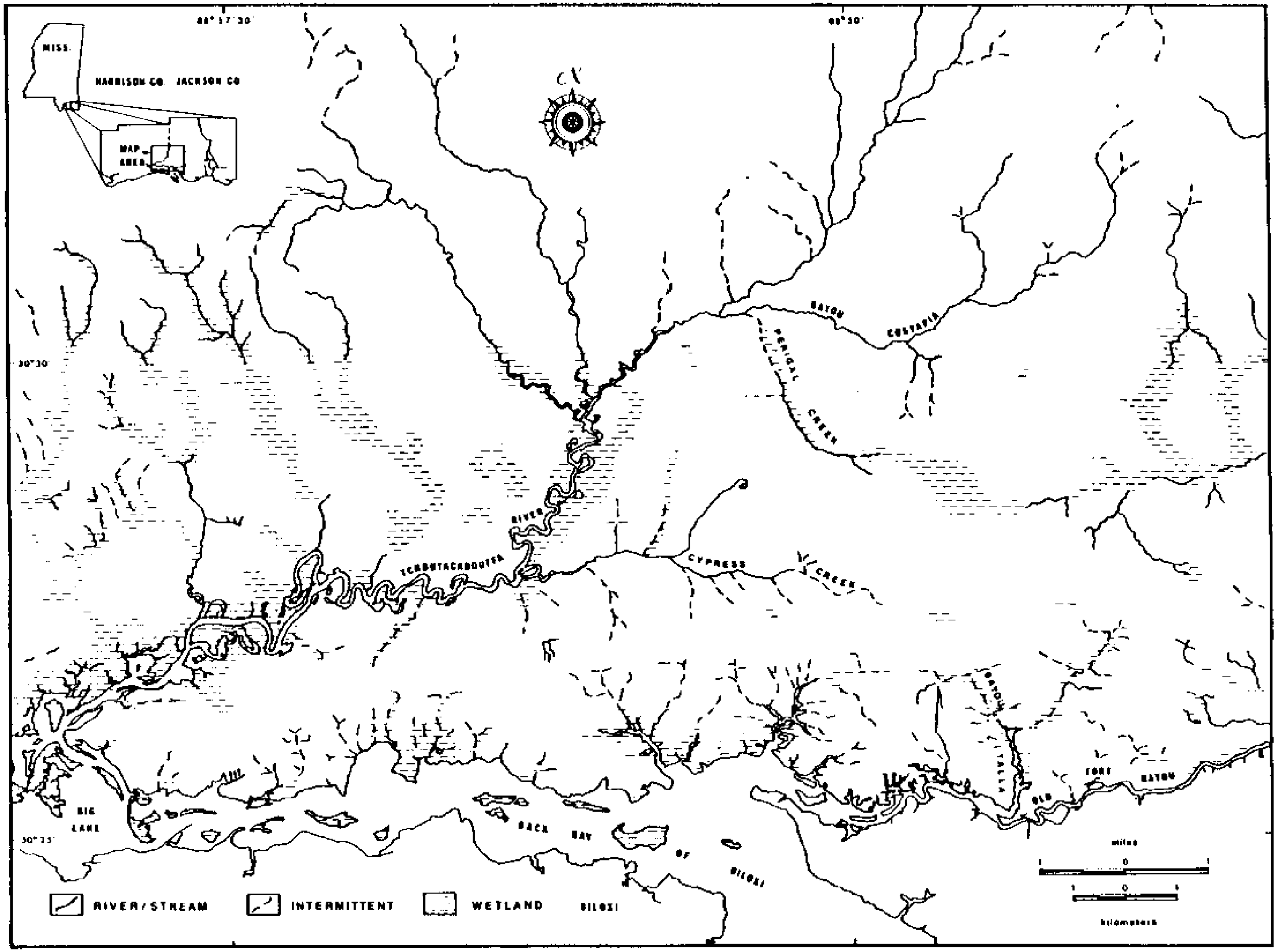
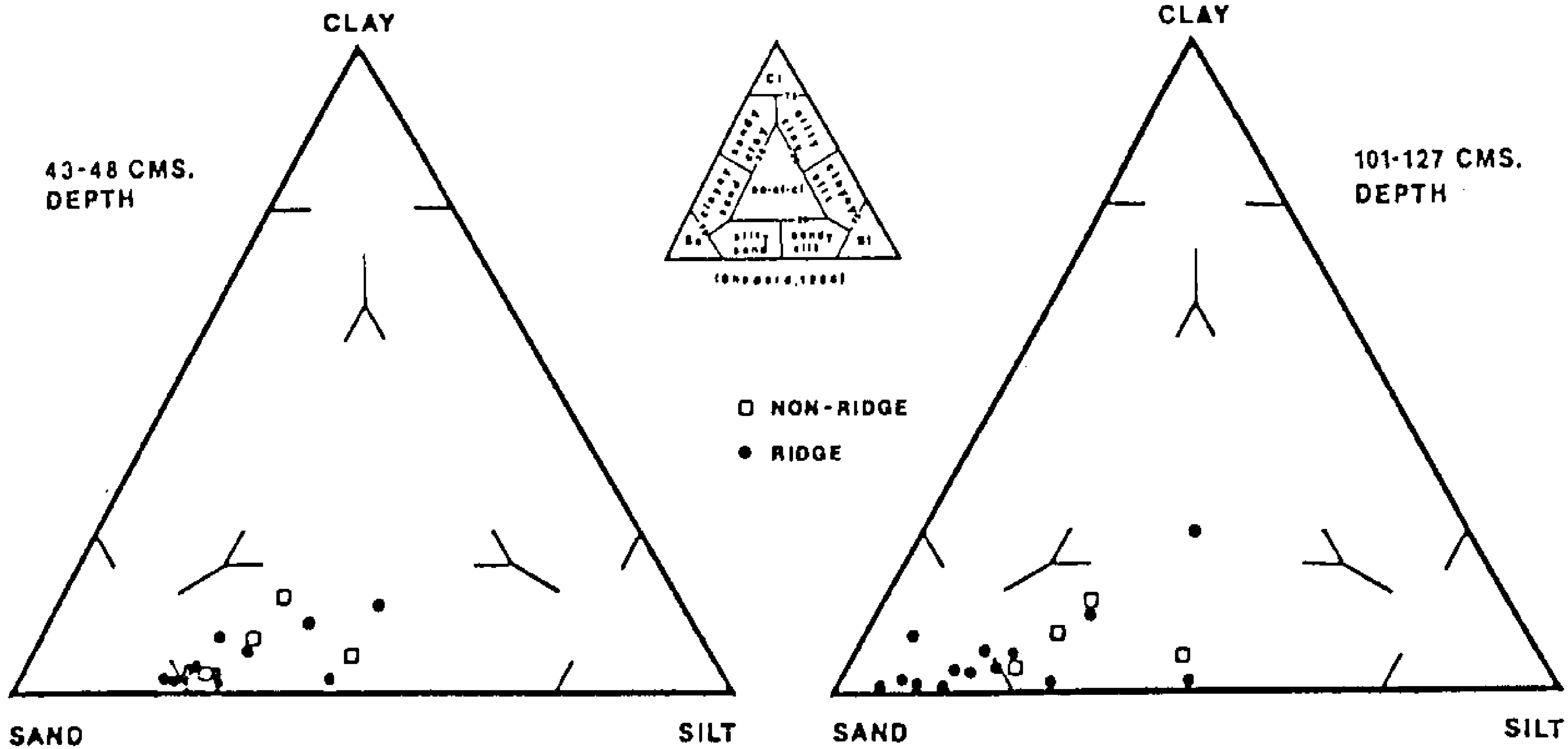


Figure 9. Drainage patterns of the study area. Note the trellis drainage in the southern part of the area and the dendritic drainage in the northwest.



BIG RIDGE, DESOTO, AND BAYOU COSTAPIA RIDGE AND NON-RIDGE SYSTEMS SAMPLED AT DEPTHS OF 43-48 AND 101-127 CMS.

Figure 10. Ternary plots for selected sample sites. Ridge samples tend to be sand or at the border of silty sand and sand. Non-ridge samples tend to be silty sand. (Classification after Shepard, 1954).

Light- and heavy-mineral percentages were determined for the mean phi size fraction of the samples. Heavy mineral content ranges from 0.04 to 2.00 percent (Table 8, appendix). According to these selected samples Big Ridge samples appear to have the least amount of heavy minerals whereas Bayou Costapia Ridge samples show the highest percentages. One exception was revealed by field evidence at site 47 (Fig. 2), the frontal or seaward side of Big Ridge, where some concentrations heavy minerals are of higher percentages than those of Bayou Costapia Ridge.

Overall tendancy indicated by the percentages is that the heavy mineral content decreases from the east to the west for all three ridges.

Magnetite is found at sites 9 and 35 and in the samples from Bayou Costapia Ridge (sample sites 17, 22, and 25). None or very small amounts were noted for Big Ridge and Desoto Ridge samples. This would tend to indicate a close relationship between the Citronelle sediments and Bayou Costapia Ridge sediments.

Other minerals noted are hornblende, staurolite, and some ironstone (hematite?) in some of the samples. These minerals vary in amounts but were present in all of the samples.

The light minerals make up at least 98 percent of the sample fraction (Table 8, appendix). Clear- and milky-quartz are the dominant minerals. Minor amounts of feldspar and chert were also noted. More chert is found in the coarser than in the finer fractions of the samples. Both of these accessory minerals appear weathered. Sample 30 had a high percentage of quartz grains with inclusions, however, overall the percentage of quartz with inclusions is variable and in minor amounts in the other samples. Generally, samples from Desoto Ridge and Big Ridge appear to have more quartz with inclusions than Bayou Costapia Ridge samples.

Textures range from angular to well-rounded in both light- and heavy-mineral fractions. This would indicate a polycyclic nature for these samples in which continual reworking of the sediments occurred and introduction of new unworked sediments occurred.

Sedimentary Structures

Sedimentary structures were absent except for four quarries (sites 1, 2, 29, and 47) (Fig. 2). Ditches along the roads showed no sedimentary structures other than bedding except for some red-orange-brown colored mottling.

A quarry (site 1) lies at the eastern end of Big Ridge and Desoto Ridge (Figs. 2 and 4). At the base of the quarry is a unit containing contorted bedding, ripples, and interlayer of light colored sand and dark gray clayey sand. Overlying this unit is a structureless white sand which is gradationally overlain by a red-orange mottled unit.

Mottling and burrows are found at site 2. The red-orange-brown mottling at site 2 is also the type of mottling found in the ditches along the roads.

The base of the quarry at site 29 contains a very dark gray, burrowed blocky clay which contains at the upper portions wavy and lenticular type bedding. Overlying this unit is a structureless sand unit which is in turn overlain by a white-yellow-brown mottled unit.

A series of low angle (less than 20°) cross-bedded units with ripples are prominent at site 47. A south facing wall at the northwest end of the quarry contains a sequence of burrowed and laminated greenish-brown sand unit overlain by a series of crossbedded and rippled white and yellow-brown and red colored sand units. The dip of these cross beds increases upward in the sequence from (5-7° to 20-27°) and the dip direction is generally southwestward and southeastward. The uppermost unit is a yellow-brown-gray mottled sand unit. An exposed peat bed (approximately 2 feet by 6 feet by 4 inches) is found on a northwest wall. Otvos (1973) described this peaty unit and attempted to date the peat but was unsuccessful. Underneath the peat unit is a clean white sand unit with almost herringbone-like low angle (4-9°) cross beds dipping southeast and northwest.

Statistical Analysis

Visher (1969) used log-probability plots of grain size analysis as a means for interpreting depositional environments. Modern environments were analyzed and used as analogues to interpret ancient sand environments.

The log-probability plots of Visher (1969) showed more than one subpopulation curve making up the sample curves which Visher(1969) attributed to different sediment transport mechanisms (surface creep, saltation, suspension). Visher (1969) was able to relate the environment of deposition to the characteristics (sorting, percentages, and coarse and fine truncation points) of the three subpopulations. Sorting was based on the steepness of the subpopulation curves. Truncation points are the break points between two subpopulation curves.

Probability plots were constructed for the analyzed samples and the characteristics of these plots were compared to those characteristics compiled by Visher (Table 4, p. 1104, 1969). Also, the curves of the probability plots were compared to Visher's (1969) probability plot curves. In interpreting the curves, sometimes more than one environment would fit so the one environment that seemed to fit best was chosen (Table 9, appendix).

Bayou Costapia Ridge sample plots are characteristic of beach environments. Sample 23 (Fig. 11A) is a representative plot from the probability curve. There are two good to well sorted saltation subpopulations (the central portion of the probability plot) which are indicative of the swash-backwash zone of the beach (Visher, 1969). The coarse and fine truncation points for the saltation subpopulation are 1.38ϕ and 3.75ϕ which lies within Visher's (1969) range for beaches of 0.50ϕ - 2.00ϕ and 3.00ϕ - 4.25ϕ.

Sample 25 (Fig. 11B) may represent a tidal channel-fluvial environment. The sorting of the saltation subpopulation is good and comprises 80 percent of the sand sample. The suspension subpopulation is 19 percent of the sand sample and is well sorted. The coarse truncation point (0.80ϕ) of the saltation subpopulation lies 0.50ϕ outside of Visher's (1969) saltation coarse truncation point range of 1.50ϕ - 2.00ϕ, however, the fine truncation point (3.38ϕ) lies within Visher's (1969) fine truncation point range of 1.50ϕ - 3.50ϕ. This may be due to the fine size nature of the Bayou Costapia Ridge sediments.

Desoto Ridge is characterized by dune and beach environment interpretations. Sample 21 (Fig. 11C) is a representative dune curve. The saltation subpopulation shows an excellent sorting and comprises 95 percent of the total sample. Also, the coarse and fine truncation points (1.30ϕ and 3.25ϕ) lie within Visher's (1969) range of 1.00ϕ -

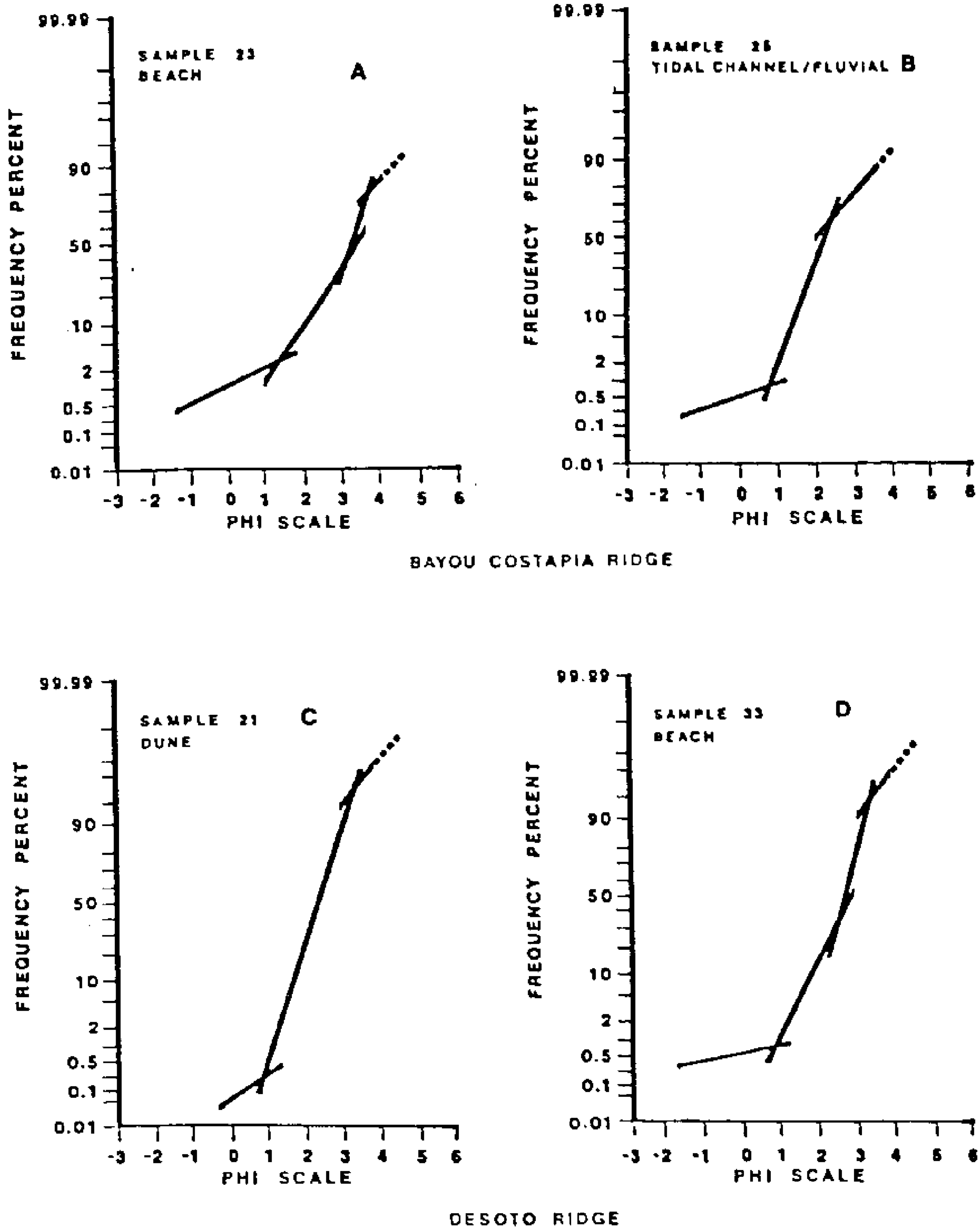


Figure 11. Representative plots of Bayou Costapia and Desoto Ridges samples and their interpretative environments of deposition based upon Visher's (1969) method.

2.00ϕ and 3.00ϕ - 4.00ϕ. Suspension and surface creep subpopulations comprise only a small percentage of the samples.

Sample 33 (Fig. 11D) represents a beach interpretation. The saltation subpopulation is composed of two excellently sorted populations and comprises 94 percent of the sample. Less than one percent of the sample is contained in the fine end and only about five percent is composed of lag or surface creep material.

Big Ridge samples yield curves which can be interpreted for the most part as a beach-dune system. Sample 6 (Fig. 12A) represents the beach interpreted curves. Two good to excellent sorted saltation subpopulations are present and 90 percent of the sample falls within this subpopulation. Truncation points of the saltation curve (0.90ϕ and 3.50ϕ) lie within Visher's (1969) range for beach curves.

Dune interpretation is made from curves of samples 20, 31, 52, 53 and 54 (not illustrated) which contain the indicative characteristics of excellently sorted saltation subpopulations and greater that 94 percent of sample falls within this subpopulation.

Sample 46 (Fig. 12B) reflects a fluvial/tidal channel interpretation. The saltation subpopulation comprises 89 percent of the sample and has good sorting. There are two saltation subpopulations which would be indicative of beach, however, the small percentage of one tends to indicative the possibility of interpreting the line fit to just one saltation subpopulation. The coarse truncation point (0.40ϕ) does not lie within Visher's (1969) range for a fluvial system (-1.50ϕ - 1.00ϕ), however, taking into account the fine sediment nature would shift the truncation point towards the finer size. A comparision of plotted curves with sample 46 supports the fluvial/tidal channel interpretation.

Undifferentiated non-ridge sample curves reflect a variety of environmental interpretations. Fluvial related curves are noted by sample 9 (Fig. 12C), 13, 19, 34, and 51. Sample 9 shows the higher percentage of surface creep (20 percent) and suspension (11 percent) subpopulations. The saltation subpopulation shows fair to good soring and comprises only 69 percent of the sample. Truncation points between suspension and saltation subpopulations (3.88ϕ) lies about 0.25ϕ outside of Visher's (1969) range of 2.75ϕ - 3.50ϕ. Tidal channel environments are represented by the curves of samples 16 and 40.

Sample 8 (Fig.. 12D) may represent a beach or strandplain by the good sorting of two saltation subpopulations. Truncation points are within Visher's (1969) range. This curve also would fit the data for tidal channels if the saltation subpopulation was of only one population.

Table 9 (appendix) indicates the possible environments for all of the samples. As indicated, several possible interpretations were made for each sample and the first one listed appeared to be the "best-fit" of the data.

Based on these comparisons, Bayou Costapia Ridge, Desoto Ridge and Big Ridge sediments were deposited in the coastal environments of beaches and dunes. Those samples of the undifferentiated non-ridge indicate a variety of environments which probably would be associated with a coast. In those areas (sample sites 25, 34, 42, 46, and 51) where fluvial or tidal channel environments are expected, the samples were interpreted as fluvial or tidal environments.

Friedman (1961 and 1967) used the statistical parameters of standard deviation and mean plus skewness derived from grain size analysis to differentiate between beach, river, and dune sands. Scatter plots of standard deviation, mean, and skewness were used to differentiate these environments of deposition. Hails and Hoyt (1969) also included kurtosis for distinguishing barrier sands from lagoonal and salt marsh sediments. The scatter plots of Friedman (1961 and 1967) generally showed two groupings; beach sands and river sands.

Only a few of the various scatter plots of statistical parameters appeared to be significant for distinguishing the sediments of the three ridges and the undifferentiated non-ridge. The standard deviation and mean appear to be the dominant distinguishing parameters. Skewness also aids in defining some sample segregation.

Standard Deviation vs. Mean

Scatter plots of standard deviation versus mean separates Big Ridge and Desoto Ridge samples from Bayou Costapia Ridge and undifferentiated non-ridge samples (Figs. 13 and 14).

Area one (Figs. 13 and 14) containing Big Ridge and Destoto Ridge samples reflects coarser and better sorted sediments than area two (Bayou Costapia Ridge and non-ridge samples). Big Ridge samples appear to cluster within area one at both depths, Desoto Ridge samples tend to cluster in a slightly finer size grouping. Bayou Costapia Ridge samples also tend to cluster at the finest and poorest storted regions of area two and the non-ridge samples also tend to cluster between Bayou Costapia Ridge samples and the separation line. In area two more samples are needed to confirm the probable clustering.

Some overlap of samples does occur with the exception of some of the non-ridge samples the overlaps are at the separation line.

Both parameters appear to be affected by the samples. As sorting becomes poorer the mean size becomes finer. This tendancy is relected by the sample clustering - Big Ridge samples are the best sorted and coarsest; Desoto Ridge samples show a slightly finer sediment; and Bayou Costapia Ridge samples reflects the poorest sorting and finest mean size.

Standard Deviation vs. Skewness

Separation between samples is again noted in the scatter plots of standard deviation versus skewness (Fig. 15). Big Ridge and Desoto Ridge samples are separated from Bayou Costapia Ridge and undifferentiated non-ridge samples. In area one (Fig. 15A), Desoto Ridge samples tend to show a higher positive skewness than Big Ridge samples thereby showing a tendancy to cluster separately from Big Ridge samples. This same tendancy is also noted at 101-127 cms. depth (Fig. 15B).

In area two (Fig 15A and B) Bayou Costapia Ridge and non-ridge samples do not show a strong tendancy to cluster. Separation into areas one and two (Fig. 15) appear to be the result of sorting differences and further, Big Ridge and Desoto Ridge data are separated into groups due to differences in skewness.

There are minor amounts of overlap, however, the overlapping samples are very near the separation line.

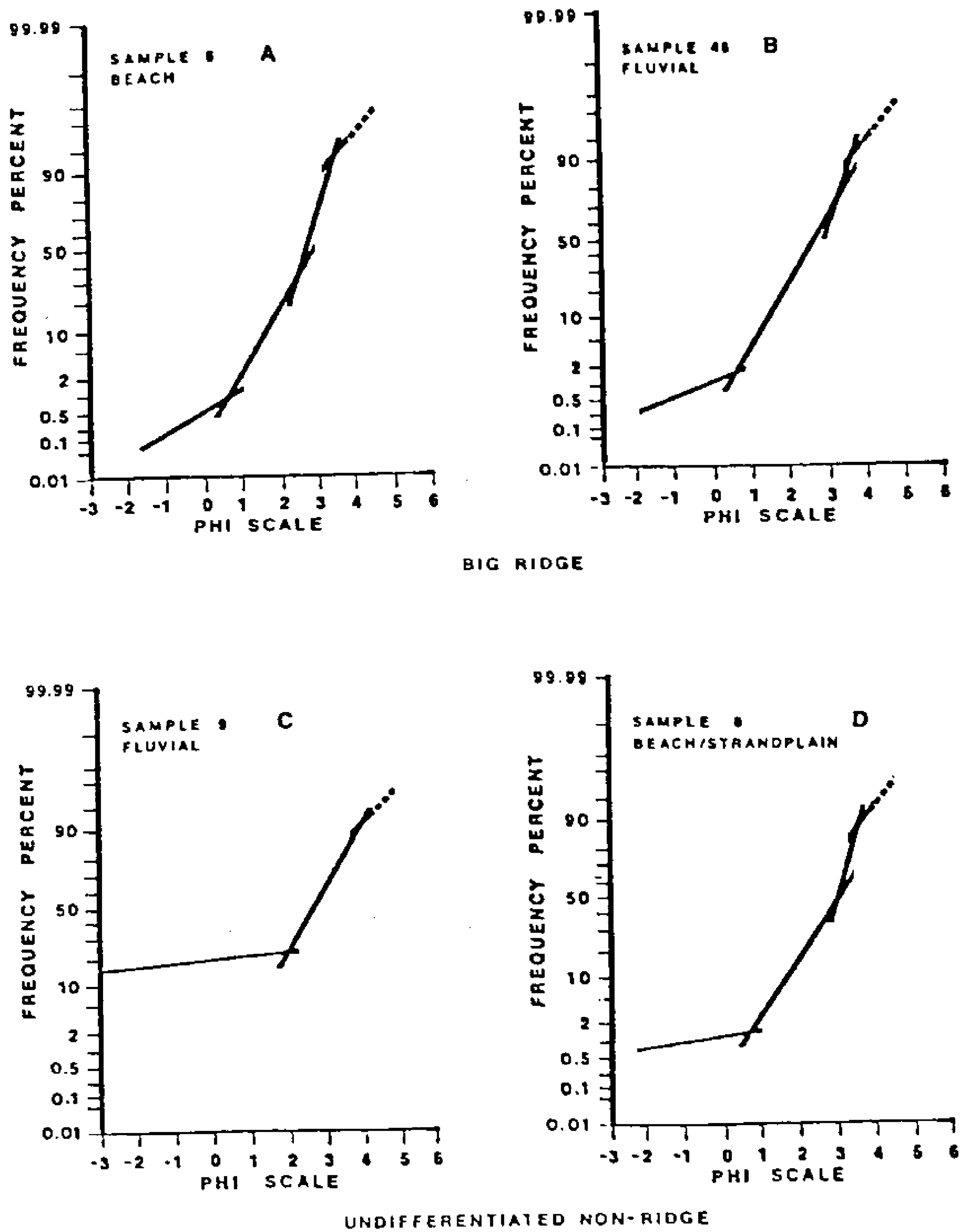


Figure 12. Representative plots of Big Ridge and undifferentiated non-ridge samples and their interpretative environments of deposition based upon Visher's (1969) method.

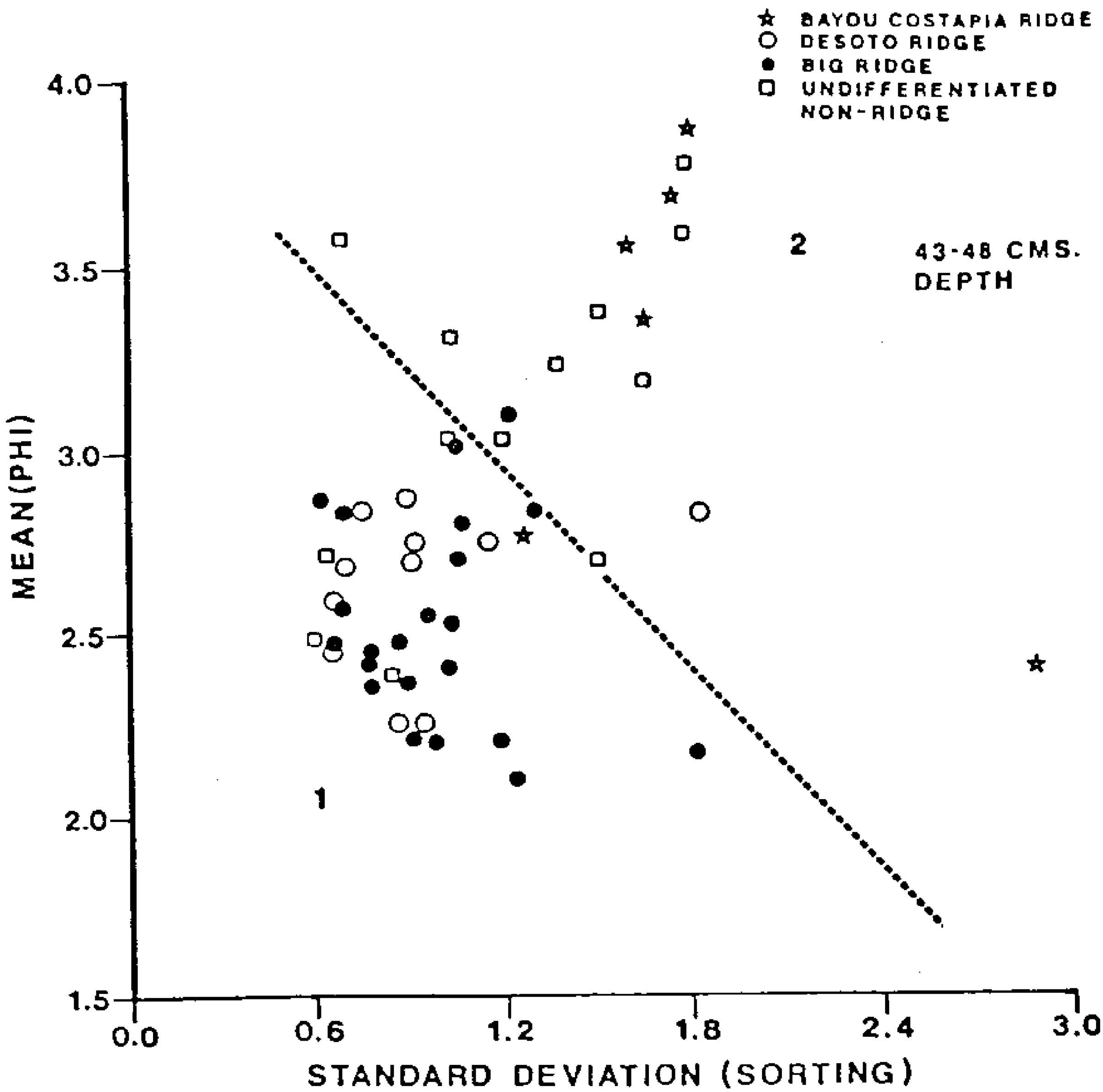


Figure 13. Scatter plot of standard deviation (sorting) vs. mean at 43-48 cms. depth. Area 1: Big Ridge and Desoto Ridge. Area 2: Bayou Costapia Ridge and undifferentiated non-ridge. Note that Big Ridge and Desoto Ridge tend to group separately in Area 1.

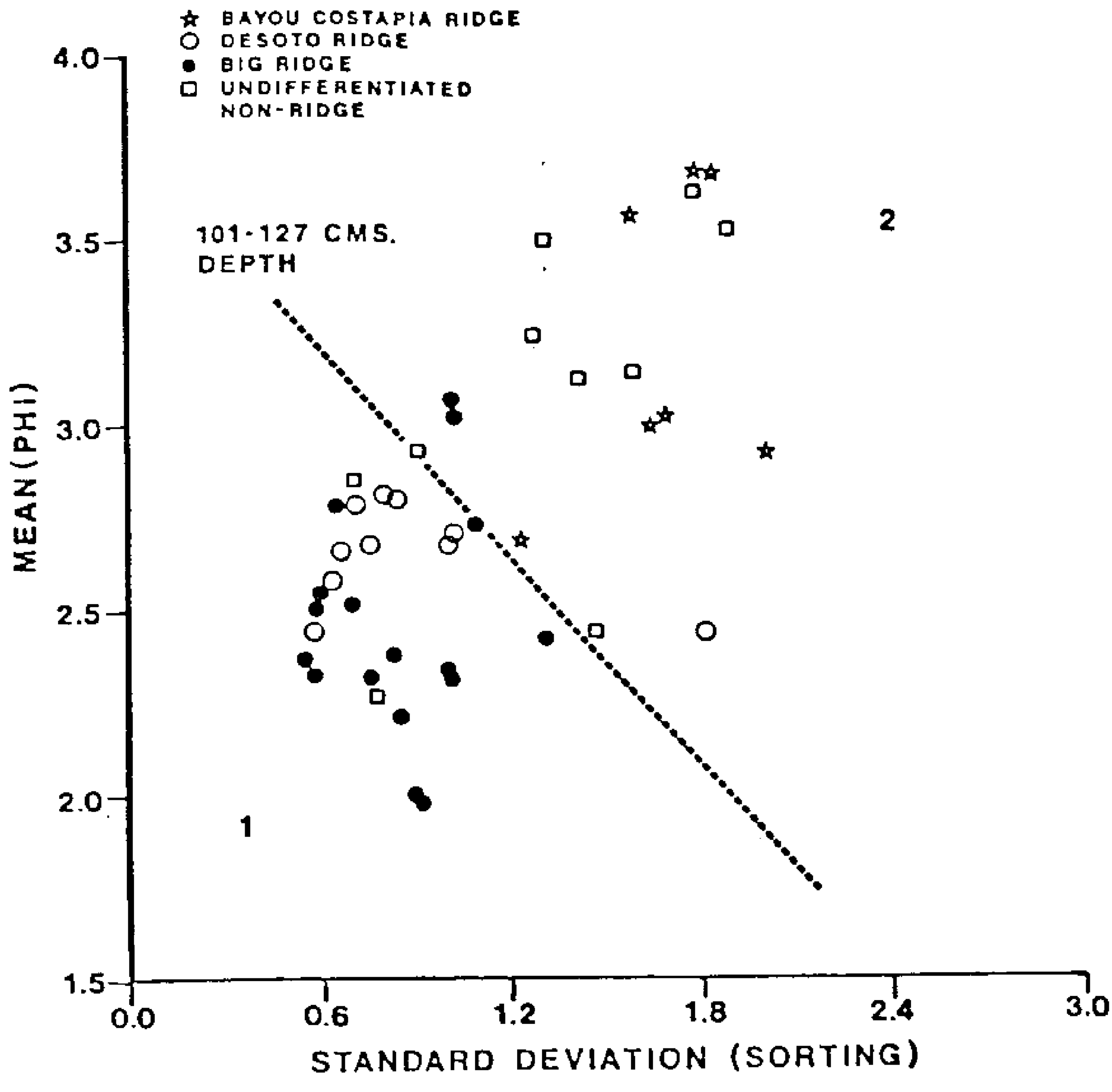


Figure 14. Scatter plot of standard deviation (sorting) vs. mean at 101-127 cms. depth. Area 1: Big Ridge and Desoto Ridge. Area 2: Bayou Costapia Ridge and undifferentiated non-ridge. Note tendancy for Big Ridge and Desoto Ridge to group separately in Area 1.

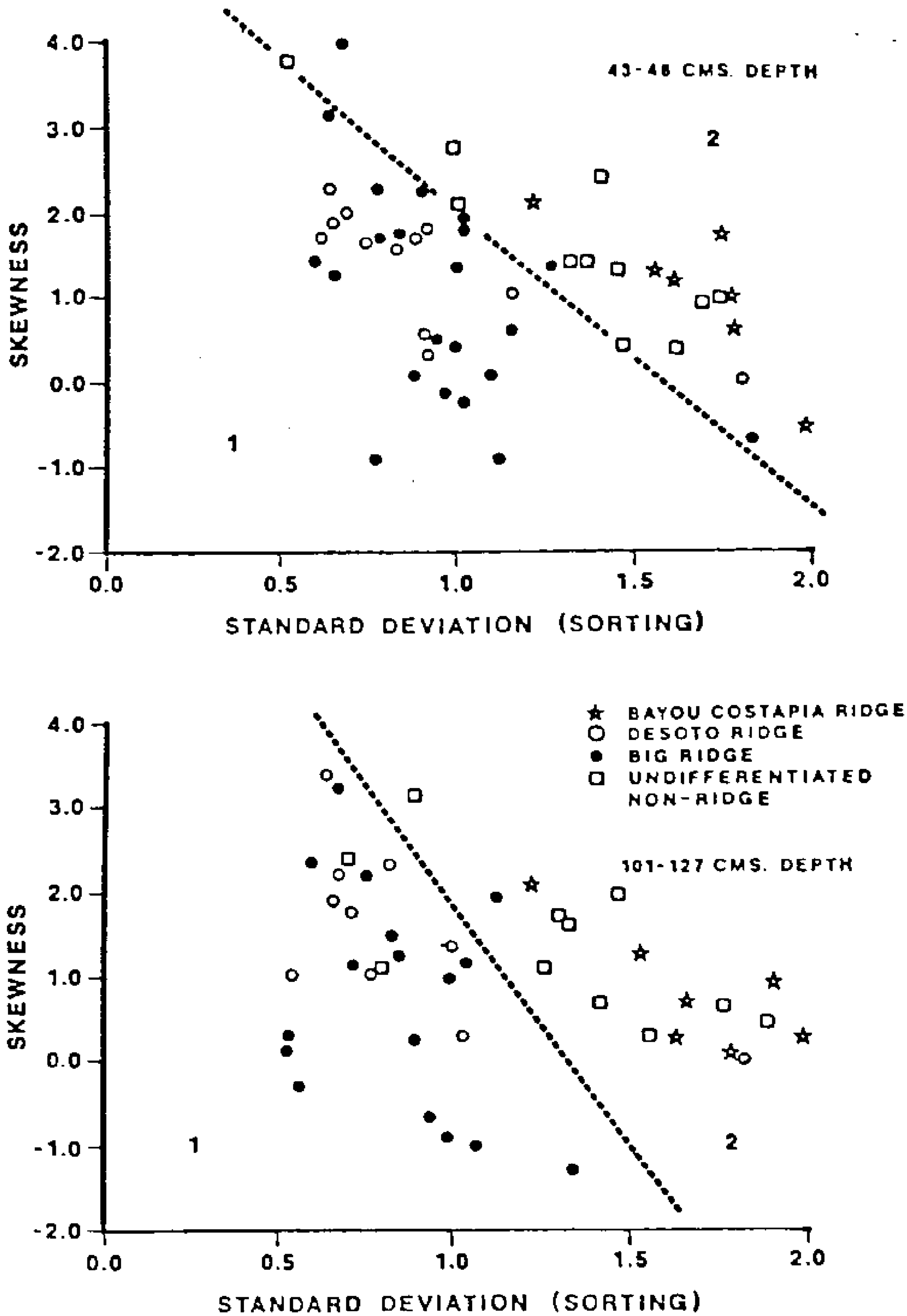


Figure 15. Scatter plots of standard deviation (sorting) vs. skewness. Area 1: Big Ridge and Desoto Ridge, note tendancy of Big Ridge and Desoto Ridge to group separately. Area 2: Bayou Costapia Ridge and undifferentiated non-ridge, note tendancy for Bayou Costapia Ridge to group.

Mean vs. Skewness

Scatter plots of mean versus skewness also show a separation of Big Ridge and Desoto Ridge samples from Bayou Costapia Ridge and undifferentiated non-ridge samples (Fig. 16A and B). At the shallower depth, three separate areas are noted. Big Ridge samples in area one show the coarsest sediments and have a tendancy to have small positive to negative skewness values. Desoto Ridge samples in area two tend to show a larger positive skewness value and a slightly finer mean size. Bayou Costapia Ridge and non-ridge samples are positively skewed and cover a wide range of means with the coarser mean sizes having the larger skewness values.

These tendancies are not reflected at 101-127 cms. depth (Fig. 16B). Bayou Costapia Ridge and non-ridge samples are separated from Big Ridge and Desoto Ridge samples along a line almost vertical at mean size of 2.90ϕ. Desoto Ridge samples are clustered along this line. Big Ridge samples show a wide range of skewness values while only ranging over a small mean size range. No tendencies are noted in area two except possibly with finer sizes the skewness values tend to be of a smaller range.

Overlapping of samples are few. The predominant factor appears to be the mean parameter in separating the ridges and non-ridge sediments.

Isopleth Maps of Statistical Parameters

Isopleth maps of mean grain size (Figs. 17 and 18) reveal three trends. Generally, the coarser mean grain sizes lie around the peripheries and western ends of the east-west oriented isopleths and areas of finer sizes lie within the central portions.

The northernmost isopleth patterns show a northeast-northwest arcuate trend in which grain size increases from 3.50ϕ to 2.00ϕ (fine/very fine to medium sand) from the center to the periphery and from the northeast to the northwest (Fig. 17). This northernmost pattern is more pronounced at 101-127 cms. depth (Fig. 18).

The central set of isopleth patterns are oriented in a southeast-northwest direction and exhibit a slightly arcuate trend (Figs. 17 and 18). The sediments are more uniform in the trend noted at 43-48 cms. depth (Fig. 17).

The third and southernmost isopleth patterns exhibit an east-west linear trend with relatively uniform (2.00ϕ to 300ϕ) mean grain sizes featured at both depths. At 101-127 cms. the trend is broken up into three sections for the 2.50ϕ means size.

The isopleth map of particle sorting (standard deviation) at 43-48 cms (Fig. 19) reveals three trends of very poorly to moderately well sorted sediments. The northernmost pattern of isopleths exhibits an arcuate, northeast to northwest oriented pattern of very poorly sorted to moderately sorted sediments.

A second or central set of isopleth patterns is noted but not as definite as the northernmost isopleth pattern. This pattern is oriented southeast to northwest (Fig 19) and shows a generally uniform moderately sorted sediment with poorer sorting located in a small area in the northwest. This central set of isopleth patterns is separated from a third, southernmost isopleth pattern by an area of very poor sorting. The southernmost set of isopleth patterns is an east-west oriented feature of moderately to moderately-well sorted sediments. Except in the east, the sorting appears to be uniform.

At 101-127 cms. (Fig. 20), three similar trends occur in the same areas as described in figure 19. However, the sorting is better overall and the distinction of the trends is more apparent. The sediment sorting becomes better around the peripheries of the trends. In the area just south of where the Tchoutacabouffa River turns westward is an area of very poorly sorted sediments.

Isopleth maps of percent sand suggest three trends (Figs. 21 and 22). The three trends are well developed at both depths.

The northernmost isopleth pattern at 43-48 cms. (Fig. 21) shows an increase in percent sand from 40 to 70 percent followed by a decrease in percent sand. This pattern is oriented in a northeast to northwest arcuate fashion. At 101-127 cms. (Fig. 22), the same pattern exists - a northeast to northwest trending set of isopleths with an increase in percent sand from the northeast to northwest (40 to 80 percent). Separating the northernmost and central set of isopleth patterns are areas of lower (50 percent) percent sand.

The central set of isopleths show an increase in percent sand towards the central portions from 60 to 70 percent (Fig. 21) and 60 to 90 percent (Fig. 22). The orientation is east to northwest. Noteable differences can be seen in the northwest area. At 101-127 cms. there is an area of high (90 percent) percent sand and at 43-48 cms. (Fig. 21) there is an area of much lower percent sand in the same location.

Separating these patterns from the more gulfward patterns is an area of lower percent sand. The southernmost pattern is an eastwest linear feature of 60 to 90 percent sand (Fig. 21). At 101-127 cms. (Fig. 22), there are two areas of high percent sand with a much lower precent sand gap. The western end shows a high percent sand build up at both depths.

RESULTS

Bayou Costapia Ridge, Desoto Ridge, and Big Ridge are delineated on topographic maps as northeast-northwest, southeast-northwest, and east-west trending features, respectively. These ridges as further evidenced by black and white aerial photographs reflect coastal morphologies. Bayou Costapia Ridge appears as a recurved spit; Desoto Ridge as a barrier ridge complex and Big Ridge as a barrier-spit complex. Sedimentologic analysis further supports these morphological interpretations.

Bayou Costapia Ridge is composed of yellow-brown, poorly sorted, silty sand. The sand is predominantly angular to well-rounded quartz.

Isopleth maps (Figs. 17-22) indicate the growth of Bayou Costapia Ridge in a westward coarsening, better sorted and increasingly higher sand percent fashion. Statistical inferences based upon Visher's (1969) method support the coastal environmental interpretation of the sediments (Fig. 11 and Table 9). However, Friedman's (1967) statistical inferences do not indicate a beach interpretation. This may be due to the overall fine nature of the sediments and proximity to source.

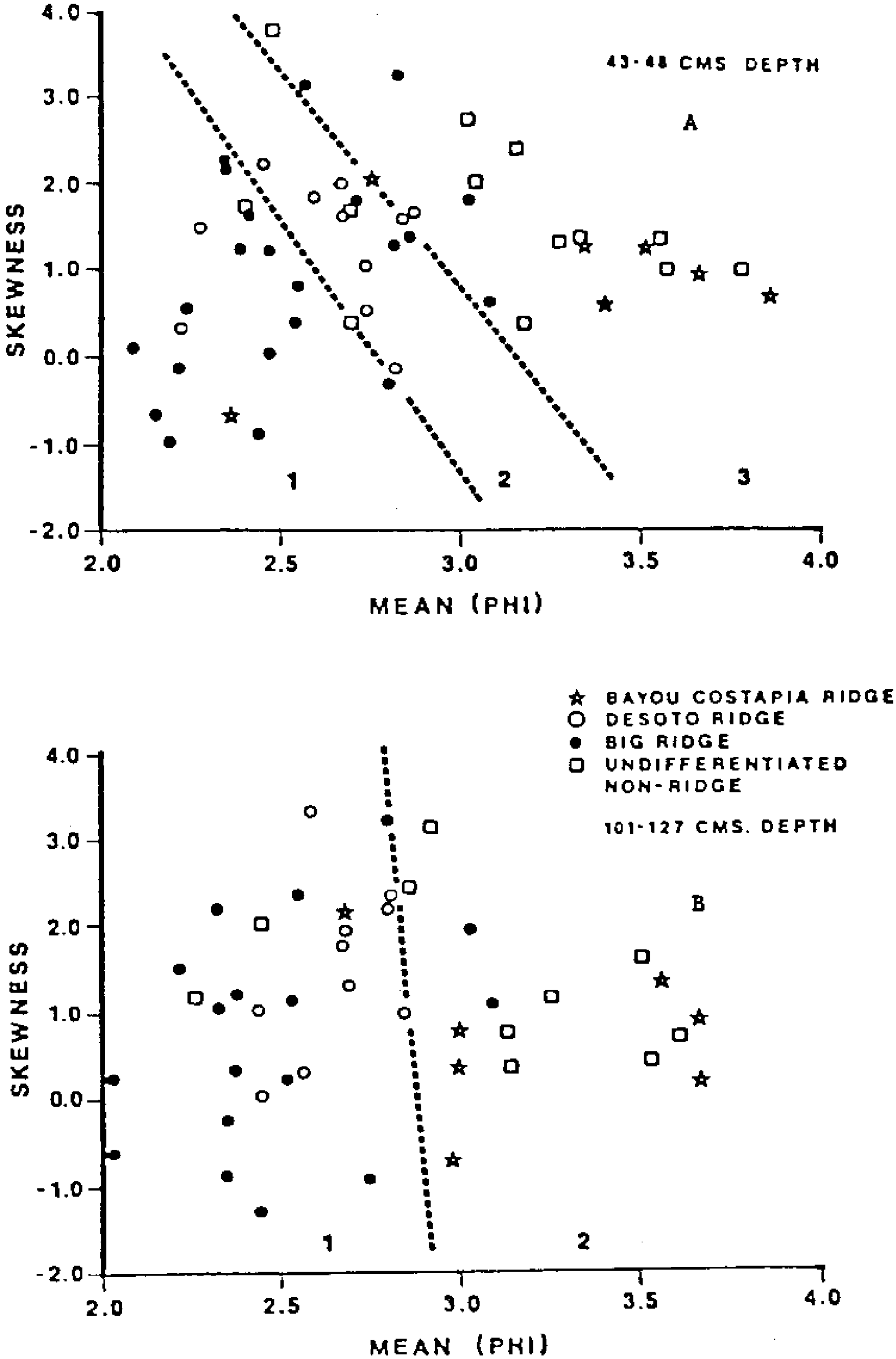


Figure 16. Scatter plots of mean vs. skewness. Plot A: Area 1 - Big Ridge; Area 2 - Desoto Ridge; Area 3 - Bayou Costapia Ridge and undifferentiated non-ridge. Plot B: Area 1 - Big Ridge and Desoto Ridge, note tendancy for Big Ridge and Desoto Ridge to group; Area 2 - Bayou Costapia and undifferentiated non-ridge.

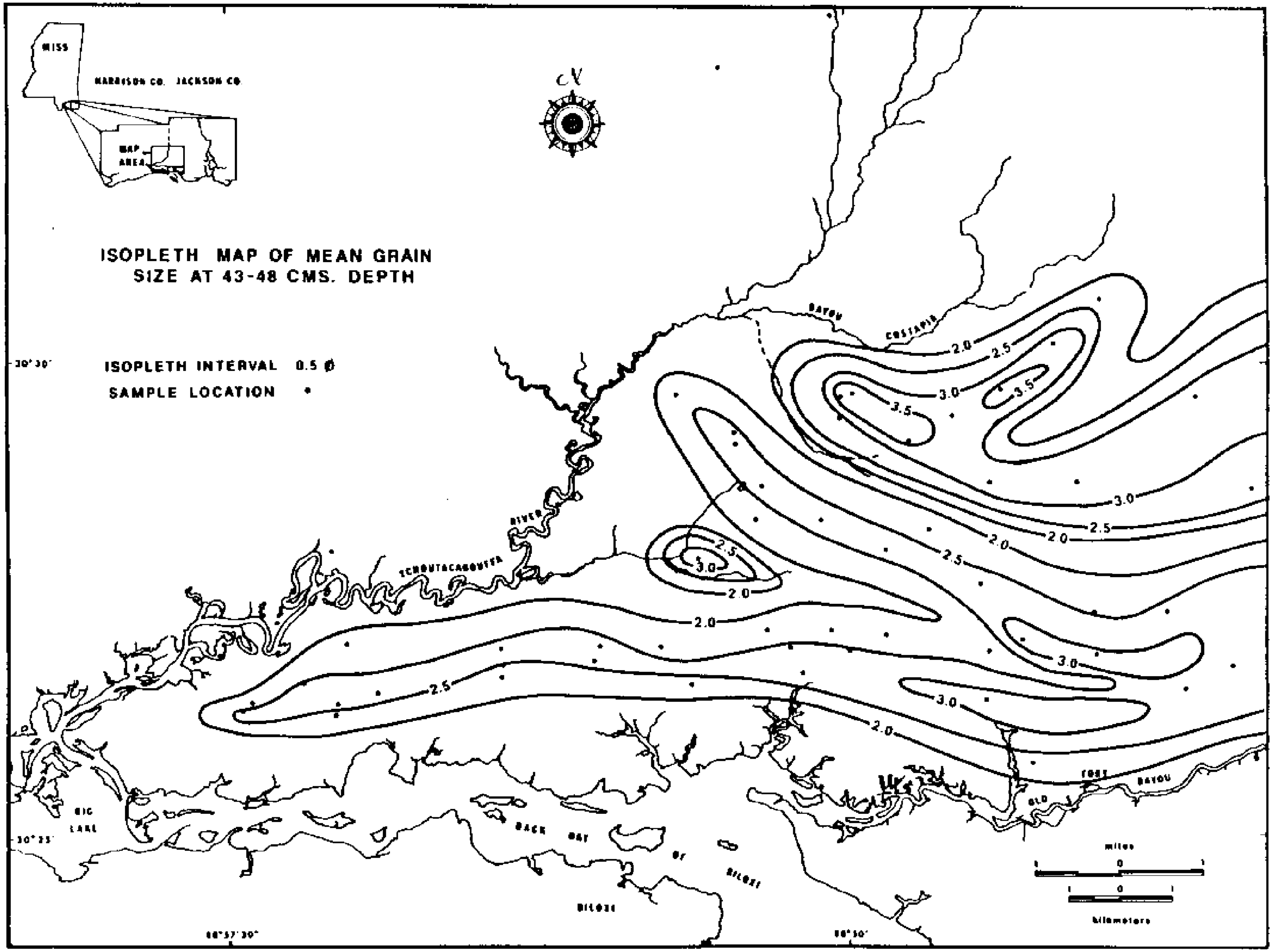


Figure 17. Isopleth map of mean grain size at 43-48 cms. depth depicting three patterns of westerly coarsening sediments.

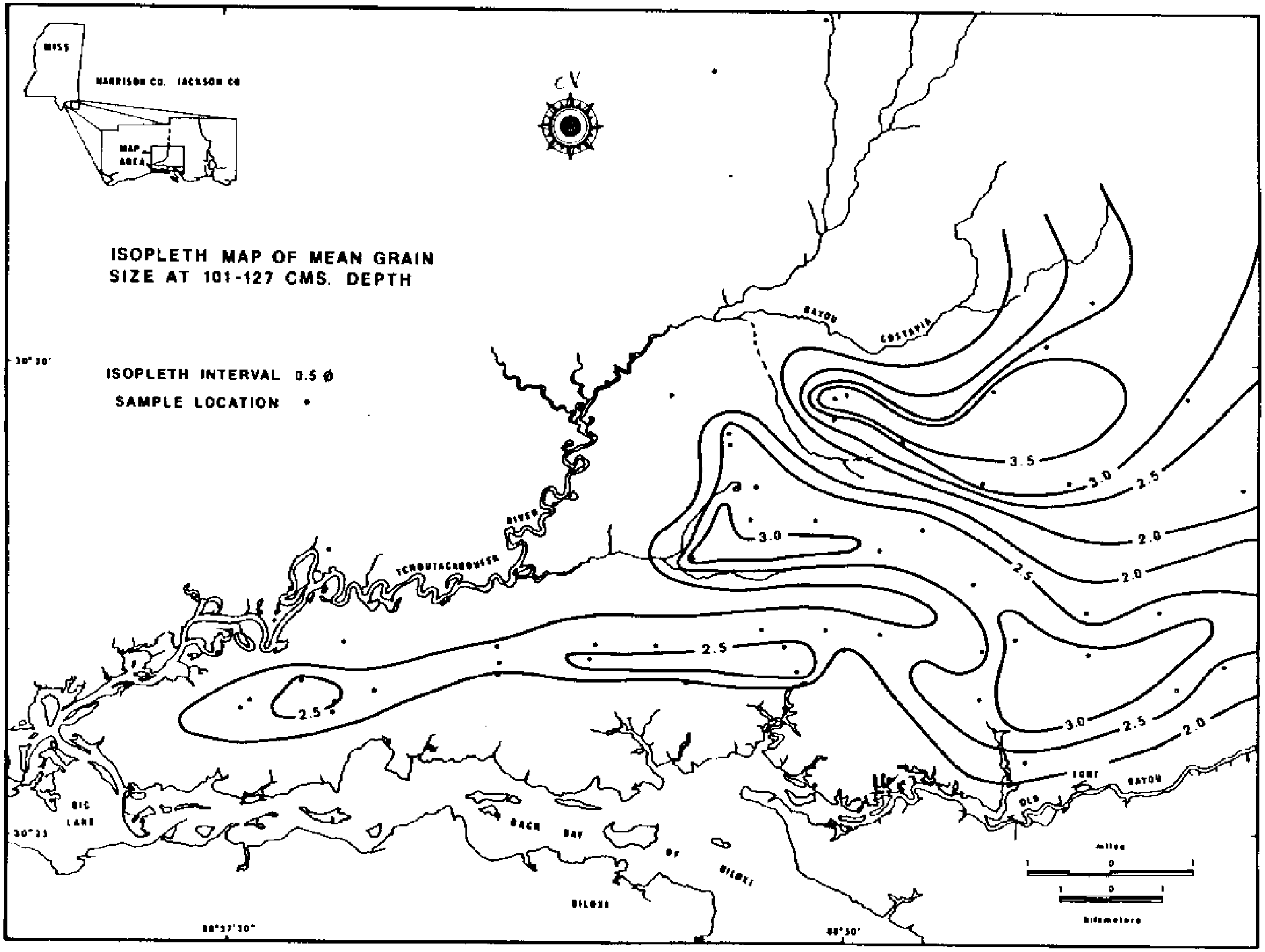


Figure 18. Isopleth map of mean grain size at 101-127 cms. depth depicting three patterns.

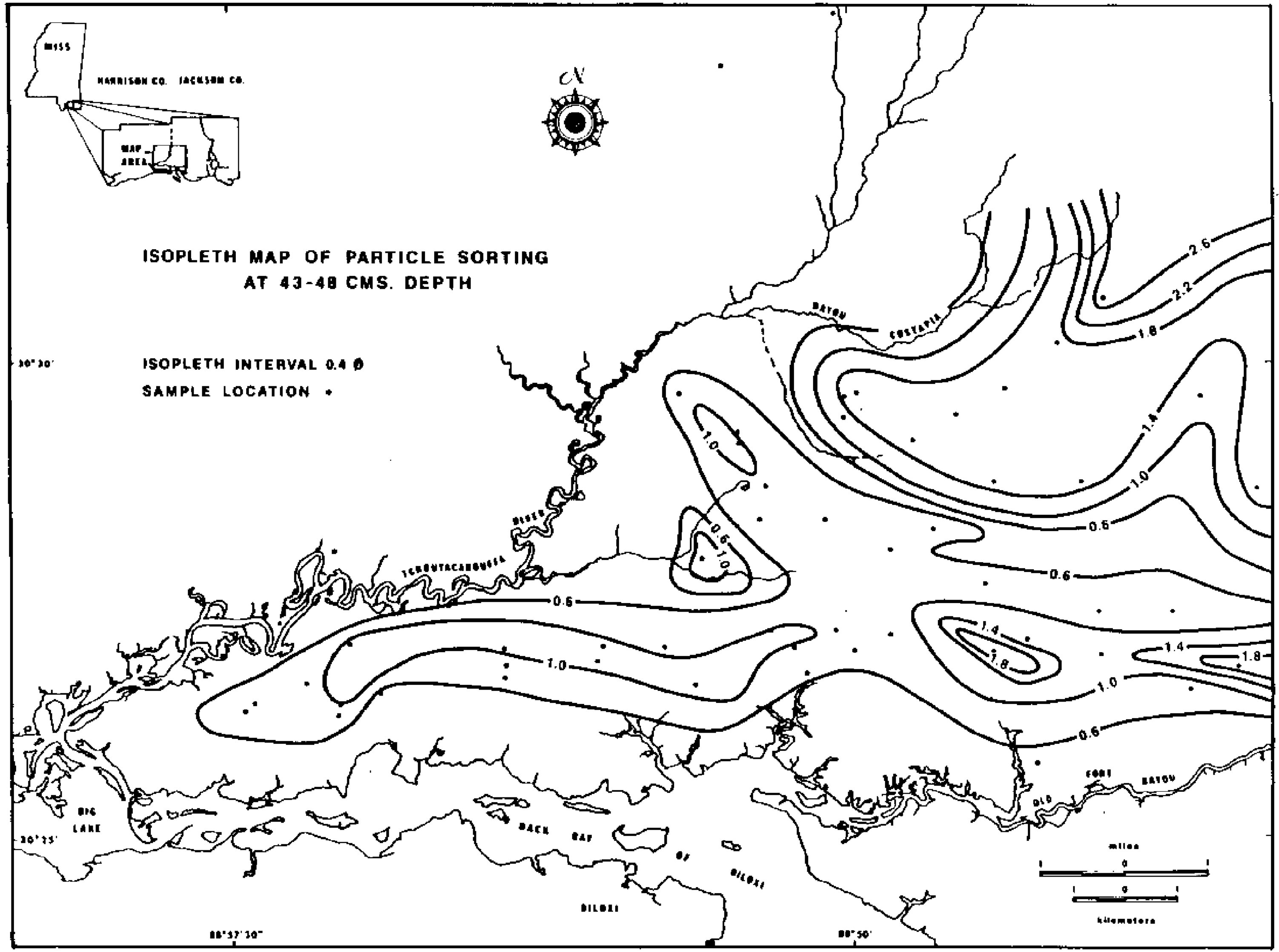


Figure 19. Isopleth map of particle sorting (standard deviation) at 43-48 cms. depth indicating three patterns of poor to moderate sorting.

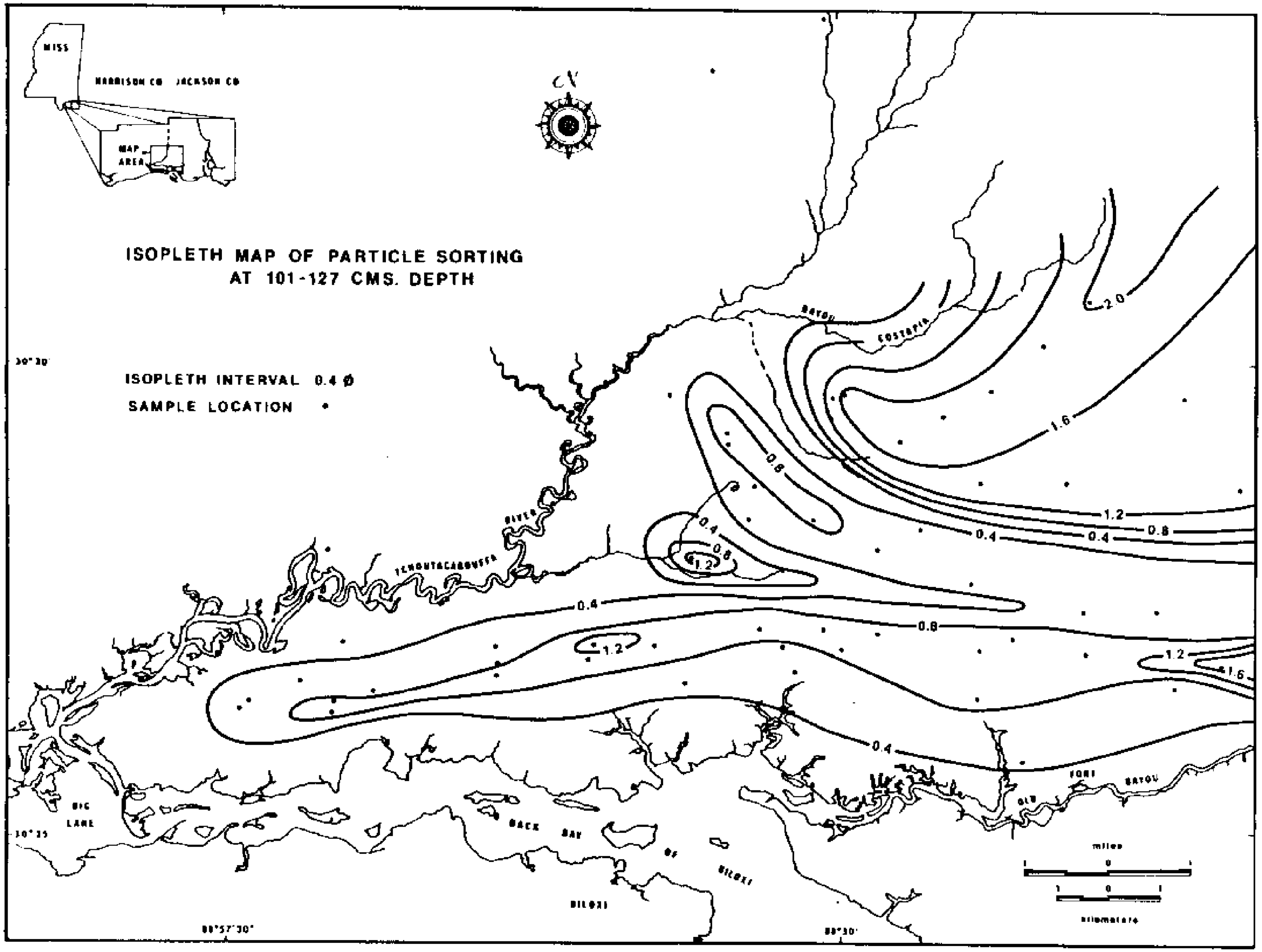


Figure 20. Isopleth map of particle sorting (standard deviation) at 101-127 cms. depth indicating three patterns of poor to moderately well sorting. Note the area of poor sorting south of the Tchoutacabouffa River's westward deflection.

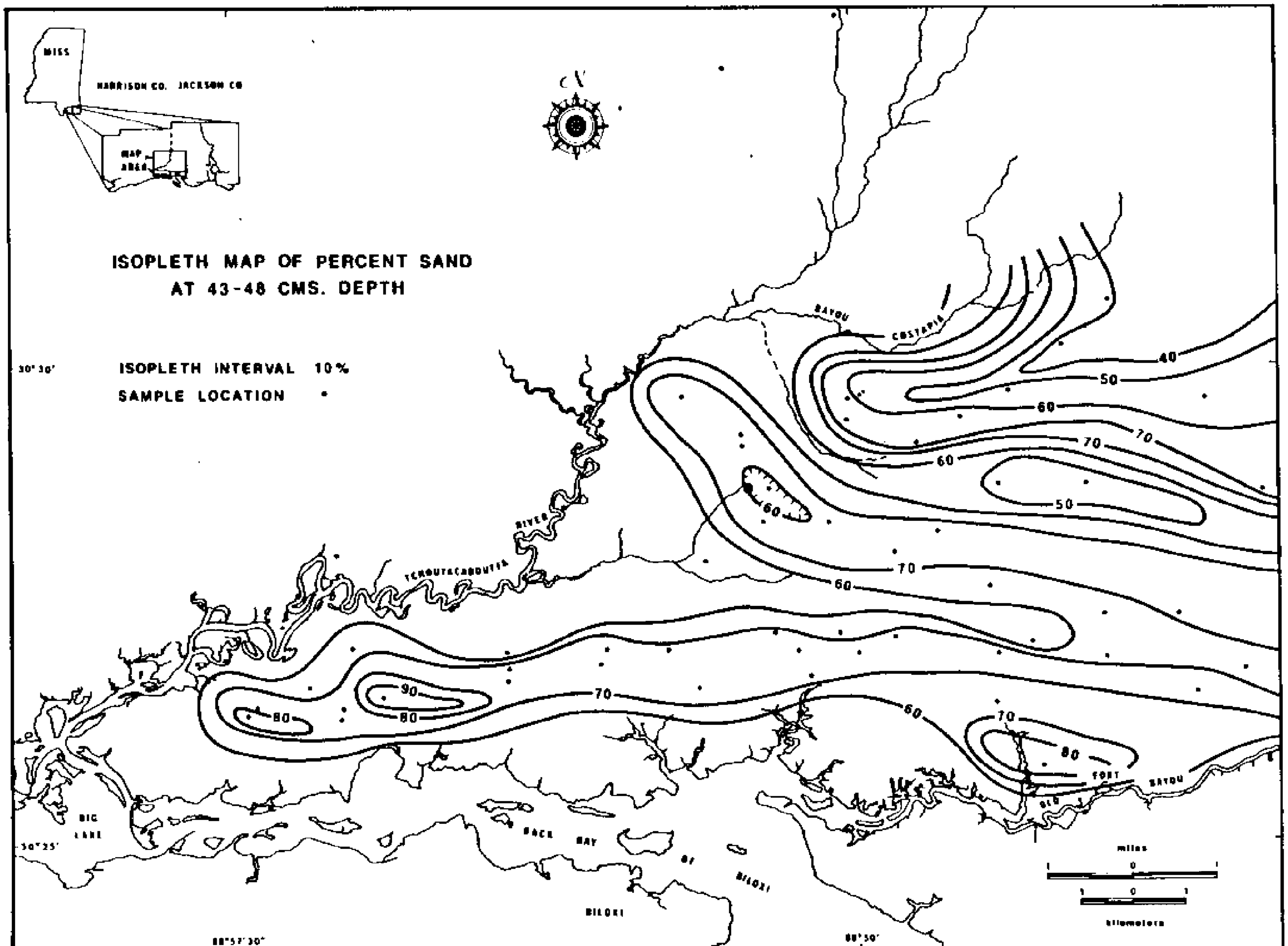


Figure 21. Isopleth map of percent sand at 43-48 cms. depth indicating three patterns of increasing sand.

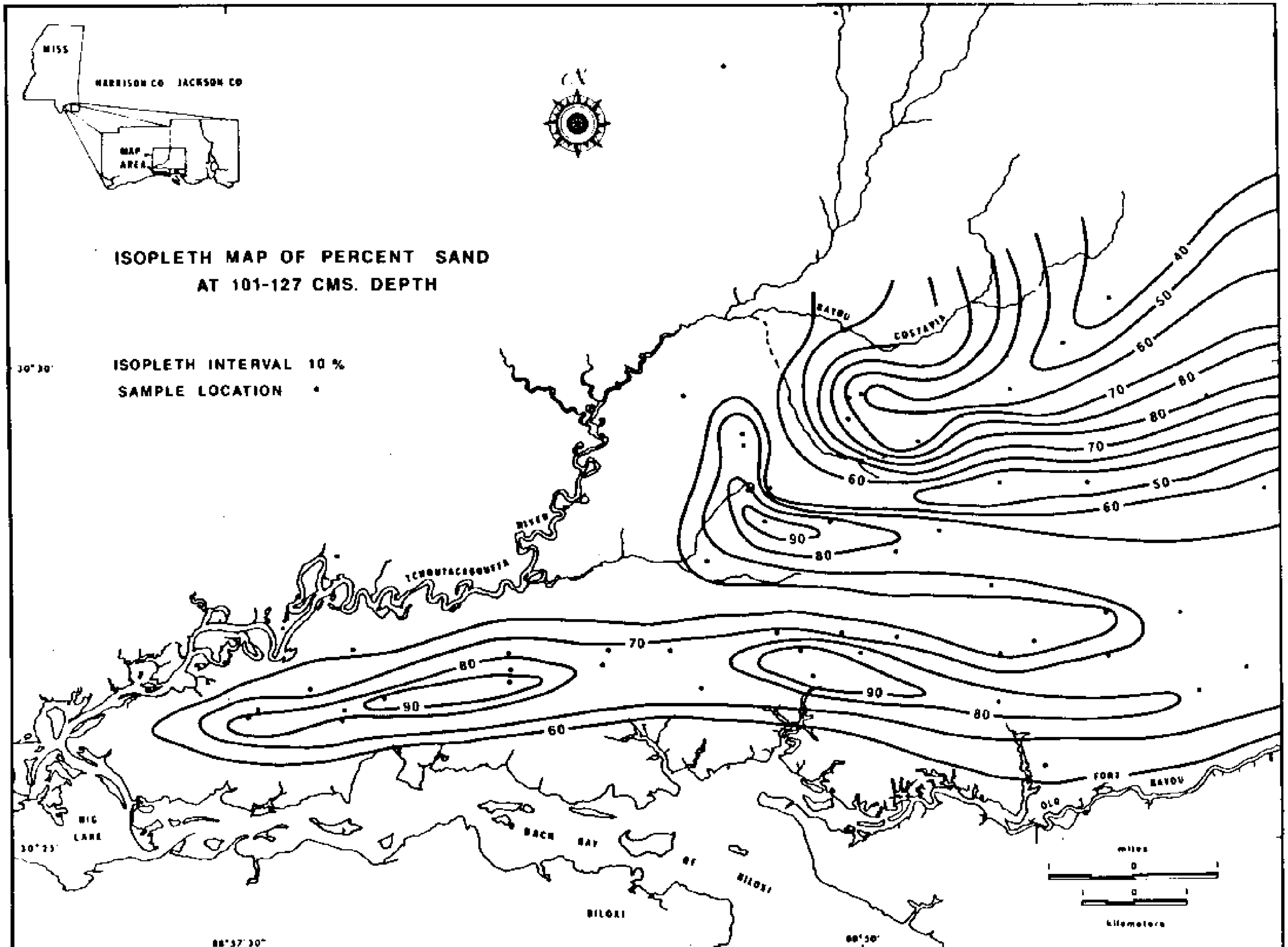


Figure 22. Isopleth map of percent sand at 101-127 cms. depth indicating three patterns of increasing sand. Note on the southernmost pattern two areas of high sand percent with a low sand percent gap.

The only structures noted were red-orange mottling near the surface, which may indicate post depositional weathering.

Drainage of Bayou Costapia stream (Fig. 5) parallels the Bayou Costapia Ridge until the drainage, deflected by the curved spit, takes a more northwestward flow direction.

To the south of Bayou Costapia spit, and separated by a topographically low area, is a curvilinear barrier ridge complex, Desoto Ridge. Topographic and aerial photographic analysis delineates this feature as a series of multiple subparallel ridges in the southeast which coalesce into a single ridge towards the northwest. A tidal delta-like feature is delineated at the northwest end (Figs. 5 and 6) of Desoto Ridge.

Moderately well sorted fine silty sand sediments are found along the periphery of this ridge while the interior portions are moderately sorted, finer and sandier sediments (Figs. 17-22).

Composition of these sands is angular to well-rounded quartz with minor amounts of heavy meinerals. At site 1 (Fig. 2), contorted bedding and wavy/lenticular bedding structures are found indicating foreshore or tidal flat environments (Reineck and Singh, 1975) in front of Desoto Ridge.

Statistical inferences indicate a dune/beach environment for the sediments. These samples cluster in the beach area of the scatter plots (Figs. 13-16) and are interpreted as beach or dune sands (Fig. 11 and Table 9).

Beach and dune build up in the northwest is reflected by the northward shift in drainage of the Perigal Creek and the westward flow of the Tchoutacabouffa River (Figs. 5 and 6).

At a lower elevation (7 m.) a spit-like barrier ridge complex is defined by topographic and aerial photographic analysis (Figs. 5 and 6). This ridge complex denoted as Big Ridge has a series of ridge and swale features at the eastern end in front of Desoto Ridge. These ridge and swale-like features coalesce into a single coastal subparallel spit-like barrier ridge. Aerial photographic trends (Fig. 6) give evidence for the linear ridge and recurved pull-out appearance of Big Ridge.

Sedimentary structure sequences reflect the build up pattern of Big Ridge. The contorted and lenticular beddings at site I are overlain by a structureless white sand unit and a mottled unit. Further west a borrowed dark gray clay unit with lenticular bedding is also overlain by a white sand unit (site 29). Site 47 has a vertical sequence of low angle southward dipping cross beds and ripples overlying a greenish-brown burrowed sand unit. This would indicate sand units prograding over foreshore, tidal flat type sediments.

Overall composition of these sediments is an angular to well-rounded quartzose, moderately to moderately well sorted, medium to fine silty sand.

Beach, dune, and fluvial environments are inferred by statistical analysis. Scatter plots also reveal a beach type enviornment for the sediments (Figs. 13-16).

Trellis drainage patterns indicative of ridge and swale topography are on the south side of Big Ridge (Fig. 9). The westward build up is also reflected by the drainage pattern changes. The Tchoutacabouffa River is deflected westward almost at a 90^{o} angle, however, sorting and sand percents (Figs. 19-22) indicate areas where the Tchoutacabouffa River probably continued southward bisecting Big Ridge until sediment build up forced the westward deflection.

Economic Implication

Potential resources of the area north of Back Bay of Biloxi appear to be limited to two sources - heavy minerals and sand. The gravel deposits are sparse and limited to the northern border of the study area.

Tentative heavy mineral analysis (Table 8, appendix) revealed no obvious trends which would indicate potential concentrations. A slightly higher percentage of heavy minerals was noted in the eastern portions of the ridges. Also, field observations noted a high concentration of heavy minerals in a clean white fine sand unit in a quarry (site 47) on Big Ridge. Therefore the area near site 47 on Big Ridge present the best areas for further study or potential exploitation for heavy minerals. These are limitations for these areas. Urban development is very prominent on Big Ridge and in the eastern portion of the area is the Mississippi Sandhill Crane National Wildlife Refuge.

The most promising resource appears to be the fine sand sediments found on Desoto Ridge and Big Ridge. The sediments are moderately to moderately well sorted (standard deviation range: 0.528ϕ-1.817ϕ) and fine to very fine sands (mean phi range: 1.986ϕ-3.107ϕ). Areas of best potential are located in the northwestern portion of Desoto Ridge and in the central and western portions of Big Ridge. These areas are composed of the highest sand percents for the two ridges (Fig. 22). Limitation on potential exploitation is the urban development on Big Ridge.

Field reconnaissance noted several clay pits northwest of the Tchoutacabouffa River, however, no surface or shallow subsurface clay deposits were noted in the study area except at site 29. The area northwest of the Tchoutacabouffa River appears as the best area for clay.

CONCLUSIONS

North of Back Bay of Biloxi in western Jackson and eastern Harrison Counties, Mississippi, topographic and aerial photographic analysis reveal three subparallel coastal features which resemble: 1) a spit; 2) a barrier ridge; and 3) a spit-barrier ridge complex. Sedimentologic analysis and geostatistical inferences reveal beach, dune, tidal channel and fluvial sediments on these morphological features. This combined analysis indicated an origin of coastal marine processes for the three ridges.

Bayou Costapia Ridge is the northernmost feature and is the oldest. Desoto Ridge is just south of Bayou Costapia Ridge and both ridges are delineated by the 50 foot (15 m.) contour line. Further south and at a lower elevation (25 foot (7 m.) contour line), Big Ridge is delineated and reflects a younger age.

Deposition of the alluvial-fluvial Citronelle Formation occurred during a low sea level stand during Plio/Pleistocene time and was subjected to reworking during the subsequent submergence.

During this submergence, Bayou Costapia Ridge developed in response to longshore current reworking of the Citronelle sediments. This spit grew laterally towards the west and terminated in a recurved pull-out. Penecontemporaneously, an offshore barrier bar began forming just south of Bayou Costapia Ridge. The presence of this sand bar dampened the effects of incoming waves on Bayou Costapia Ridge which would account for the fineness of the sediments.

As sea level lowered, the offshore bar system became exposed and developed into a barrier ridge system (Desoto Ridge). The sediments from Desoto Ridge indicate beach and dune environments (Table 9, appendix). The beach ridges and dunes of Desoto Ridge were developed by longshore currents which transported the sediments, by incoming refracted waves which built up the ridge, and by aeolian forces which formed the dunes. Sediments were transported in by longshore currents from the east (possibly from the Pascagoula Bay area) and from the estuary-like area to the north of Desoto Ridge (Fig. 5).

A small lagoon formed between Desoto Ridge and Bayou Costapia Ridge (Fig. 5). This lagoon drained east, west and through a probable outlet at the north end of Desoto Ridge.

The elevation of Desoto Ridge (15 m. (50 feet)) reflects a Talbot shoreline. With renewed lowering of the sea reflected by the lower Pamlico coastal features, a spit-barrier ridge (Big Ridge) formed in front of Desoto Ridge parallel to the present coast.

The east end of Big Ridge consists of a series of ridges and swales which coalesce into a westward building spit. The beach and dune sands were brought in from the east and were reworked into the ridges by incoming waves. Further west a barrier ridge of beach and dune sands is separated from the spit by the estuary-like drainage and noted by poorly sorted, low percent sand fluvial sediments (Figs. 19, 20, and 22 and Table 9). As sea level lowering continued the spit and barrier ridge coalesced. This connecting deflected the drainage towards the west.

Shortly afterwards another set of ridges and swales (Mississippi City Barrier Complex, McAuliffe, et al. 1980) developed in front of and parallel to Big Ridge.

Associated with the development of Big Ridge was an uplift of the land resulting in a steeper gulfward scarp-like face of Big Ridge. The Tchoutacabouffa River shifted northward as evidenced by the relict meanders, oxbow lakes and non-encroachment of the north side of Big Ridge (Figs. 4 and 9). Also, increased drainage dissected the eastern portion of Desoto Ridge.

Therefore, the three ridges found in western Jackson and eastern Harrision counties, Mississippi as delineated by U.S.G.S. topographic maps and black and white aerial photographs represent coastal morphologies (spit, barrier ridge and spit-barrier ridge complex) which developed on a regressive-transgressive coast and are described by sedimentologic analysis.

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APPENDIX

CORING METHOD

The coring equipment consists of five-foot and ten-foot, two-inch diameter PVC pipes, a 2 x 6 inch board, a number 11 rubber stopper, and a water supply. The coring method consists of driving the pipe into the ground using the board until strong resistance is encountered, then the remaining portion of the pipe is filled with water. The rubber stopper caps the end, creating a vacuum. The pipe is pulled out, the vacuum released, and the core is removed and stored in a core box (Shier and Oaks, Jr., 1966).

LABORATORY METHODS

Pretreatment

Laboratory analysis of each sample was based on techniques in Carver (1971). Preparations began with drying the samples either in the open air or in the oven at 40° C. After drying, the samples were very gently disaggregated. Care was taken to prevent any breaking of grains. Next, a split of the sample was made using a Fischer Scientific Co. Splitter. The entire sample was continuously split until about 70-80 grams was obtained. Ingram (1971) suggests 25-50 grams for fine sand in order not to overload the sieves. After wet sieving, the sand size weight averaged 52 grams.

Wet Sieving

The sample was dispersed in a beaker containing approximately 500 ml. of distilled water and 50 ml. of dispersant. The dispersant was 0.1 M solution of 0.005 M Sodium Bicarbonate and 0.005 M. Sodium Oxalate (Galehouse, 1971). After five to ten minutes of agitation, the sample was washed through a 4.00 phi (ϕ) sieve screen (0.062 mm., no. 230 U.S. Standard mesh). This procedure insured a cleaner sand fraction and aided the disaggregation of the total sample.

The greater than 4.00ϕ sand fraction was dried at 70° C. and allowed to come to equilibrium with room temperature and weighed. The less than 4.00ϕ silt/clay fraction was dried at 40° C. and allowed to come to equilibrium with the room and weighed.

Dry Sieving

The sand fraction was sieved at 0.25ϕ intervals for 20 minutes on the Ro-Tap Mechanical Shaker. The fractions were weighed and stored for future analysis. Sieve gain/loss error ranged from 0.00 to 2.22 percent.

Pipette

The silt/clay fraction was split into five gram fractions for pipetting. The room temperature was monitored for 12 hours to check temperature constancy. Times for withdrawals were based on a temperature of 23° C. and calculations were based on Stoke's and Waddell's formulas found in Galehouse (1971). The five gram sample was placed in a 1000 ml. cylinder containing 950 ml. of distilled water and 50 ml. of dispersant. A waiting period of 12 hours was allowed to determine if any flocculation would occur. Only the initial 4.00ϕ and 8.00ϕ withdrawals were needed as silt and clay percentages were to be determined. Care was taken to insure no contamination of the aliquots occurred. The aliquots were then dried at 40° C. and allowed to come to room temperature and humidity before weighing to the nearest 0.001 gram.

Heavy Mineral Separation

Procedure for separation of heavy and light minerals was based on techniques of Royse (1970) with some modifications in the amount of sample and centrifuge time and speed. The advantage of this method was that a large number of samples could be separated in a short period of time.

The mean phi size fraction of selected samples was divided into 5.00 gram splits. Each split was mixed in a 50 ml. centrifuge tube containing tetrabromoethane (specific gravity of 2.963 at 20° C.) and centrifuged at 3000 rpms for 10 minutes. The tubes were then placed in an acetone-dry ice bath until the lower portion containing the heavy mineral fraction was frozen. The upper portion containing the light mineral fraction was poured into a labelled funnel with filter paper. The lower portion was allowed to thaw and poured into a labelled funnel with filter paper. After the tetrabromoethane drained, the fractions were rinsed with acetone and dried.

The light and heavy mineral fractions were weighed to the nearest 0.001 gram and percentages of each calculated. Both fractions were set aside for furture mineralogic analysis.

Table 1. Gulf Coast eustatic sea level correlations with East Coast equivalent terminology. Sea level determinations by various workers are given in meters (feet).

		COOKE, 1935	BROWN et al., 1944	CARLSTON, 1950	COLQUHOUN, 1974	HOYT AND HAILS, 1974	WINKER AND HOWARD, 1977	PELLEGRIN, 1978	McAULIFFE, et. al. 1980	WILLETTS et al., 1980
PLEISTOCENE	PLIO/PLEISTOCENE			60-64 m. (190-210')						
	SUNDERLAND	58 m. (170')								
	WICOMICO	30 m. (100')			33 m; (110')	29-30 m. (95-100')				
	PENHOLOWAY	21 m. (70')	12.8 m. (42')		21 m. (70')	21-22 m. (70-75')				
	TALBOT	12.8 m. (42')			12.1 m. (40')	12.1-13.7m. (40-45')		9 m. (30')		12-15 m. (40-50')
	PAMLICO	7.6 m. (25')	12.8 m. (42')		7.6 m. (25')	7 m. (24')	10 m. (33')	6 m. (20')	7.6 m. (25')	6-9 m. (20-30')
	PRINCESS ANNE							3.6 m. (12')		
	SILVER BLUFF									

Table 2: Sample site locations.

Sample Site	Location	Elevation (meter/feet)
1	NW1/4, SE1/4, Sec 11, T7S, R8W	14.1 m. (47')
2	NW1/4, SE1/4, Sec 35, T6S, R8W	9.0 m. (39')
3	SW1/4, NW1/4, Sec 26, T6S, R8W	13.5 m. (45')
4	NE1/4, NE1/4, Sec 10, T7S, R8W	15.0 m. (50')
5	SW1/4, SW1/4, Sec 11, T7S, R8W	13.8 m. (46')
6	NW1/4, SW1/4, Sec 10, T7S, R8W	12.0 m. (40')
7	NE1/4, NE1/4, Sec 9, T7S, R8W	15.0 m. (50')
8	SW1/4, NE1/4, Sec 33, T6S, R8W	10.8 m. (36')
9	SE1/4, SW1/4, Sec 14, T6S, R8W	21.0 m. (70')
10	NW1/4, SE1/4, Sec 21, T6S, R8W	21.0 m. (70')
11	SW1/4, NW1/4, Sec 9, T7S, R8W	12.9 m. (43')
12	NW1/4, SW1/4, Sec 16, T7S, R8W	6.0 m. (20')
13	NW1/4, NE1/4, Sec 17, T7S, R8W	6.9 m. (23')
14	NW1/4, SE1/4, Sec 8, T7S, R8W	9.0 m. (30')
15	NW1/4, SE1/4, Sec 5, T7S, R8W	15.6 m. (52')
16	SW1/4, NE1/4, Sec 3, T6S, R8W	11.4 m. (38')
17	SE1/4, NE1/4, Sec 29, T6S, R8W	17.1 m. (57')
18	NE1/4, SW1/4, Sec 29, T6S, R8W	17.1 m. (57')
19	SE1/4, SE1/4, Sec 31, T6S, R8W	12.0 m. (40')
20	SE1/4, SE1/4, Sec 30, T6S, R8W	13.8 m. (46')
21	SW1/4, NE1/4, Sec 6, T7S, R8W	15.6 m. (52')
22	SW1/4, SE1/4, Sec 30, T6S, R8W	15.3 m. (51')
23	SE1/4, NE1/4, Sec 25, T6S, R9W	14.1 m. (47')
24	SE1/4, NE1/4, Sec 25, T6S, R9W	13.5 m. (45')
25	NE1/4, SE1/4, Sec 25, T6S, R9W	15.3 m. (51')
26	SW1/4, SE1/4, Sec 36, T6S, R9W	15.0 m. (50')
27	SE1/4, NE1/4, Sec 12, T7S, R9W	13.8 m. (46')
28	SE1/4, NW1/4, Sec 7, T7S, R8W	9.9 m. (33')
29	SW1/4, SE1/4, Sec 12, T7S, R9W	4.5 m. (15')
30	NE1/4, SW1/4, Sec 12, T7S, R9W	8.1 m. (27')
31	SE1/4, NW1/4, Sec 12, T7S, R9W	12.9 m. (43')
32	SW1/4, SW1/4, Sec 36, T6S, R9W	14.4 m. (48')
33	NE1/4, SE1/4, Sec 35, T6S, R9W	15.9 m. (53')
34	NE1/4, NE1/4, Sec 4, T6S, R9W	9.1 m. (30')
35	NW1/4, SE1/4, Sec 5, T6S, R9W	18.9 m. (63')
36	NW1/4, NE1/4, Sec 35, T6S, R9W	16.5 m. (55')
37	NW1/4, NE1/4, Sec 35, T6S, R9W	15.0 m. (50')
38	NE1/4, NW1/4, Sec 14, T7S, R9W	4.2 m. (14')
39	NW1/4, SW1/4, Sec 11, T7S, R9W	12.0 m. (40')
40	SW1/4, SW1/4, Sec 2, T7S, R9W	9.3 m. (31')
41	SE1/4, NE1/4, Sec 27, T6S, R9W	15.0 m. (50')
42	NW1/4, SW1/4, Sec 10, T7S, R9W	12.3 m. (41')
43	NE1/4, SE1/4, Sec 9, T7S, R9W	9.0 m. (30')
44	SW1/4, SW1/4, Sec 8, T7S, R9W	9.9 m. (33')
45	SW1/4, SW1/4, Sec 8, T7S, R10W	12.9 m. (43')
46	SW1/4, NW1/4, Sec 8, T7S, R10W	10.5 m. (35')
47	NE1/4, NW1/4, Sec 8, T7S, R10W	13.5 m. (45')
48	SW1/4, NW1/4, Sec 10, T7S, R10W	7.2 m. (24')
49	SW1/4, NW1/4, Sec 18, T7S, R10W	8.4 m. (28')
50	SW1/4, NW1/4, Sec 7, T7S, R10W	11.1 m. (37')
51	NE1/4, SE1/4, Sec 1, T7S, R10W	2.1 m. (7')
52	SW1/4, SE1/4, Sec 12, T7S, R10W	15.3 m. (51')
53	NW1/4, NW1/4, Sec 13, T7S, R10W	16.2 m. (54')
54	NW1/4, NW1/4, Sec 13, T7S, R10W	15.6 m. (52')

Table 3: Flight numbers and dates of the black and white aerial photographs.

Flight Number	Photo Frame	Date
CZK 9H	60 to 69	12-16-52
CZK 9H	76 to 82	02-08-52
CZK 9H	146 to 154	12-16-52
CZK 9H	182 to 183	01-03-53
CZK 10H	104 to 110	12-12-52
CZJ 5V	127 to 132	01-16-58
CZJ 5V	144 to 149	01-16-58
CZJ 5Y	208 to 213	01-16-58

Table 4: Sand-silt-clay percentages.

Sample number	Sand percent	Silt percent	Clay percent
4A	76.98	20.37	2.65
4B	89.16	9.00	1.84
5A	74.83	22.40	2.77
5B	79.73	17.03	3.24
8A	49.50	44.19	6.31
8B	48.65	45.70	5.65
9A	42.18	45.10	12.72
9B	37.53	37.48	24.99
12B	85.66	6.11	8.23
15A	62.54	29.37	7.81
15B	69.54	28.33	2.13
17A	52.58	35.57	11.85
17B	58.61	29.39	12.00
19A	72.89	24.94	2.17
19B	73.82	23.95	2.23
22A	62.04	29.23	8.73
22B	65.06	26.21	8.73
25A	66.07	25.28	8.65
25B	75.42	18.19	6.39
26A	71.56	27.16	1.28
26B	85.05	13.08	1.87
28B	81.51	15.72	2.77
30A	75.64	22.64	2.07
30C	94.52	3.52	1.96
33A	55.11	42.42	2.47
33B	50.78	48.24	0.98
35A	54.36	31.26	14.38
35B	58.21	28.21	13.58
36A	73.38	22.76	3.86
36B	75.51	21.43	3.06
42A	70.83	26.25	2.92
42B	73.48	22.01	4.51
45A	73.43	23.38	3.19
45B	88.19	11.40	0.41

Table 5: Formulas for geostatistical calculations. (After Friedman, 1961)

Mean: $\bar{x}_\phi = \frac{\Sigma f m_\phi}{N}$

Standard Deviation: $s_\phi = \frac{\Sigma f(m - \bar{x}_\phi)^2}{N}$

Skewness: $Sk_\phi = \frac{\Sigma f(m - \bar{x}_\phi)^3}{N s_\phi^3}$

Kurtosis: $K_\phi = \frac{\Sigma f(m - \bar{x}_\phi)^4}{N s_\phi^4}$

f = fraction weight percent
m = midpoint of fraction size interval
N = 100

Table 6: Descriptive statistical values of the analyzed samples at 43-48 cms. depth.

Sample Number	Mean	Standard Deviation	Skewness	Kurtosis
1	2.822	1.817	- 0.015	5.952
2	2.688	1.466	0.407	6.932
3	3.303	1.097	2.048	8.770
4	2.842	0.756	1.612	17.143
5	2.817	0.689	3.299	22.591
6	3.016	1.091	1.861	9.539
7	2.445	0.645	2.258	21.773
8	3.336	1.467	1.288	4.970
9	2.377	2.868	- 0.617	2.984
10	3.389	1.770	0.583	4.521
11	3.107	1.189	0.543	9.663
12	2.487	0.578	3.848	29.991
13	3.010	1.002	2.707	12.090
14	2.145	1.807	- 0.673	5.191
15	2.669	0.715	2.002	19.585
16	3.165	1.626	0.394	5.764
17	3.676	1.766	0.945	2.825
18	3.345	1.621	1.217	4.030
19	2.386	0.849	1.710	12.022
20	2.405	0.778	1.700	14.580
21	2.586	0.644	1.874	23.201
22	3.588	1.733	0.920	3.259
23	3.866	1.750	0.684	3.084
24	3.557	1.586	1.267	3.868
25	2.761	1.235	2.068	8.286
26	2.742	0.903	0.570	16.542
27	2.336	0.885	2.198	13.677
28				
29	2.703	0.632	1.731	18.271
30	2.529	0.957	0.831	7.843
31	2.365	1.000	1.289	9.128
32	2.212	0.931	0.367	7.069
33	2.866	0.886	1.674	14.678
34				
35	3.780	1.752	0.902	2.790
36	2.672	0.891	1.695	11.194
37	2.741	1.175	1.010	8.944
38	2.079	1.224	0.098	8.990
39	2.187	0.970	- 0.142	10.260
40	3.263	1.332	1.347	6.364
41	2.266	0.816	1.553	10.673
42	2.691	1.031	1.816	10.357
43	2.788	1.061	- 0.272	9.447
44	2.205	0.914	0.591	11.812
45	2.333	0.771	2.262	15.927
46	2.819	1.291	1.324	7.042
47	2.850	0.604	1.415	21.488
48	2.477	0.867	0.046	11.558
49	2.514	1.001	0.399	11.759
50	2.188	1.154	- 0.945	10.762
51	3.562	1.376	1.343	5.460
52	2.562	0.662	3.105	23.581
53	2.430	0.773	- 0.892	26.407
54	2.461	0.645	1.237	18.079

Samples without data were not analyzed.

Table 7: Descriptive statistical values of the analyzed samples at 101-127 cms. depth.

Sample Number	Mean	Standard Deviation	Skewness	Kurtosis
1	2.441	1.796	0.024	4.964
2	2.443	1.458	0.207	6.152
3				
4	2.794	0.693	2.240	17.897
5	2.783	0.666	3.224	23.407
6	3.015	1.141	1.978	8.707
7	2.439	0.569	1.022	18.731
8	3.127	1.407	0.756	6.805
9	2.915	2.003	- 0.720	5.590
10	3.009	1.661	0.768	4.715
11	3.088	1.021	1.178	10.911
12				
13	2.913	0.880	3.184	15.709
14				
15	2.663	0.663	1.985	20.165
16	3.132	1.567	0.383	6.354
17	3.657	1.811	0.893	2.765
18	2.997	1.616	0.333	6.617
19	2.264	0.765	1.184	10.048
20	2.372	0.818	1.232	14.757
21	2.589	0.640	3.379	25.161
22	3.511	1.888	0.458	3.747
23	3.670	1.780	0.194	4.635
24	3.567	1.565	1.362	3.778
25	2.686	1.220	2.184	8.749
26	2.797	0.826	2.385	15.980
27	2.207	0.832	1.509	14.037
28	1.986	0.880	0.235	6.286
29	2.845	0.691	2.439	18.513
30	2.522	0.704	1.135	13.140
31	2.311	0.990	1.047	9.001
32	2.673	0.736	1.805	17.262
33	2.829	0.785	1.028	17.088
34				
35	3.613	1.763	0.721	3.517
36	2.677	1.005	1.384	11.457
37	2.568	1.088	0.334	10.905
38				
39				
40	3.252	1.291	1.193	7.642
41				
42	2.418	1.322	- 1.283	11.837
43	2.733	1.076	- 0.919	10.485
44	1.986	0.905	- 0.615	16.813
45	2.305	0.754	2.216	16.254
46				
47	2.338	0.575	- 0.225	8.558
48	2.333	0.955	- 0.851	12.608
49				
50				
51	3.504	1.304	1.641	5.392
52	2.544	0.600	2.356	22.341
53	2.365	0.528	0.318	9.291
54	2.503	0.581	0.266	10.638

Samples without data were not analyzed.

Table 8: Percentages of light and heavy minerals.

Sample Number	Percent Light Minerals	Percent Heavy Minerals
4B	98.41	1.59
5B	99.37	0.63
8B	99.48	0.52
9B	98.38	1.62
12B	99.57	0.43
15B	99.59	0.41
17B	98.84	1.16
19B	99.58	0.42
22B	98.00	2.00
25B	99.54	0.46
26B	99.12	0.88
28B	99.84	0.16
30C	99.93	0.07
33B	99.86	0.14
35B	98.73	1.27
36B	99.92	0.08
42B	99.96	0.04
45B	99.80	0.20
47C	99.80	0.20
51B	99.55	0.45
53C	99.91	0.09

Table 9: Interpretations of the sample probability plots. (Based upon Visher's (1969) method)

Sample Site	43-48 cms.	101-127 cms.
Bayou Costapia Ridge		
17	dune	dune
18	beach, wave zone	wave zone
23	beach, tidal channel	beach
24	wave zone	
25	tidal channel, beach	tidal channel, beach
Desoto Ridge		
1	beach	beach
4	dune, beach	dune, beach
7	dune	dune
15	dune, beach	dune, beach
21	dune, shoal area	dune, shoal area
26	dune, plunge zone, beach	dune plunge zone
32	beach	beach
33	beach	beach
36	dune, beach	beach, dune
37	beach, plunge zone	beach, dune
41	dune	
Undifferentiated non-ridge		
2	beach	beach
3	beach, tidal channel	
8	beach, tidal channel, strandplain	beach tidal channel, strandplain
12	beach, tidal channel, wave zone	
13	fluvial, plunge zone	fluvial, plunge zone
16	tidal channel, fluvial, beach	
19	channel sands, dune	channel sands
22	plunge zone	plunge zone
29	dune, beach	dune, beach
34	fluvial	
35	plunge zone, fluvial	fluvial
40	tidal channel	tidal channel
51	fluvial	
Big Ridge		
5	beach	
6	beach	beach
11	beach, tidal channel	beach, tidal channel
14	tidal channel, fluvial	
20	dune, beach	dune, beach
27	tidal channel, beach, dune	dune, fluvial
28		beach, plunge zone
31	dune, beach	dune, tidal inlet, beach
38	tidal channel, beach, plunge zone	

Sample Site	43-48 cms.	101-127 cms.
39	shoal area, plunge zone, beach	
42	fluvial, tidal channel	fluvial
43	tidal channel, beach	tidal channel, beach
44	fluvial, beach, shoal area	plunge zone
45	beach, dune, wave zone, plunge zone	beach, dune
46	fluvial, tidal channel	
48	beach, dune	beach, dune
49	beach, fluvial, wave zone	
50	beach, dune	
52	dune, fluvial	dune, fluvial
53	dune	dune, beach
54	dune, beach	dune, beach