

FLORIDA STATE UNIVERSITY

SEDIMENTS OF THE TEN THOUSAND ISLANDS

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fulfillment of the requirements for
the degree of Master of Science.

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INTRODUCTION

Purpose

Much of the marine interest on the Gulf Coast tends to center on the study of the shallow water environs where there are many lagoons, bays, and inlets of great importance to fishing, recreation, navigation, and many other activities. Each of these presents its own particular problems, and extensive investigations have been carried on in many of them, especially those of the Northwest Gulf (Shepard, 1961).

The study of modern sediments has become one of the major research fields in marine geology. The main reason for this is that the geologist has come to realize that much knowledge can be gained by these studies to help in interpretation of the paleogeography of a region. This is based on the premise that the physical and chemical factors acting in the modern environment have been constant throughout geologic history.

The specific objectives of this paper are (1) to explain the distribution of the sediments in terms of the environments and the agents of their distribution, (2) to suggest criteria for recognition of equivalent ancient sediments as aids to paleogeographic interpretations,

(3) to establish a theory of formation of the Ten Thousand Islands, and (4) to attempt to determine the relationship of the sedimentary characteristics to their environment.

Location and Description

The area of investigation is located along the Gulf Coast between Chatham Bend and Gullivan Bay in Collier County, Florida. The center of the area is located on the intersection of $26^{\circ} 50'$ latitude and $81^{\circ} 30'$ longitude. The Ten Thousand Islands occupy an area of approximately one hundred and ten square miles.

Natural geographic boundaries defined the study area. The Gulf of Mexico is the westward limit; the mangrove swamp proper is the eastward. In the north the Blackwater River marks the boundary, whereas the Lopas River is the southern limit of the study area.

The entire area is a low-lying coastal region with many tidal inlets, rivers, bays, lagoons, and small to large shoal water islands. This area is the most topographically dissected coastal region in Florida, and it is this dissected appearance which separates the Ten Thousand Islands from the rest of the southwest coast of Florida.

Climate

The climatic data were obtained from records of the

United States Weather Bureau at Everglades City. The Ten Thousand Islands are located in the zone of tropical climate. The average annual precipitation is 52.82 inches. The wet season (May to October) has an average total precipitation of 42.69 inches, with a mean of 7.11 inches per month. The dry season (November to April) has an average total precipitation of 10.14 inches, with a mean per month of 1.50 inches. The mean annual temperature of the region is 75.3 degrees with an average of 82 in the wet season and 67.2 in the dry season. The lowest temperature ever recorded in the area was 24 degrees.

The wind is predominantly from the east, offshore. During the dry season the winds vary with equal percentage from the northeast and the southeast, whereas 6 percent of the time they are light and variable. Winds during the wet season are predominantly from the southeast, while 19 percent of the time they are variable.

Previous Investigations

Davis (1940), in his work on the ecology of the mangroves of southern Florida, included a small section on the mangroves of the Ten Thousand Islands. His work was mostly concerned with the distribution and types of mangroves present, but he devoted a section to the geologic role of these plants. This was a general discussion of the action of the mangrove roots as sediment traps,

rather than a treatment of any specific region. A study was made of the hydrology of this region by Dragovich, Finucane, and May (1956) as a part of the investigation of the Red Tide organisms.

An investigation of sediments similar to those described herein was carried out by Van Andel et al (1954) in the Gulf of Paria, Venezuela. Van Andel's work included a section on the mangrove environment of the Gulf. This is the only environmental study, similar to the present investigation, known to the author.

GEOLOGICAL SETTING

General

The Ten Thousand Islands lie on the southwestern fringe of the Big Cypress Swamp. Northwest of the Islands is the Cape Romano barrier spit, which lies at the southern end of a series of straight beaches extending north nearly 180 miles. The barrier spit was probably built by a combination of storm waves and longshore drift.

Extending south from the Cape are the Cape Romano Shoals. These shoals, which mark the southern extremity of the longshore drift on the western Florida Coast, extend approximately nine miles into the Gulf of Mexico (fig. 1). Between the shoals and the Ten Thousand Islands is a triangular shelf, averaging about nine feet in depth.

The shoreline becomes increasingly dissected north of Cape Sable, reaching maximum complexity in the Ten Thousand Islands. South of the islands the coast is broken only by tidal channels and in the northern section near the islands by an outer line of islets and small peninsulas. Three to eight miles inland from the coast, there is a zone of interconnected lagoons and channels, roughly parallel to the outer coast. Between the lagoons and channels there is a mangrove barrier. Davis (1940) showed that the height of the barrier should be a function of the tidal range, the slope of the bottom and the topography of the adjacent land surface across which the mangrove belt originally spread.

The entire coast south of the Cape Romano barrier spit is composed of mangrove swamp and lagoons except for the sandy beaches of Cape Romano itself, some small islands on the outer edge of the Ten Thousand Islands, and the sandy beaches of Cape Sable.

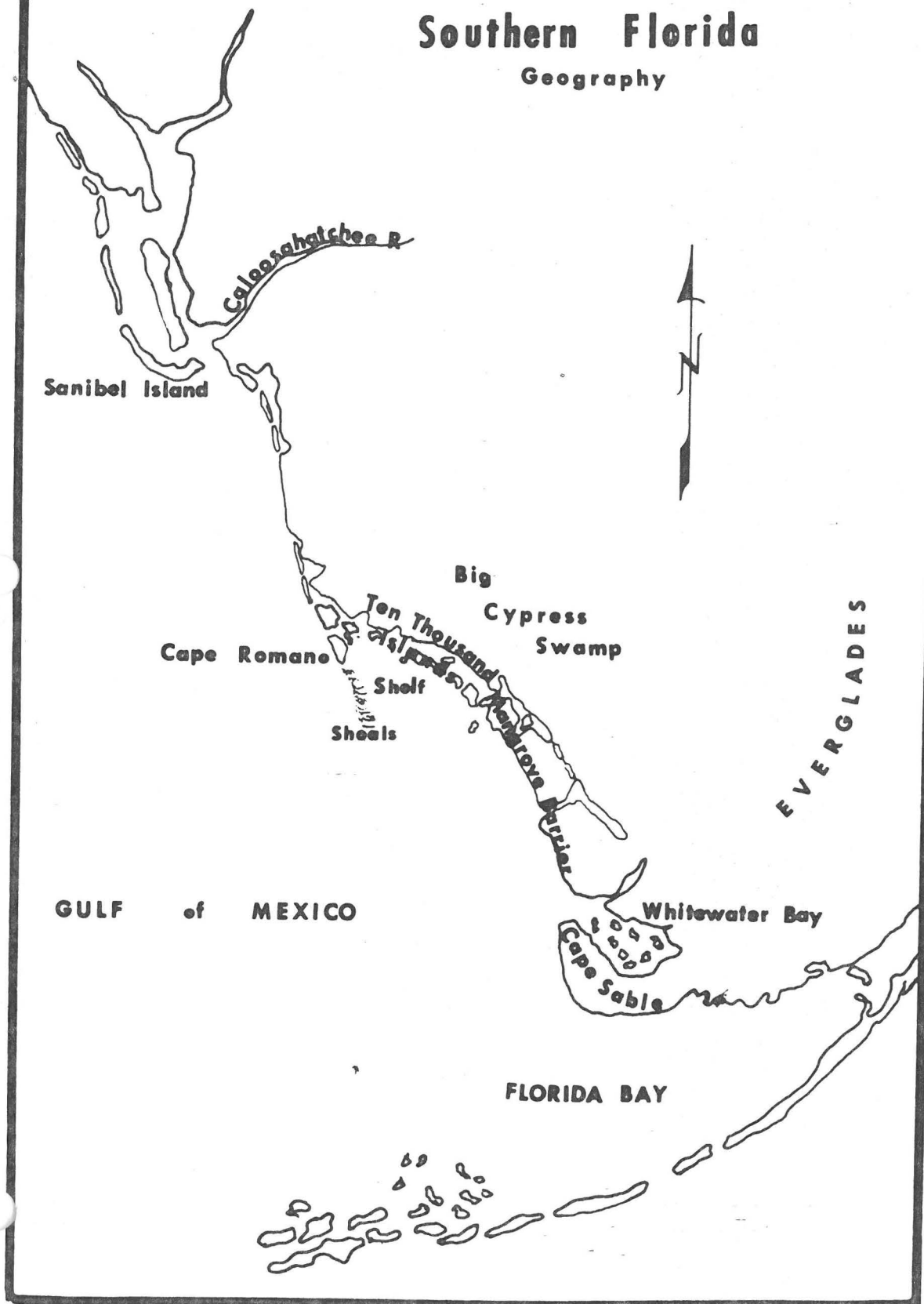
Mangrove Barrier

Approximately 98 percent of the land area is covered by a dense growth of mangroves. It is along this cliffless and beachless coast that the mangrove ridge and lagoons are found. This growth is reported by Davis (1940) to be one of the greatest known. In this subtropical environment the red mangrove (Rhizophora mangle) predominates. This species drops its roots from the branches and can exist in

Fig. 1: Geography of Southern Florida

Southern Florida

Geography



water two feet below the low tide level (Davis, 1940). Another common species found in this region is the black or honey mangrove (Avicennia nitida). The white mangrove, sometimes called Buttonwood (Laguncularia racemosa), is the third species found. The fact that the red mangrove builds out the shore on which it grows has long been known to geologists (Vaughn, 1909). The abundant roots and the manner of seeding on shoals by the floating of well-sheathed seedlings aid these trees in occupying marginal marine and lagoonal areas in protected waters, such as is found in the Ten Thousand Islands (Davis, 1940). The black mangrove seeds immediately under its branches, and tends to grow toward the land from the shore. This species is responsible for the build-up of the interior of the larger islands.

The formation of the mangrove barrier ridge is due to a combination of three major factors; an offshore wind, the climate, and the tide. The history of the formation of a mangrove barrier such as is found in southern Florida may be somewhat as follows: On a broad, well-protected tropical shoal coast where the wind is dominantly offshore, but with some onshore wave movement present, advance of the mangrove forest is assured. The ground swells from the open water bring in the elongated, winged mangrove pods which take root in water from six to eight inches deep.

Once seeded, mangrove trees spread rapidly by sending their roots out into deeper water. Root growth may extend as far offshore as a 2-foot depth at low tide (Davis, 1940). The dense growth of the roots, trunks and associated vegetation slowly advances seaward by the consolidation of the peaty growth and by trapping fine-grained inorganic sediment (Vaughn, 1909). Shells are added by small species of mollusca which inhabit such an environment. The maximum accretion is toward the open water since this accretion is helped by storms and high tide piling up more of the inorganic material in the swamps.

With the maximum accretion toward the open water, the lack of or decrease in accretion in the zone near the original mainland permits the normal compaction of peat and marl, which results in the formation of lagoons and bays behind the mangrove barrier. Along the southwest coast of Florida, the mangrove barrier is dissected by many tidal channels which allow the penetration of Gulf waters into the lagoons and bays. (Price, 1954).

Mangrove Islands

In the Ten Thousand Islands, the mangrove barrier is composed of small low-lying islands, some of which are awash at high tide. These islands seem to stretch out end to end in somewhat parallel rows, all trending in a southeast direction. These are thought to have been shell

bars on which the mangrove swamp has developed (Davis, 1945; Cook, 1945). Concurrent with the formation of the mangrove swamp on these shell bars was the formation of the Cape Romano Shoals. It is believed that the shoals helped to create the strong tidal currents which formed the deep channels now dissecting the islands. The dissection of these islands gives the area the appearance of being drowned.

Bays and Channels

Behind the mangrove barrier are a number of irregular, more or less interconnected bays. The largest of these is Chokoloskee Bay which is approximately six miles long and one mile wide. This is a typical bay for the region except in size. The bottom is flat and smooth except for the areas around the tidal channels and rivers where submarine deltas are formed. A large number of oyster bars exist on the Gulfward side of the bays, the largest population being found in the southern portion of the islands, around Chokoloskee Island.

The bays are connected by small inlets dissecting what is believed to have been old oyster bars, on which the mangroves have trapped sediment. These bars are now acting as narrow barriers separating one bay from another. A peculiar feature of these barriers is that they all curve toward the north. An example of this can be seen

at the southern end of Fakahatchee Bay (fig. 2).

Many channels dissect the mangrove barrier connecting the Gulf with the lagoonal chain. These channels are deep and have swift currents at the change of the tides. The number of these channels per unit area increases toward the south. One probable reason for this is that the southern end is open to direct attack from the open Gulf, and is not protected by the shoals as is the northern portion. Another possible cause is that the highest local tide range occurs in the south, giving rise to potentially strong tidal currents.

The hinderland swamp region is drained by numerous streams. These streams have many characteristics of the tidal channels which cut across the mangrove barrier. It was noticed by the author that the tidal currents were the only detectable currents in these streams.

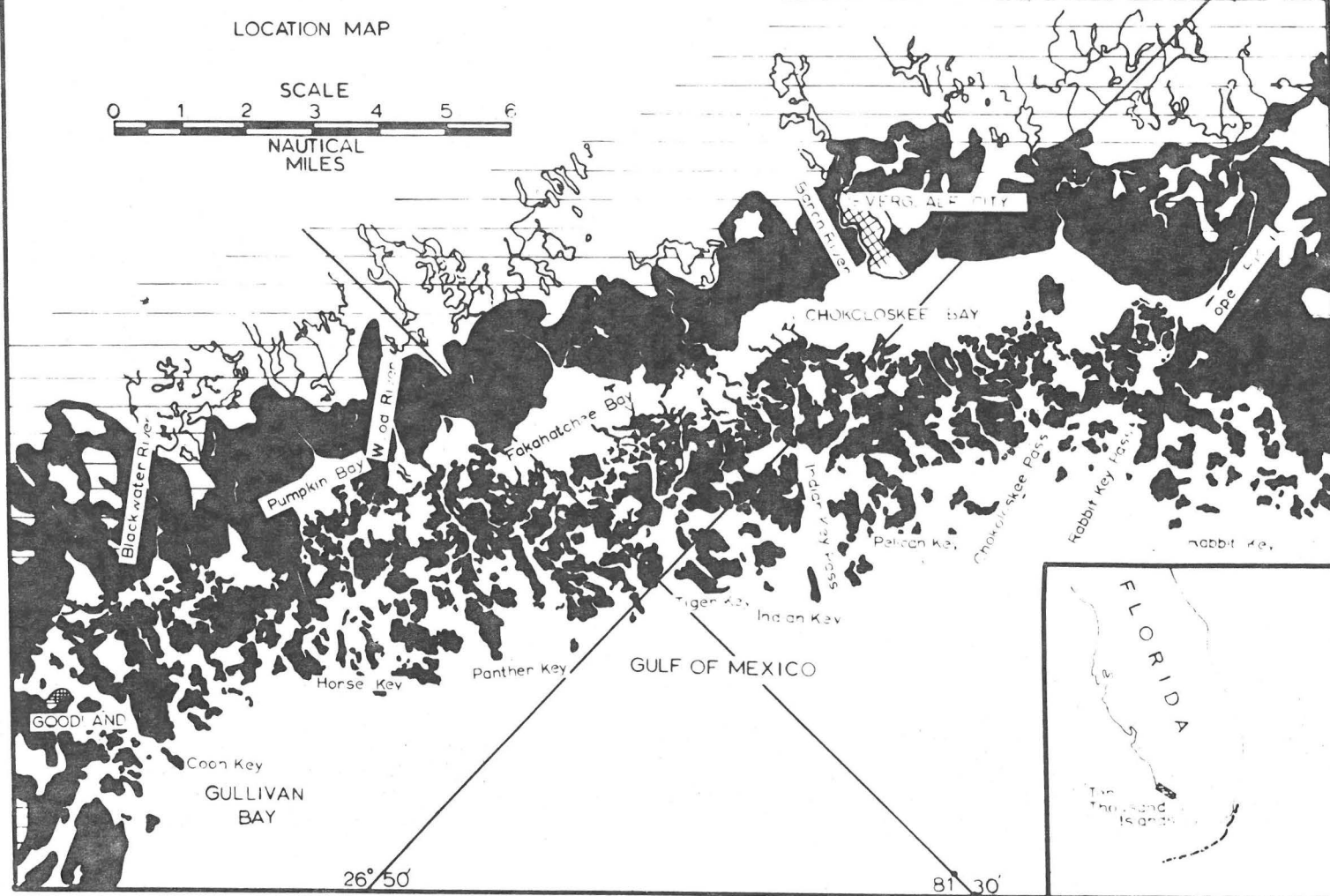
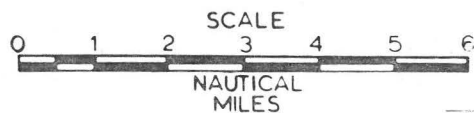
Shorelines

Price (1954) classifies this modern shoreline as a submergent, biogenous shoreline. It is very irregular in this region because of the mangrove forest which makes it difficult to delineate. In the Ten Thousand Islands the recognized shoreline starts in the coastal lagoon behind Cape Romano and curves to the southeast, ending at Lopas River.

Fig. 2: Location Map of the Ten Thousand Islands, Florida

TEN THOUSAND ISLANDS COLLIER CO., FLORIDA

LOCATION MAP



On the southwest coast of Florida there is a diagnostic feature which could well be considered as a shoreline marker. This feature is the "worm rock" which is found on the Gulfward side of the outermost islands. The rock is found in the littoral zone and is believed to be restricted by the tidal range. The rock is a bioherm of calcareous tubes believed to be formed by the gastropod, Lemintina sp. It appears in the form of slabs and on the Gulfward side of the islands ends in an abrupt slope. On some of the small keys there can be seen more than one ledge present below the low water level. These ledges could possibly indicate tidal ranges at a lower stand of the sea.

The "worm rock" is found from Marco Island to Lawson Creek, some 35 miles southward. In the central portion of the Ten Thousand Islands, from Panther Key to Pelican Key, the rock is covered by a veneer of quartz sand. These sand-covered keys seem to have been built on a platform of worm rock. South of Coon Key in the north, the rock forms spits which extend Gulfward from the island. In the south the rock is found hugging the fringes of the islands. The rock seems to be limited to the outer fringes of the present islands, as there was no evidence of its presence in the mangrove barrier or lagoonal chain.

The islands on the outer fringe can be classed into

two groups, those composed of sand, and those composed mostly of shell hash. The sand keys are found in the north from Coon Key to Indian Key. In the south from Indian Key to the southern end of the Ten Thousand Islands, the outer keys are built of shell hash. Most of these shell keys are covered with a thin veneer of sand giving an indication to the present sedimentological activity.

Shell Mounds

In the center of the mangrove barrier are four man-made islands. These shell mounds are kitchen middens built up by pre-Columbian Indians (Galtstoff, 1954). These shell mounds give a clue to the existence of shell bars in this region. The largest of these is Chokoloskee Island which is a quarter of a square mile in area.

Ancient Shoreline

In the northern region, an old shoreline can be recognized. The ancient shoreline, seen on the areal photographs of the region, is composed of coarse sand. This feature trends northwest to southeast.

Physiography

The Ten Thousand Islands region has been classified physiographically by the author into four main divisions. The four are: (1) the Gulf area, located between the shoals and the islands, (2) the mangrove barrier (Price,

1954) which separates the open Gulf from the bay chain, (3) the bay chain, which is bordered on the east by the (4) mangrove swamp (fig. 3).

AGENTS OF DISTRIBUTION

General

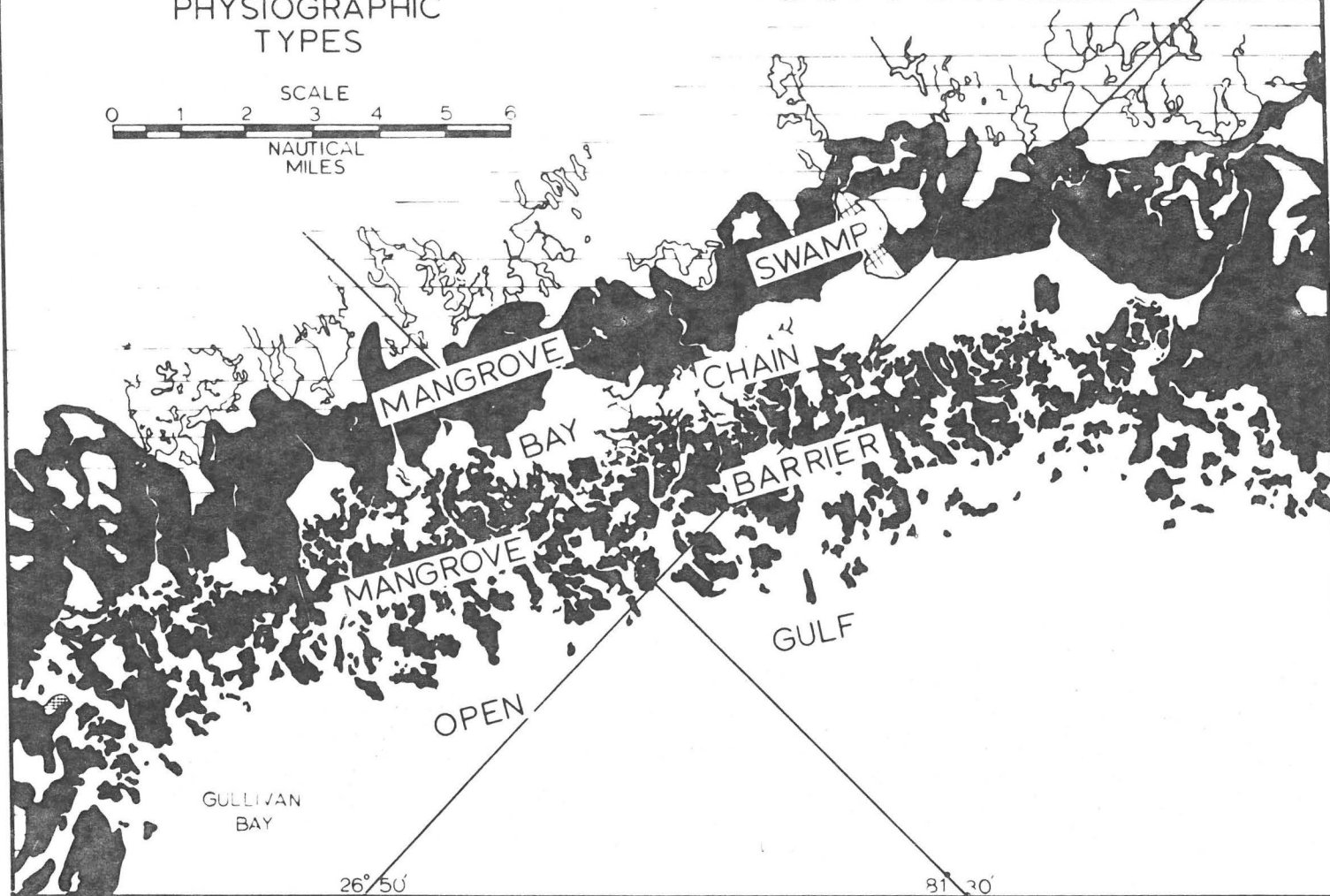
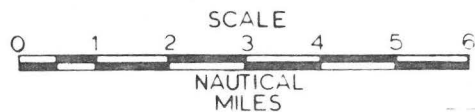
The physical agents active in the Gulf which affect the distribution of the bottom sediments are currents, normal wind waves, storm waves, and tidal currents. These agents affect the bottom sediments in three ways; first, in the distribution of sediments from the source to the site of accumulation, second, in the reworking and post-depositional modifications of sediments already deposited, and third, in controlling the chemical parameters of the environments.

In the Ten Thousand Islands the ocean currents and the normal waves affect the sediment distribution very little if at all. The storm waves help to form some of the physical features found in the vicinity of the Islands, such as the shoals. Storm waves and storms, however, produce minor changes in the Islands as was noticed from aerial photographs taken before and after hurricane "Donna" in 1960, which passed directly over the study area (Tupper, personal communication).

Fig. 3: Physiographic divisions of the Ten Thousand Islands

TEN THOUSAND ISLANDS
COLLIER CO., FLORIDA

PHYSIOGRAPHIC
TYPES



Tide

Tide is the predominant transporting agent in the Ten Thousand Islands. The tide in this region is the mixed type, with two high and two low tides not of the same amplitude. The range of the tide is from four feet at Pavilion Key to two feet at Marco Pass.

The tide at any place is not an isolated phenomenon, but is the local manifestation of large-scale, long-period wave motions, characterized by enormous wave lengths and comparatively small amplitudes, which are called tidal waves (Fleming and Revelle, 1939). Although the amplitude of the tide can be arrived at theoretically, the range of the tide at any place is also controlled by the horizontal and vertical topography. The topographical effects are not predictable; thus the variables must be determined by actual observations. After these observations have been made, it is then possible to predict the tide in a particular location. If the topography changes, then the tide predictions based on the old tide observations are erroneous, and new observations must be taken.

In and near the Ten Thousand Islands, the Coast and Geodetic Survey has established eight tidal observation stations. From the constants derived from tidal observations, the present tidal activity can be computed. The computations of the times of high and low tides, and the

tidal range, give some clues to the regional tidal circulation.

Associated with the vertical movement of the tide are horizontal movements or tidal currents. These currents are believed to be responsible for the distribution of sediment in this area. The current has its maximum velocity in the direction of wave progress at the crest of the wave, that is at high tide. The maximum current in the opposite direction occurs at low tide, with no current at mean sea level. In the Ten Thousand Islands, with the mixed type of tide, there is a larger range about the mean at high tide than at low tide, indicating a larger net flow in the direction of the tidal wave.

The highest tidal range in this section of the Gulf occurs at Pavilion Key. The probable reason for this is the configuration of the coast with the superimposed local bottom topography of the shoals. The tidal wave is funnelled by the curvature of the southwest coast of Florida and the Florida Keys, creating a tidal bulge at the apex near Pavilion Key. The tidal wave is further restricted by the Cape Romano Shoals which tend to force the tide movement around them.

The tidal currents in the Ten Thousand Islands are believed to be directly related to this tidal bulge. The

plots of the tidal curves for the eight stations show that the highest water level occurs at all times at Pavilion Key (fig. 4A), and that corresponding low water occurs at Coon Key and Marco Pass (fig. 4A). The net flow of the tidal currents was calculated by finding the ratio of the time that the water level at one station was higher than at an adjacent station. As an example, the water level at Indian Key is higher than the water at Everglades for fourteen hours of the day. Thus the current flows from Indian Key to Everglades for fourteen hours and from Everglades to Indian Key for ten hours, resulting in a net flow toward Everglades. Similar ratios were computed for all eight stations and the resultant flow mapped (figs. 4B and 4C).

SAMPLING METHODS

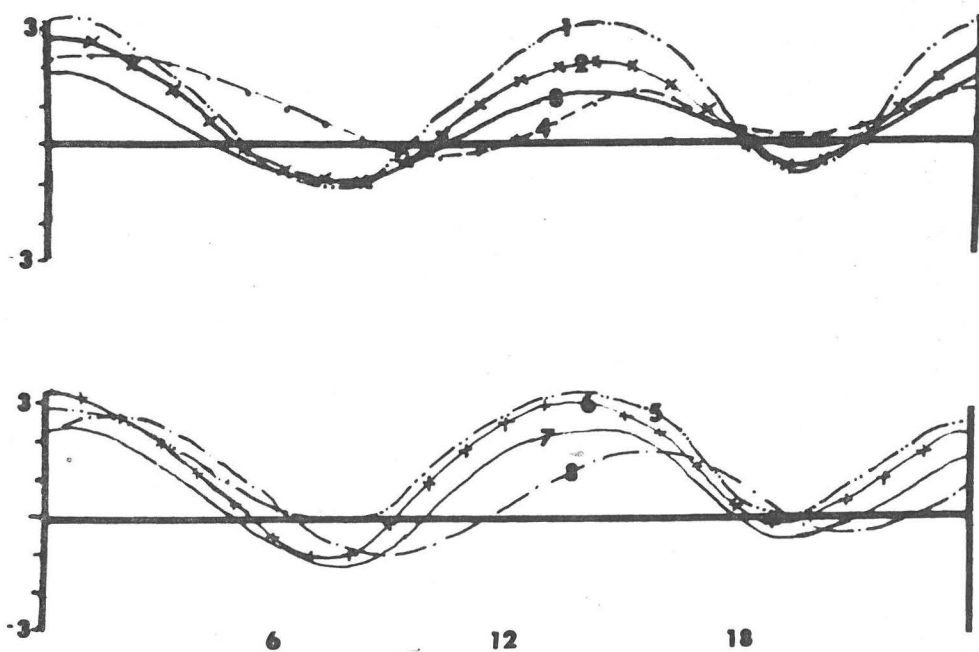
Field Methods

The collection of the samples was carried out during the month of June, 1960. The samples were collected on three sampling patterns. The first pattern was the multi-level (nested) sampling pattern. With this method, the samples were collected in a hierarchial design. In the investigation the axis which connects four sample locations, two on each end, was selected to include two physiographic divisions. The direction of the arm at the end of this was randomly oriented and then extended to reach

Fig. 4A: Tidal curves of the eight tidal stations
(1 Indian Key, 2 Coon Key, 3 Marco Pass,
4 Everglades City, 5 Pavilion Key, 6 Rattlesnake
Key, 7 Cape Romano, and 8 Pumpkin Bay)

Fig. 4B: The regional tidal currents of the

Fig. 4C: The local tidal current in the Ten Thousand



Time



B

C

water. The purpose of this sampling grid was to compare each of the physiographic divisions of the region.

This sampling is perhaps the most effective way of estimating the variability of the population at various sampling spacings. But because this sampling technique is not as effective as other methods for mapping the variables, samples were taken on a grid extended from that used in the nearby open water (Richey, 1960).

The third method of sampling used was core lines. Three profiles of five cores each were taken. The positions of the five cores again were located to give a comparison of the physiographic provinces of the investigated area.

The samples collected on the hierarchial pattern and the offshore grid pattern were collected by grab methods. Three devices were used in obtaining these samples. The first was the Van Veen sampler which was very suitable for sampling the region of soft bottom. In areas where the water was settled enough, free diving was employed. In the shoal water another method was used. This was a scooping device with a top to keep the sample in. This device proved to be unsatisfactory and it was abandoned in favor of the Van Veen.

At each station descriptions of the location, water

and position of the tide were made. A great number of photographs were also taken for future reference.

A sixteen foot skiff was used in the collection of most of the samples. However, some of the samples were collected from a twenty-eight foot skiff.

Cores were taken by a coring tube made of four inch aluminum irrigation pipe. The coring tube was driven into the bottom and a cap was placed on the top. The suction brought out the core and a column of water. The weight of the water column made the coring tube difficult to handle. The core was extracted by means of a plunger, then described, and sectioned for laboratory analysis. The pH of the water and sediment was measured at each core station.

With the use of air-photographs and hydrographic charts, samples were located with great accuracy because of the proximity of land marks.

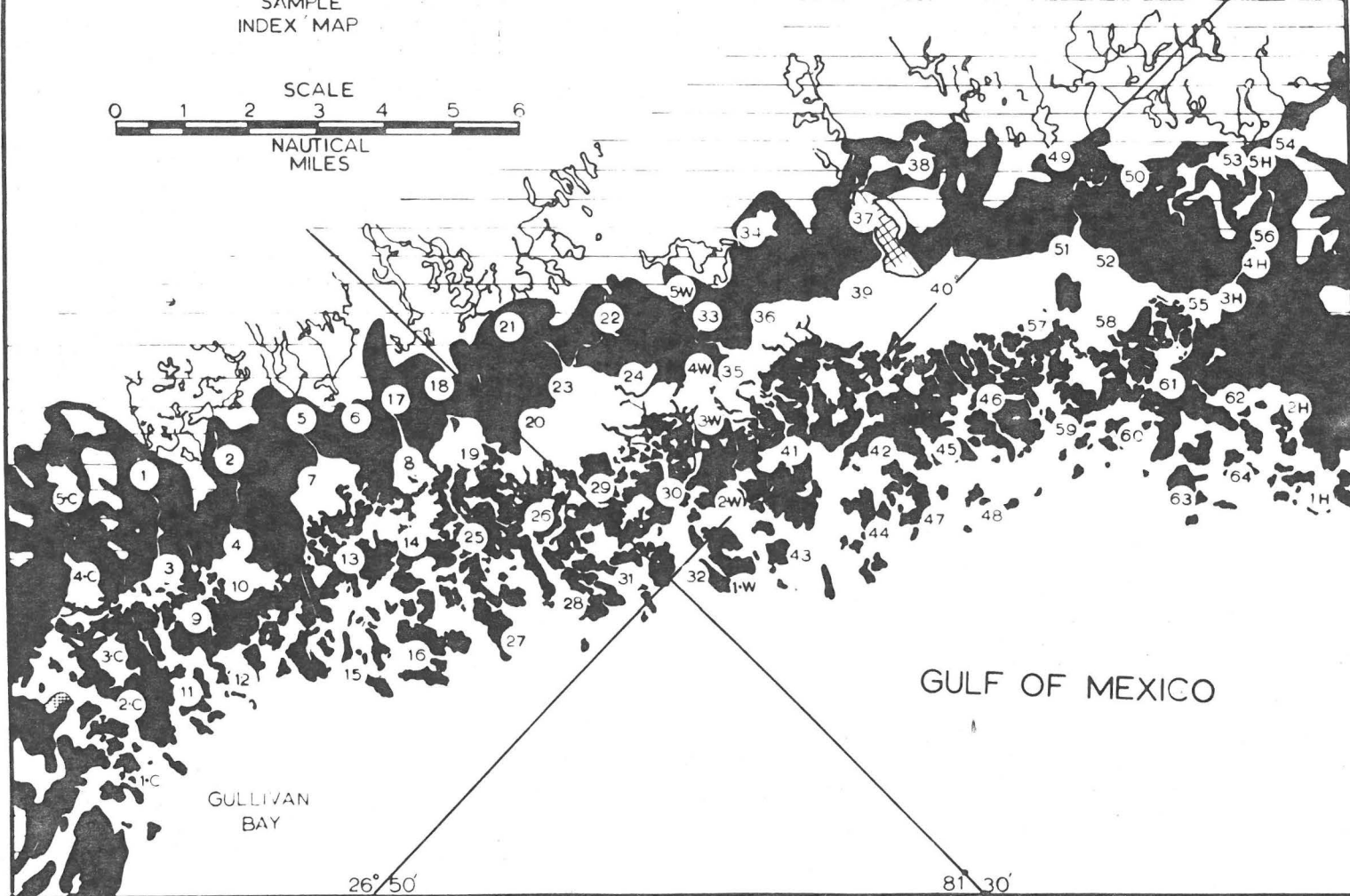
Laboratory Procedures

After the samples were returned to the laboratory, they were dried and split by the use of the Jones splitter (Pettijohn and Krumbein, 1938). A representative split was placed in a plastic box and stored. Another split was placed in the oven and dried at low temperature.

Fig. 5: Sample index map of the area

TEN THOUSAND ISLANDS COLLIER CO., FLORIDA

SAMPLE
INDEX MAP



This split was used for chemical analysis.

The textural analysis was carried out in two steps; first, a standard pipette analysis for the silt size fraction and second, a standard sieving for the sand size fraction (Pettijohn and Krumbein, 1938). Each sample was analyzed for organic carbon, carbonate, and organic nitrogen. The organic carbon was determined by the method outlined by Allison (1935). Organic nitrogen content was found using the Micro Kjeldahl method as outlined by Kabat and Mayer (1948). X-ray analysis was run on some selected samples to find the predominant clay types.

Carbonate analysis was run on each size fraction. The percent of carbonate in each size fraction was determined by the gasometric method outlined by Bien (1938). After the percentage of each size fraction was obtained, the total carbonate percentage by weight was calculated.

After the raw data had been obtained by the laboratory analysis, the total mean, the non-carbonate mean, and the carbonate mean, and the standard deviation of each sample were computed on the IBM 650 computer. The percentage of the sample in each size fraction was also obtained. With the computed parameters, such as the means, trend surfaces were computed and plotted.

In plotting the raw data it was found that the

presently accepted method of contouring the data would not be acceptable because the contours would have to cross islands, giving an erroneous picture of the distribution of the mapped parameter. To represent the raw data on a map, the parameters were first contoured as if the islands were not present. Then at all the sample stations arrows were drawn orthogonally to the isopleths. The length of the tail corresponds to the numerical value represented on the map. The head of the arrow points in the direction of the decreasing parameter value which is being mapped. This method was used to depict the raw total mean and non-carbonate mean.

SEDIMENTOLOGY

General

The sediments of the Ten Thousand Islands overlies the limestone of the Tamiami formation (Cook, 1945). The bed rock was planed essentially flat by the erosive action of the waves during the high stand of the sea during Pamlico time. The sediments are composed of marl and shell beds with interlayers of mangrove peat. The peat section varies from about 5 to 14 feet in thickness. Except where it descends into the irregularities of the bed rock, Davis (1940) thought that the sediments average about 7.5 feet thick.

The modern sediments of the region are distributed according to the main environmental conditions present in the region: the open environment, the mangrove barrier, and the lagoon. The mangrove swamp, the region on the mainland side of the lagoonal chain, seems to consist of the same environmental conditions as the mangrove barrier, and therefore was classified with the latter.

Sediment Types

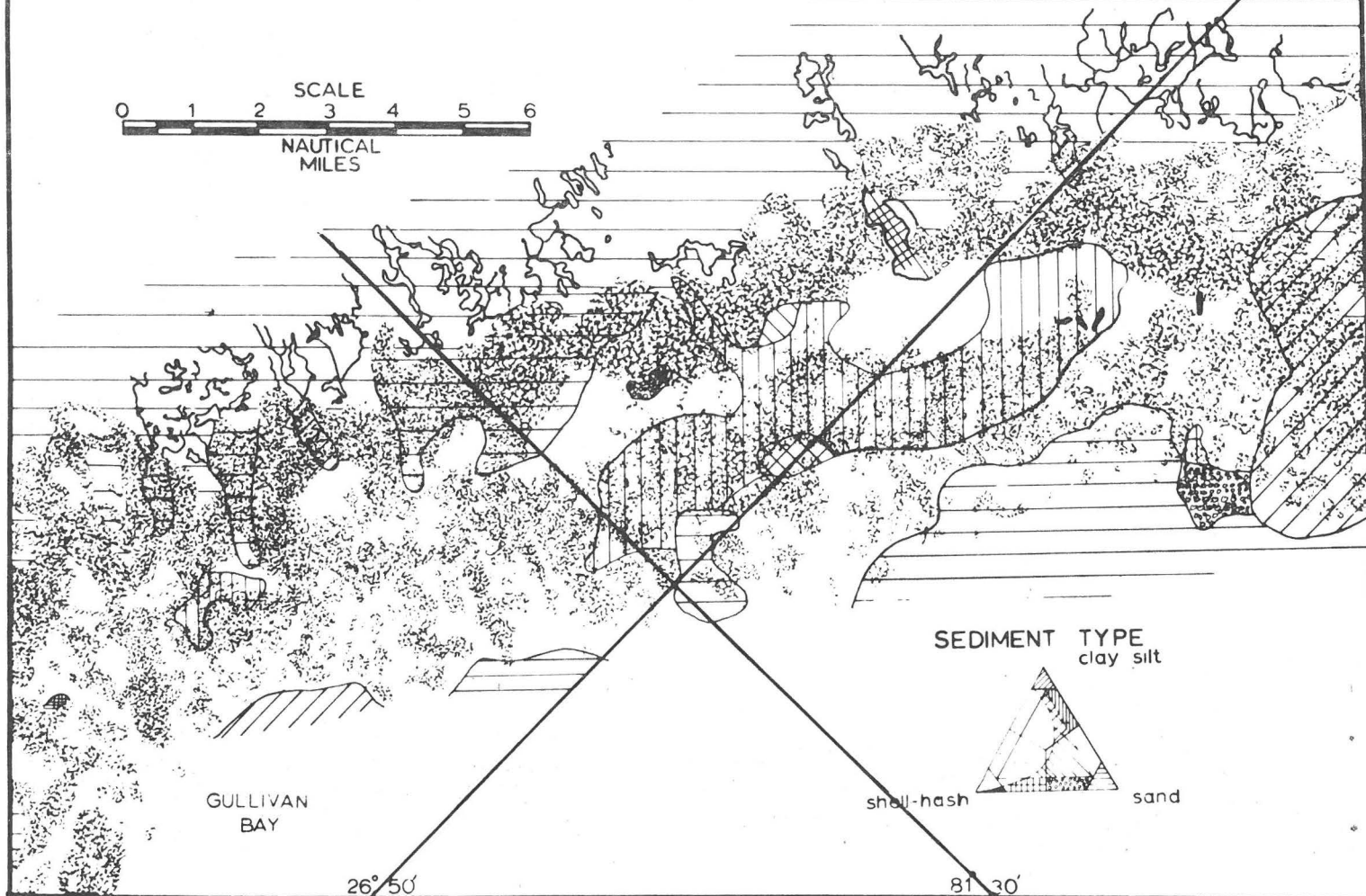
For the purpose of this study, the sediment samples were classified by the Wentworth-Udden size terms and grade scale (Pettijohn, 1957). The sediment types were defined by the use of the end-member. Thus, the three end-members used are shell hash, sand and silt-clay.

The sediments of the lagoon and bay environments consist of soft unctuous, water-soaked slime in which few particles can be seen with the naked eye. The mechanical analysis of the samples from this environment revealed that the sediment is a fine sand to sandy silt, the predominant portion being a fine sand. The sand of this area consists mainly of quartz. The slimy excrement of diatoms living in and on the bottom is an essential factor of the unctuous nature of the sediment (Brokman, 1935).

In the open Gulf environment and river environments the bottom sediments are classed as sand. The sand in

Fig. 6: Sediment types of the study area

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SEDIMENT TYPE
clay silt

shell-hash

sand

the rivers is derived from the ancient shoreline, in the northern sector of the region. The sand of these river bottoms consists of almost-pure coarse quartz sand. Sand is presently carried along the Gulf beaches in a southerly direction by the longshore drift. This accounts for the sand present on the outer fringes of the islands. The sand in this environment consists of sand with a significant portion of shell hash intermixed.

In the mangrove barrier, the sediment is characteristically finer than the material on either side of it. This material is classed as sandy-silt. Another region where the sediment type is similar to that of the mangrove barrier is located behind Rabbit Key. The environmental conditions which exist there are similar to those which are found in the mangrove barrier.

In the isolated bays behind the edge of the mangrove swamp, such as Ferguson Bay, the sediments are very fine, made up of fine silt and clay with little or no sand. This sediment type is restricted to the back bay regions and to the few isolated regions in the mangrove barrier.

Texture

Mean grain size in phi units for the total sample and the non-carbonate fraction were computed. The standard deviation was also calculated and used as a measure of

sorting. Maps were prepared showing the distribution of the mean grain size and sorting. For the purpose of mapping, the standard deviation (sorting) was broken down into: fairly well sorted, moderately sorted, poorly sorted, and very poorly sorted. A standard deviation of less than one is considered fairly well sorted, between one and two is moderately well sorted, between two and six poorly sorted, and greater than six, very poorly sorted. For the purpose of description, material whose median diameter is greater than three phi units is considered fine, and material less than three phi units is coarse.

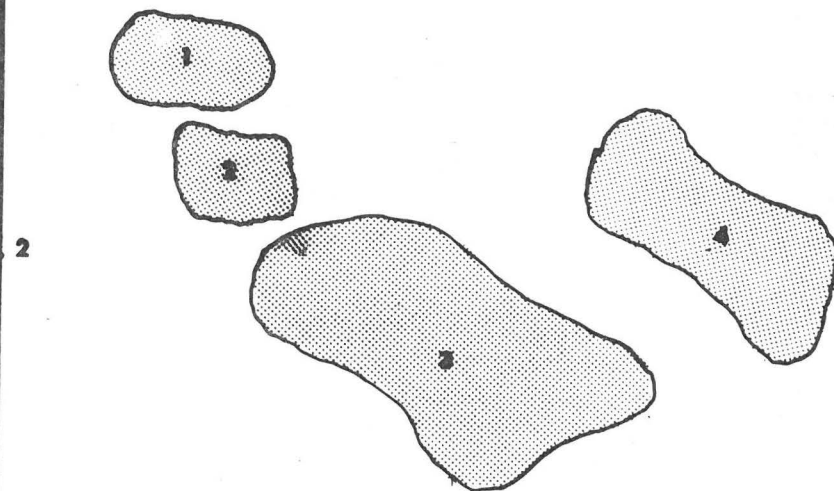
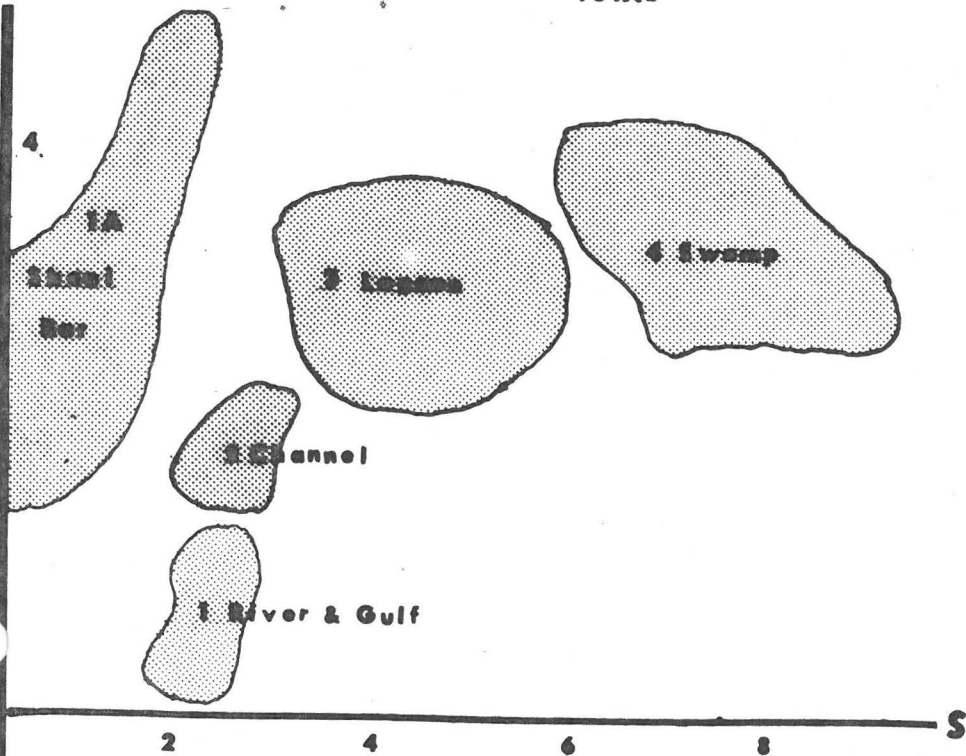
In the examination of the graph of the mean grain size plotted against the sorting, five sedimentary groups were outlined by the writer (fig. 7). These sedimentary groups are believed to be related to the environments from which the samples came. Group one consists of coarse, fairly well sorted material, indicating a relatively high energy environment. Samples in this group were taken from the region of Chokoloskee Pass and Rabbit Key Pass on the outer fringes of the islands. The map of the total texture shows that the mean grain size ranges from 1.5 to 2.5 phi units and the mean grain size decreases toward the center of the islands.

Sediments also falling into group one were found up the rivers in the north corner of the study area, from

Fig. 7: Graph of the total mean and non-carbonate mean
against the sorting of the samples.

$\bar{X}$

TOTAL



NON CARBONATE

Blackwater River to East River. These sediments, which indicate a former high energy environment, are believed to be derived from the ancient shoreline. There is a decrease in the mean grain size from the ancient shoreline to the lagoonal chain.

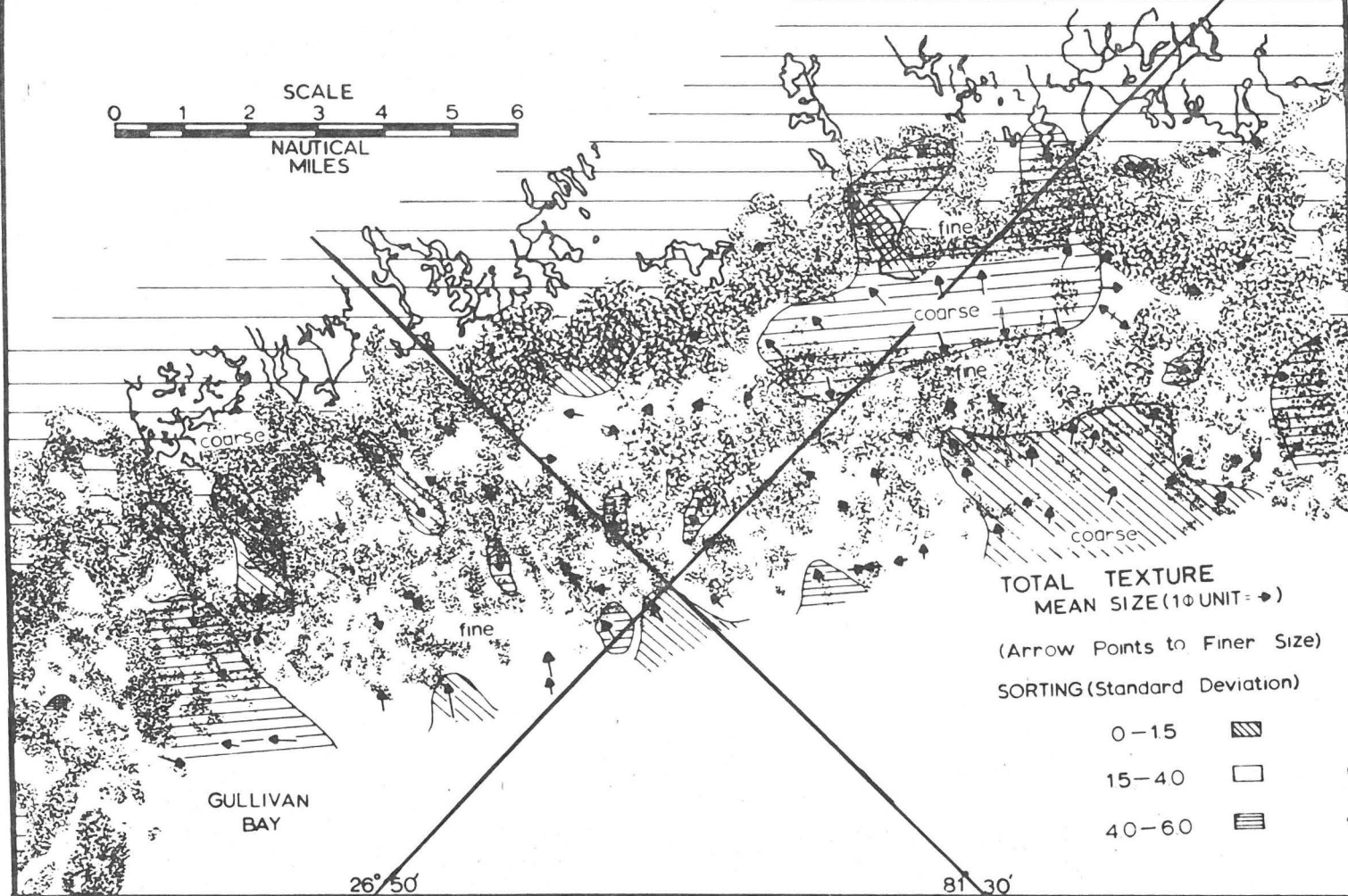
Scattered through the area are shoal bars having a high percentage of calcium carbonate in the form of shells and shell hash. Sediments taken from these features are shown on the graph as one-A. These are in areas of varied energy conditions, and thus there is a wide range of fine and coarse material. These sediments were deposited in a biogenic environment.

Group two includes samples, taken from the channels, consisting of coarse, moderately sorted material. This group is made up of sediment which ranges from two to three phi units in median diameter. These channel sediments give a clue to the energy of the currents which flow through the channels.

The sediments of the lagoonal chain vary between three and five phi units in median diameter and are classed as group three. This group, composed of fine, moderately sorted material, shows the effect of the tide as an agent of distribution in a protected environment. The map of the raw data shows that in the lagoonal chain

Fig. 8: Map of the Total Texture and Sorting

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there is a decrease in grain size from the central portion of the bays to the shore line. The distribution of the fine grain sediments in this manner can best be explained by the tidal lag effect (Postma and Van Andel, 1954).

The sediments of group four are found in the highly protected pockets such as Ferguson Bay. They are very fine and poorly sorted with the mean grain size ranging from 5.5 phi units to 7 phi units. These sediments are composed of a large percentage of clay sized particles which leads to the very poorly sorted sediments.

In general the total textural map shows coarse, fairly well sorted material present in the northern section near the old shoreline. The same type of material lies on the Gulf fringes on the islands. Fine, poorly sorted material is present throughout the mangrove barrier, and also in the protected region behind Rabbit Key.

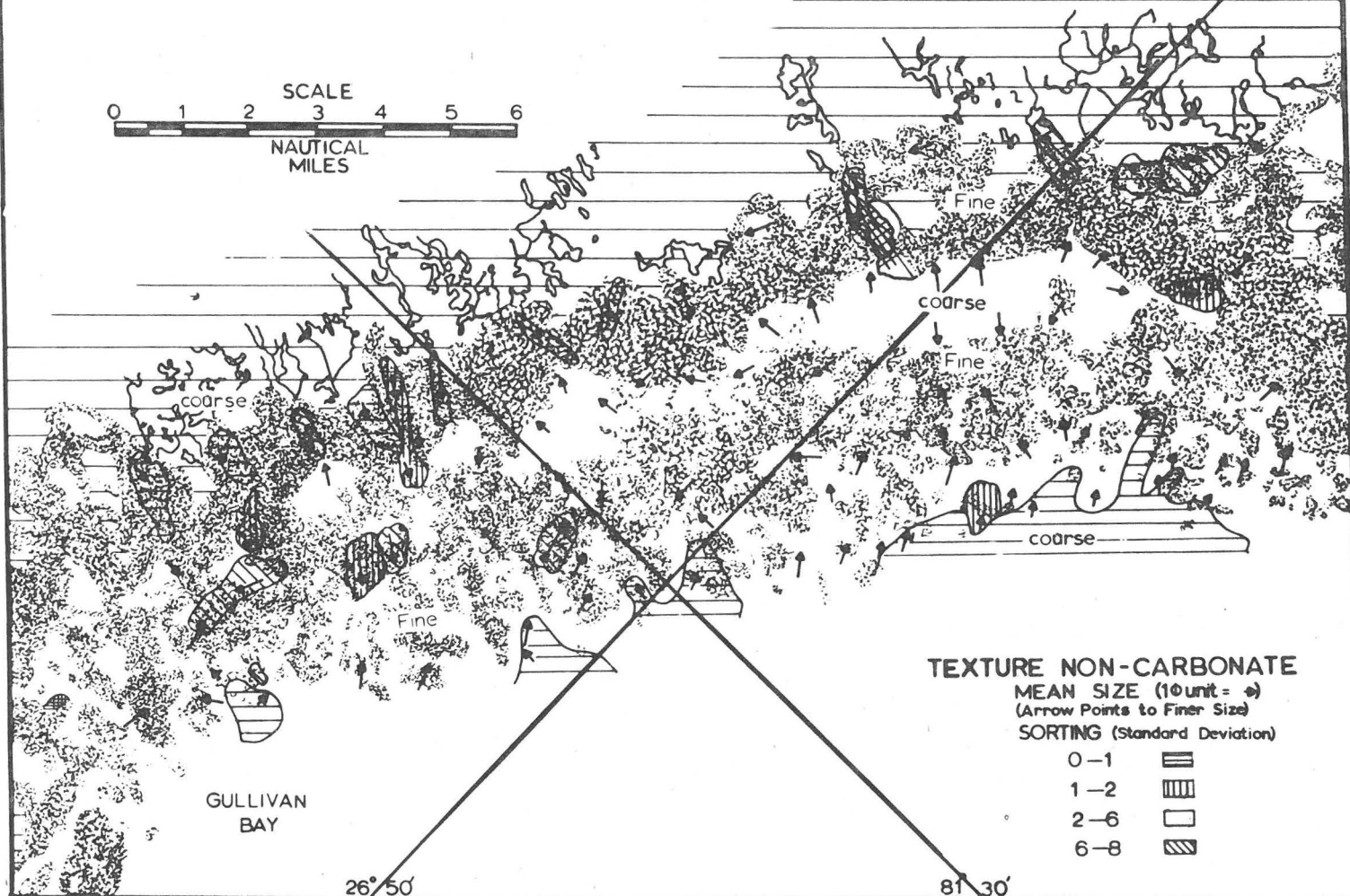
Non-carbonate

The non-carbonate fraction was studied to obtain a picture of what the region would look like if the carbonate material were leached out by subsequent diagenesis. In the Ten Thousand Islands the non-carbonate fraction is composed of quartz sand with an admixture of clay minerals.

The graph of the mean grain size against the sorting of the non-carbonate fraction outlines only four sedimentary

Fig. 9: The Non-carbonate mean and sorting

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TEXTURE NON-CARBONATE

MEAN SIZE (10 unit = ϕ)

(Arrow Points to Finer Size)

SORTING (Standard Deviation)

0-1	
1-2	
2-6	
6-8	

groups as compared to five in the graph of the total mean. Because group one-A consisted of poorly sorted samples with a high carbonate percentage, the elimination of the calcium carbonate resulted in the re-classification of these samples. Since these samples were obtained from shoal bars in the lagoonal region, they are now classed into group three of the non-carbonate graph. Thus the resultant graph and map of the non-carbonate distinctly outlines only four major sedimentary environments. These are as follows: the high energy environment on the open Gulf; channels with the moderate energy of the tidal currents; lagoons with the tide acting as the major agent of distribution; and the highly protected environments of the back bays.

Trend Surfaces

To separate the regional effects of the sediment distribution from local effects, Krumbein (1956) and Miller (1956) adapted the use of trend surfaces to the study of sediments. The regional trends reflect the relatively broad tectonic or environmental controls on sediments, whereas the more local fluctuations may be due to the local environments, structure, and topographic effects. In this paper two types of trend surfaces were used in the study of the data; the plane surface and the cubic surface. The trend surface represents the major

structural and environmental effects of southern Florida, and the cubic surface represents the major trends in the local area of study.

Total Texture

The linear regional surface of the mean grain size shows a trend dipping to the southwest at the rate of one phi unit per six miles (fig. 10). This plane accounts for twenty-two percent of the variability of the samples. The residual map shows a negative anomaly located in the mangrove barrier from Tiger Key to Coon Key. A negative anomaly is also located east of Rabbit Key. The negative anomalies represent areas of material finer than the regional plane.

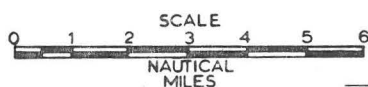
The sorting surface dips in the same direction as the mean grain size surface (fig. 11). The plane dips at a rate of half a standard deviation per six miles. The surface is almost flat, but shows a faint trend toward better sorting offshore. The mangrove barrier is represented by a negative anomaly indicating poor sorting in this region. Positive residuals occur up the rivers in the northern section near the ancient shoreline. A negative anomaly occurs behind Rabbit Key, indicating poor sorting in this region.

The cubic surface of the total mean grain size brings

Fig. 10A: Total mean linear surface

Fig. 10B: Total mean cubic surface

TEN THOUSAND ISLANDS COLLIER CO., FLORIDA



GULLIVAN
BAY

26° 50'

81° 30'

TOTAL MEAN
PLANE SURFACE
Φ UNITS ---- 3.25
RESIDUAL
Φ UNITS ~ -2

TEN THOUSAND ISLANDS COLLIER CO., FLORIDA



GULLIVAN
BAY

26° 50'

81° 30'

TOTAL MEAN
CUBIC SURFACE
Φ UNITS ---- 3.25
RESIDUAL
Φ UNITS ~ -2

Fig. 11A: Total sorting cubic surface

Fig. 11B: Total sorting plane surface

TEN THOUSAND ISLANDS
COLLIER CO., FLORIDA

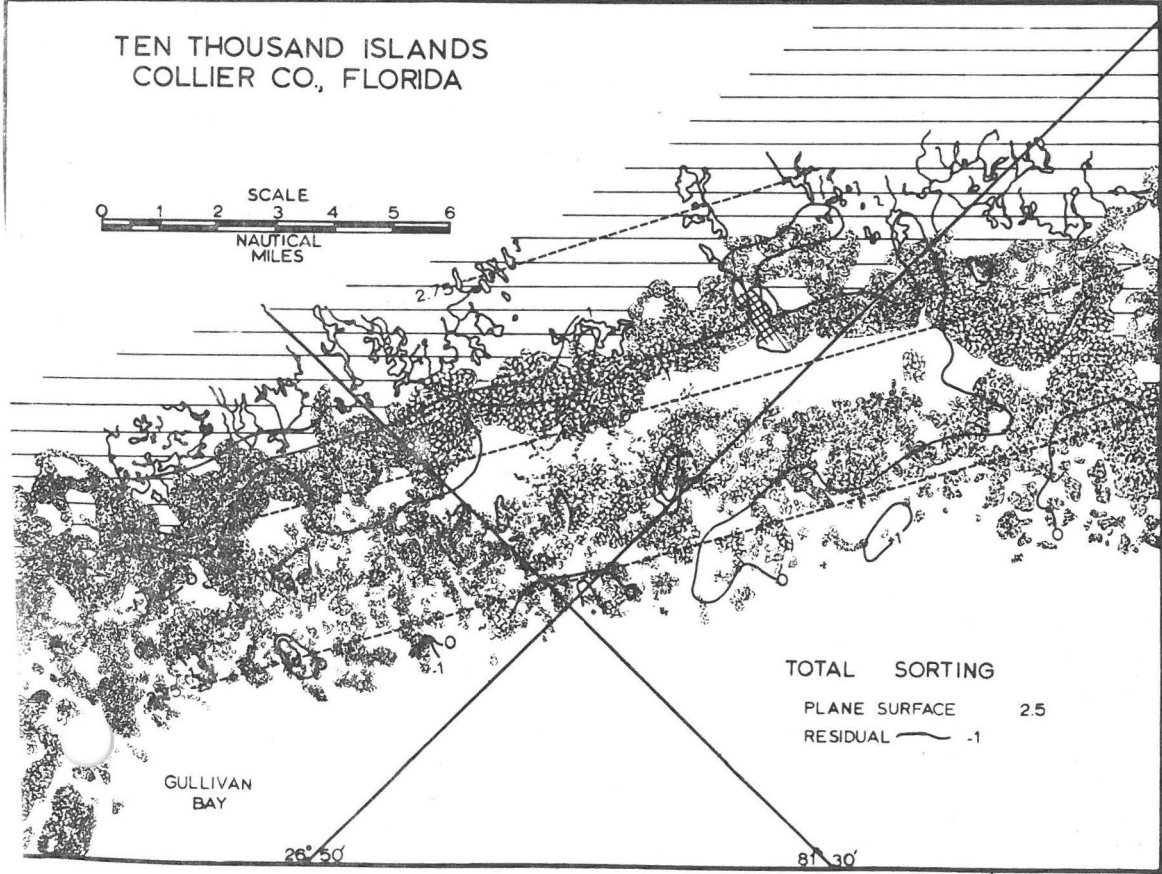
SCALE
0 1 2 3 4 5 6
NAUTICAL
MILES

GULLIVAN
BAY

26° 50'

81° 30'

TOTAL SORTING
CUBIC SURFACE ---- 2.5
RESIDUAL ——— +2



out the general trends in the specific area of the Ten Thousand Islands. The surface shows a ridge of fine material running through the central portion of the islands. This ridge represents the mangrove barrier. The residuals mapped from the cubic surface show the local variations in the general picture of the cubic surface. The surface shows that the finest material lies in the area near Lopas River. This surface accounts for thirty percent of the variability of the total mean data.

In the map of the cubic surface of the sorting, a lge of poor sorting trends east-west, coinciding with the ridge of fine material of the total texture. The poorest sorting coincides with the fine material in the area south of Chokoloskee Island. The sorting improves toward the open Gulf. This surface reduces the sample variability by twenty-seven percent.

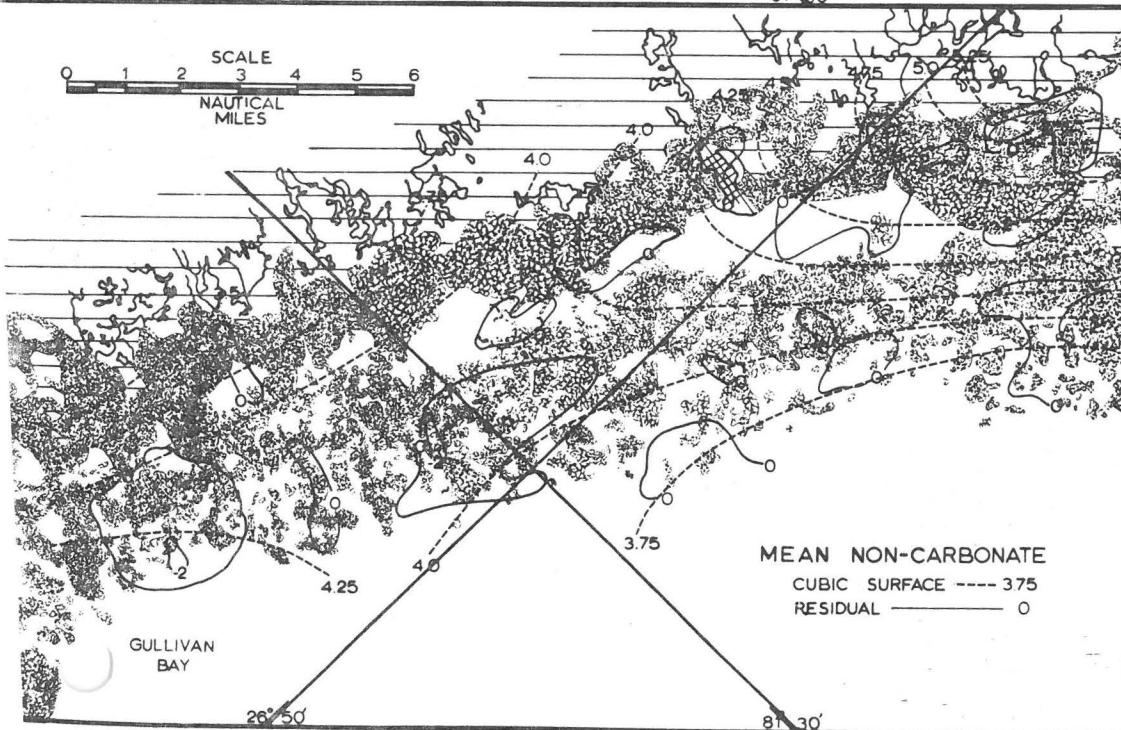
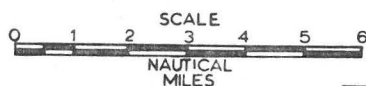
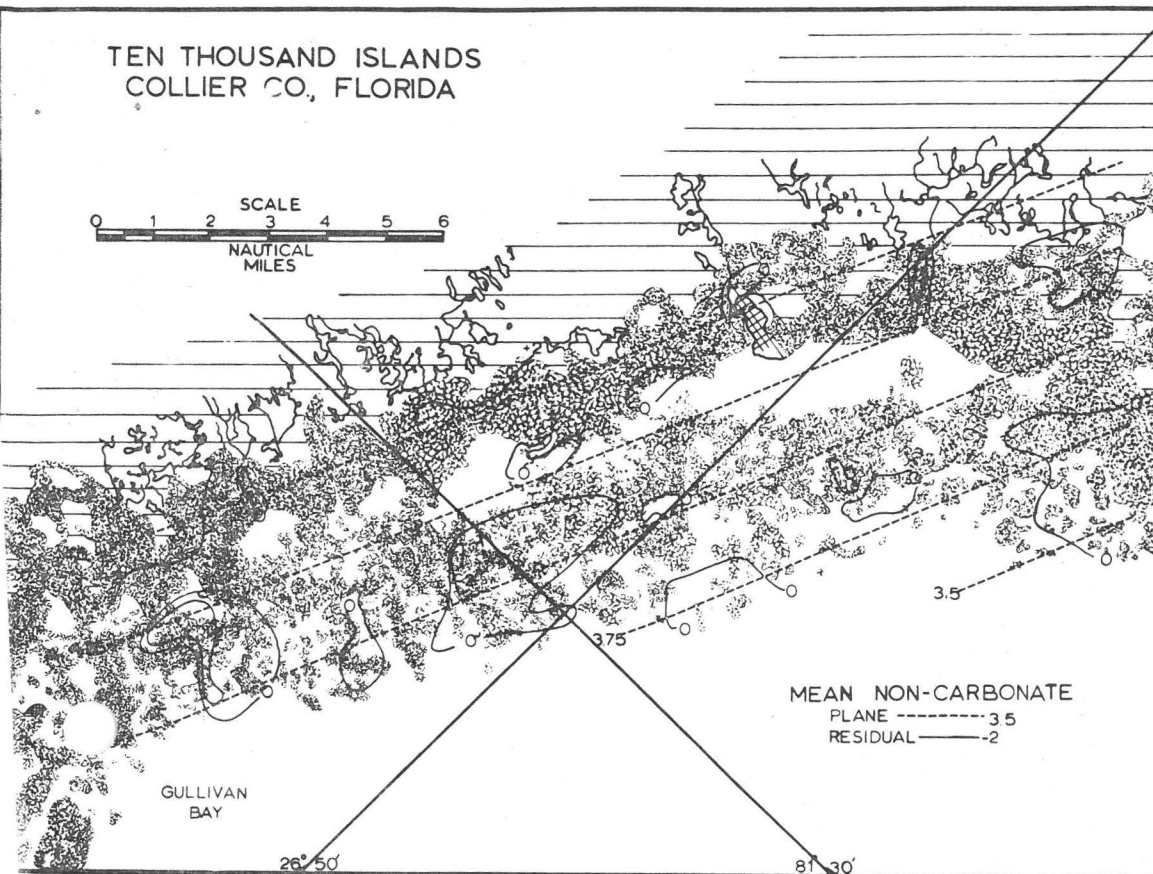
Non-carbonate Texture Surfaces

The linear surface of the non-carbonate mean grain size parallels that of the total sample surfaces. The surface dips to the south at a rate of one phi unit per six miles. The dip of the non-carbonate mean surface is the same as the dip of the total mean surface (fig. 12). The residual shows the fine sediment, located by negative anomalies, in the same locations as recognized on the raw data map.

Fig. 12A: Non-carbonate linear surface (mean)

Fig. 12B: Non-carbonate cubic surface (mean)

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The cubic mean grain size surface shows that the same fine grained ridge extends through the mangrove barrier. There is coarse material represented in the Blackwater River area and along the outer fringes of the islands. The finest material is present in the Oyster Bay region.

The trend surface of the sorting shows an increase in sorting toward the Gulf. The trend surface dips to the south at 0.1 standard deviation per mile. The residual shows poor sorting behind Rabbit Key and in the mangrove barrier (fig. 13).

The cubic surface distinctly outlines the ridge of poorly sorted fine material. The finest and most poorly sorted material is located in the vicinity of the mouth of the Lopas River.

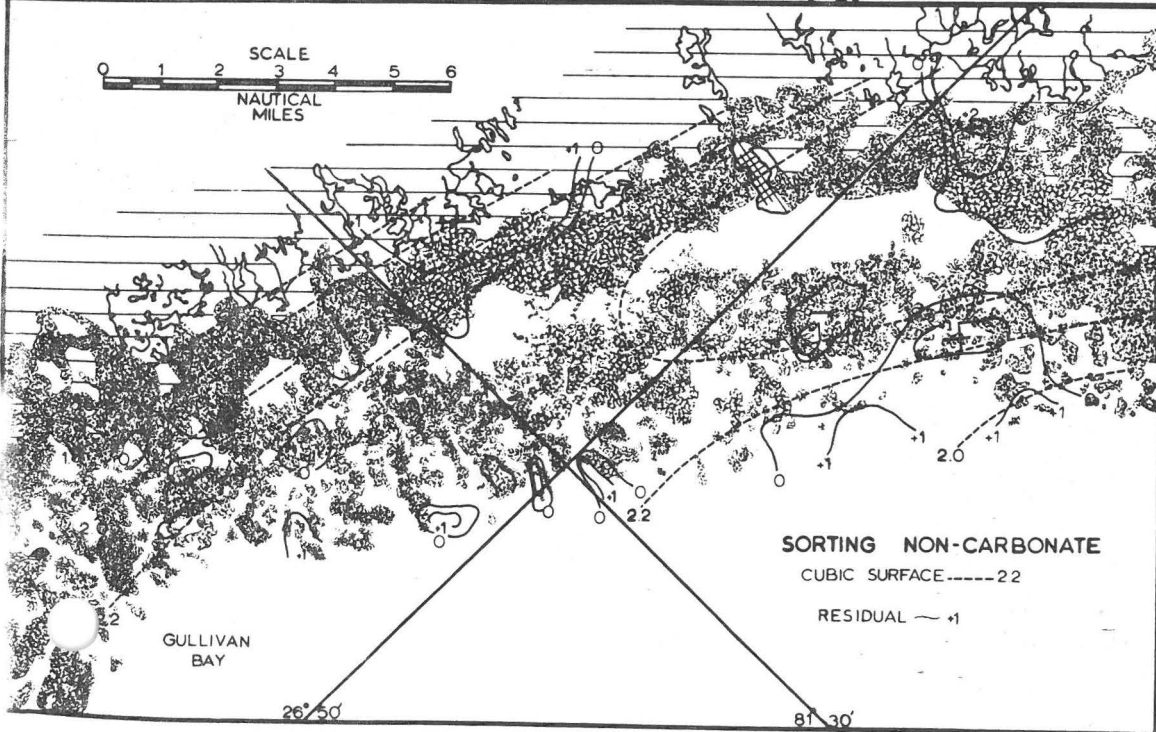
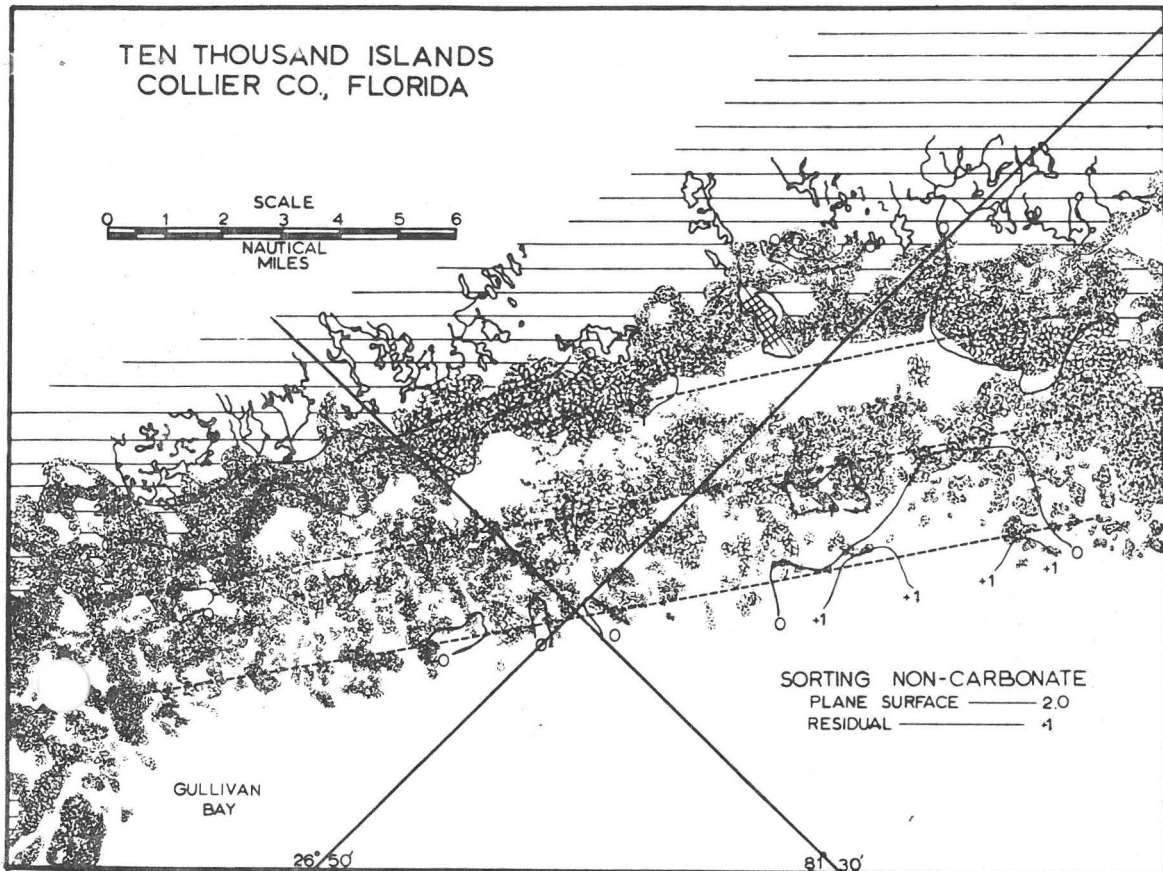
The cubic mean grain size surface accounts for 35.5 percent of the data, whereas the cubic sorting surface represents 38 percent of the data.

In the case of possible loss of the calcium carbonate by diagenesis, the non-carbonate fraction would have to be relied on for future interpretations of such a region. The non-carbonate texture could not be used alone to correctly interpret the region. Other evidence would be needed, such as structure, fossils, and organic material. The non-carbonate texture gives evidence solely of the low

Fig. 13A: Non-carbonate sorting plane surface

Fig. 13B: Non-carbonate sorting cubic surface

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energy of this environment.

Chemistry of the Sediments

The carbonate content of the sediment samples is a function of the amount of shells, foraminifera and shell hash. The distribution of calcareous material is due to the migration of the calcareous-secreting organisms, to the lag effects of the tidal currents and to the population of shell bars. The migrating organisms are made up of mollusks, such as the gastropods which inhabit the littoral environment on some of the sand keys in the northern section of the islands. The lag effect accounts for the calcium carbonate material found in the channel bottoms and on the southern fringes of the islands. The shoal bars in the region are made up entirely of oyster shells.

The map of the mean grain size of the calcium carbonate shows an area of fine carbonate material in the vicinity of Chokoloskee Pass (fig. 14). The coarsest carbonate material is found in the shell bars, located in the bays. The plane surface of the carbonate mean dips to the west at 0.25 phi units per six miles. The plane indicates that the material becomes coarser toward Cape Romano.

The cubic surface follows the trend of the shoreline, dipping toward the Gulf. This surface indicates that the

Fig. 14A: Mean Carbonate map

Fig. 14B: Carbonate mean plane and cubic surface

TEN THOUSAND ISLANDS COLLIER CO, FLORIDA



GULLIVAN
BAY

MEAN CARBONATE

CONTOUR INTERVAL — 1 Φ UNIT

26° 50'

81° 30'



GULLIVAN
BAY

CARBONATE MEAN

PLANE SURFACE ----- 12 Φ UNIT
CUBIC SURFACE ----- 10 Φ UNIT
PLANE RESIDUAL ----- 0

26° 50'

81° 30'

mean carbonate becomes finer toward the Gulf.

The percentage map of the calcium carbonate shows a high concentration of material in the bay regions and the central portion of the mangrove barrier (fig. 15). The high concentration of calcium carbonate in the bay regions is due to the oyster bars. The high percentage in the central portion of the mangrove barrier is due to the shell islands and the larger percentage of micro-organisms in this area. The cubic surface of the carbonate percentage shows the highest percentage of carbonate material is present in Chokoloskee Bay. The residual anomalies show the high percentage of carbonate in the shell islands and in the vicinity of Chokoloskee Pass.

X-ray analysis of the clay size samples showed no calcium carbonate in the mangrove swamp sediments, whereas samples from the lagoon and mangrove barrier show calcium carbonate in the form of calcite and aragonite. An examination of the micro-organisms of the mangrove swamp sediments shows that no calcium carbonate secreting organisms exist there (Benda, 1961).

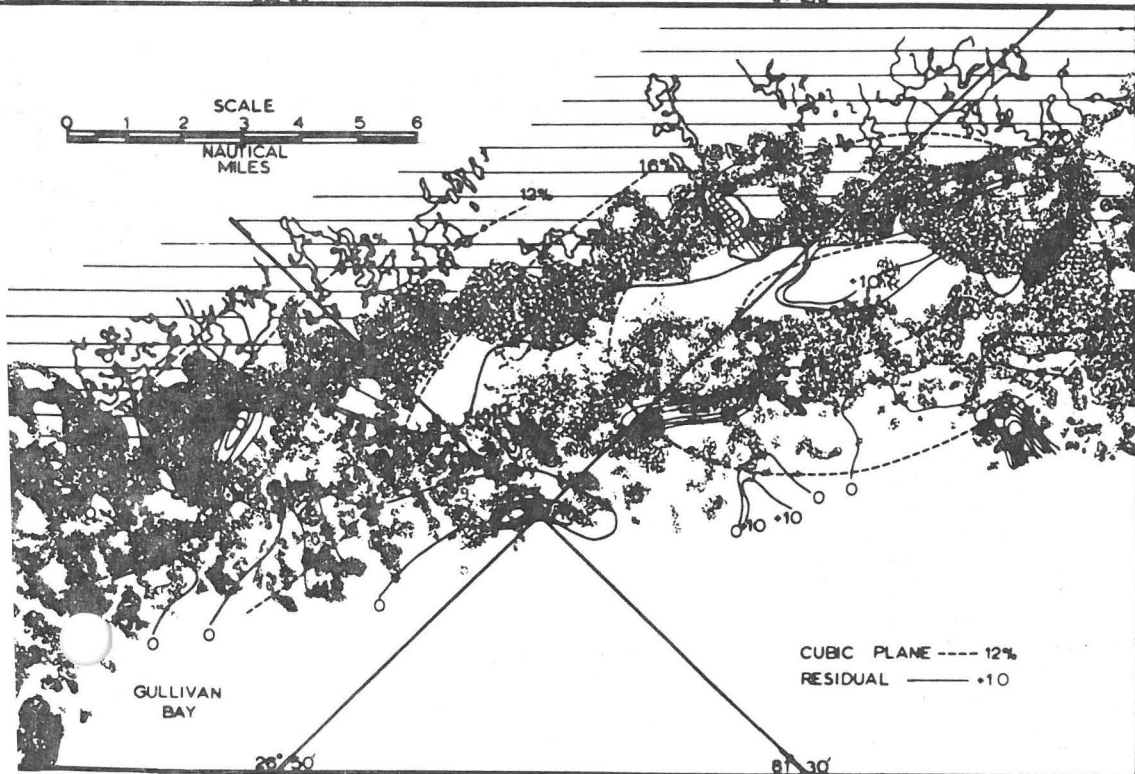
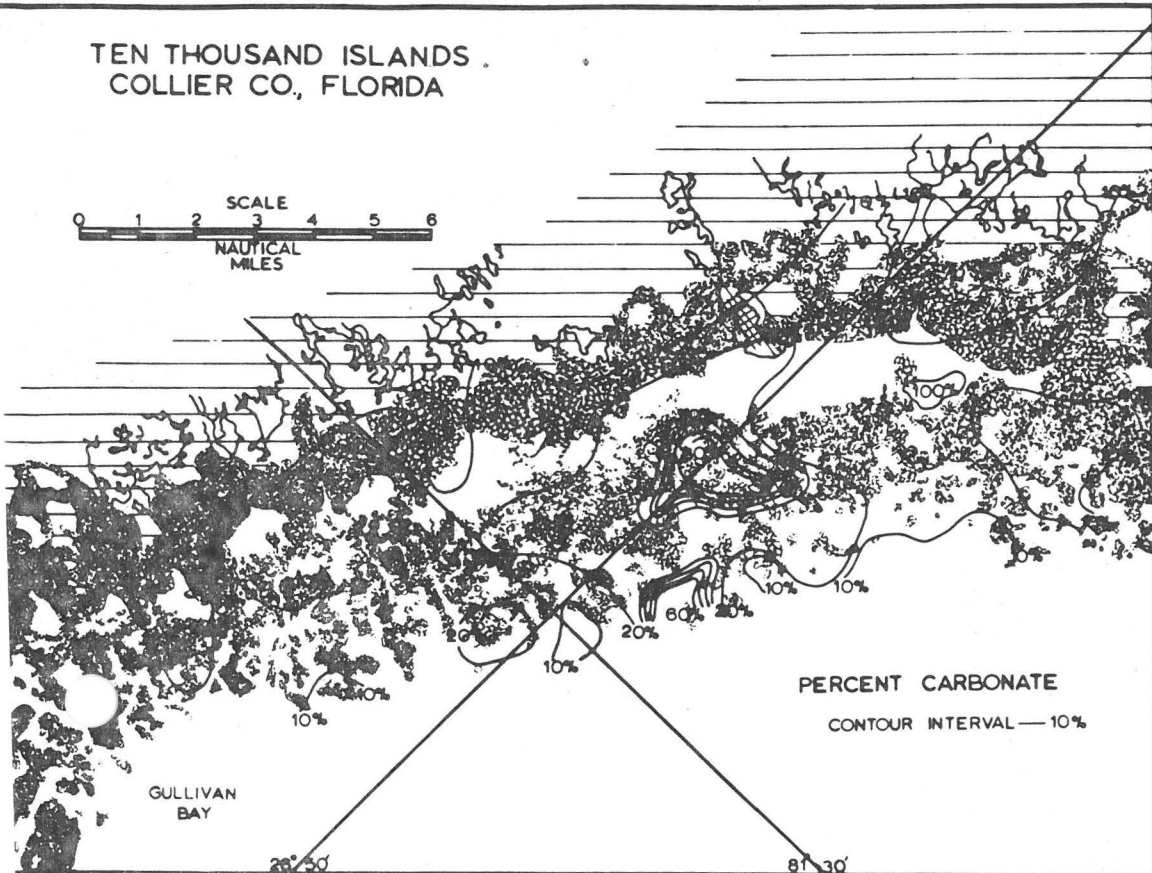
Organic Content

The investigation of organic matter has been restricted to bottom surface and is based mainly on a determination of the carbon and nitrogen percentages. The carbon cycle in

Fig. 15A: Percent carbonate map

Fig. 15B: Percent carbonate cubic surface

TEN THOUSAND ISLANDS COLLIER CO., FLORIDA



the sea forms a partially open system. The carbon dioxide is removed from the sea water by organisms and is utilized partly for their carbonate structure. The bulk, however, of the carbon is consumed in synthesis of organic compounds. In the second case most of the carbon returns to solution in the form of carbon dioxide, which occurs under oxidizing conditions. Under reducing conditions the anaerobic bacteria generate various products of putrefaction. If the calcareous structures are dissolved, the carbon, in the form of carbon dioxide, is returned to solution. However, there is always some lost in the cycle because neither the decomposition of the organic matter nor the dissolution of the calcium carbonate is complete (Rankama and Sahama, 1949).

In the analysis of the sediment sample of the Ten Thousand Islands, the carbon of the calcium carbonate, the carbon of the partially decomposed organic matter which has been washed in, and the non-decomposed carbon compounds were found. The carbon, then, is taken as an index of the total organic material in the sediment.

Nitrogen, which follows a cycle similar to carbon, is also an index to organic material. Since nitrogen is found principally in protein, the carbon-nitrogen ratio is an index to the type of organic material present. This may also represent the degree of alteration of the organic material in the sediment. In the modern sediment

a low ratio gives a clue to high protein content, whereas a high ratio indicates low protein content. A low ratio could mean that there is a high percentage of animal material in the sample, whereas a high ratio indicates a high percentage of plant material or a high degree of alteration which removed the protein from the sample. A further study of the organic material is needed to determine what the carbon-nitrogen ratio of a region means.

The areal distribution of the carbon percentage is shown in fig. 16. The carbon percentage ranges from a few tenths of a percent to twenty-three percent. The higher percentages are due to the plant debris in the swamp. The pattern of the carbon distribution delineates high percentages in the back swamp. High percentages are also present in the highly protected region behind Rabbit Key. The regional surface of the carbon percentage shows that the percent carbon increases toward the mainland. The surface dips toward the Gulf at about three percent per mile.

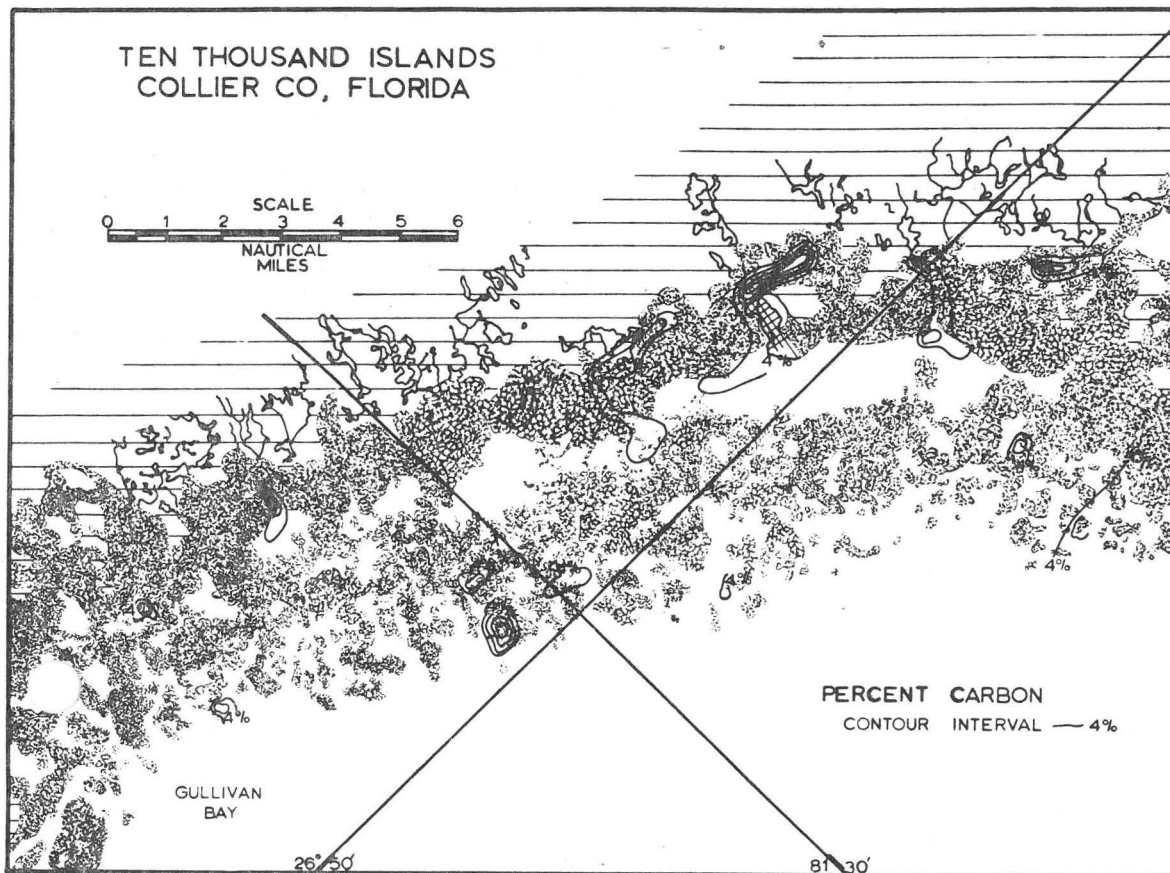
Fig. 16 shows the carbon-nitrogen ratio distribution. The map shows the high ratios of the swamp and the protected region behind Rabbit Key. The high ratio in this region is due to the abundance of plant material rather than animal material.

Fig. 16A: Percent Organic Carbon

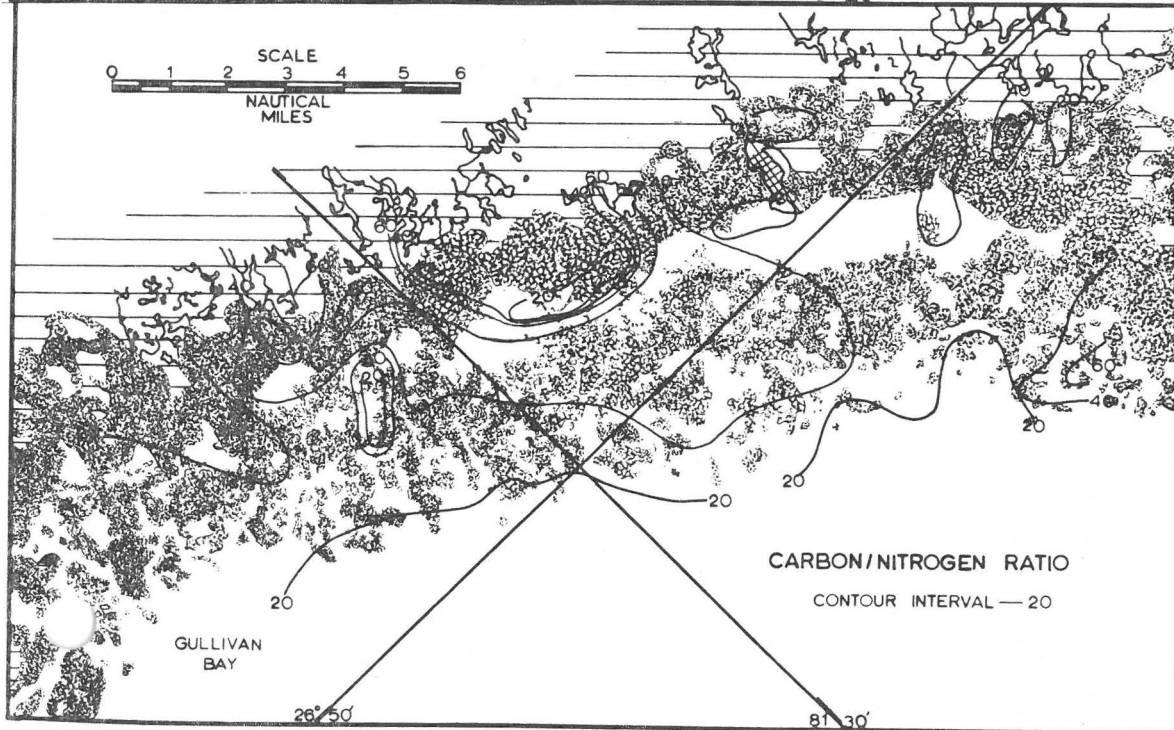
Fig. 16B: Carbon-Nitrogen ratio map

TEN THOUSAND ISLANDS
COLLIER CO, FLORIDA

SCALE
0 1 2 3 4 5 6
NAUTICAL
MILES



SCALE
0 1 2 3 4 5 6
NAUTICAL
MILES



Hydrogen Ion Concentration

The hydrogen ion concentration (pH) of the sediments is an indicator of the physical-chemical environment within the sediment and at the sediment-water interface. The acidity or alkalinity of an environment is an important factor in determining whether or not certain minerals will precipitate or be dissolved. The measurement of the pH was accomplished with a Beckman pH meter and is considered to be accurate to one tenth of one unit. The study of pH is only a cursory one, inasmuch as measurements were taken only at core stations.

Krumbein and Garrels (1952) defined three environments based on acidity, namely the most acid (pH less than 7.0); a more nearly neutral environment (pH 7.0 to 7.8); and an alkaline environment (pH over 7.8). According to this scheme, the most acid environment will produce peat; in the more nearly neutral environment silicates, organic material and other matter will form; in the alkaline environment calcite will precipitate.

The pH in the Ten Thousand Islands ranges from 7.9 in the open waters and lagoons to 6.8 in the mangrove wamp. The pH decreases with depth in the cores taken from the mangrove barrier and the mangrove swamp, whereas in the cores taken on the outer fringes of the islands the pH increased slightly with depth. The decrease in pH

readings toward the mangrove swamp is corroborated by the decrease of the fine calcium carbonate. In the sediment samples of the mangrove swamp no trace of carbonate was found in the fine grain size fraction. Also there were no calcium secreting micro-organisms found in the samples (Benda, 1961).

Clay Mineralogy

The study of the clay mineral distribution is only of a cursory nature. The clay minerals were identified and a rough approximation of the predominant clay minerals present was made by x-ray diffraction methods. The samples used were selected in order to give a representative cross section of the environments of the area. Montmorillonite, chlorite, kaolinite and illite were identified from clay size fraction of selected sediment samples. Chlorite appears to be mixed with the montmorillonite, and dominates the montmorillonite (K. Osmond, personal communication).

Two principle types of clay mineral assemblages were found to be present: a kaolinite assemblage with minor amounts of montmorillonite, chlorite, and illite, dominating the mangrove swamp sediments; and a chlorite assemblage with minor amounts of montmorillonite and kaolinite found in the near marine environments of the lagoonal chain and the open Gulf. The presence of illite is marked only in

the southern portion of the study area; however, illite is believed to be the predominant clay mineral in the off-shore area (R. G. Evans, personal communication).

In addition to the carbonates, silica and the forms of iron sulfide which are pH-sensitive, it is believed that kaolinite requires an acid environment for its formation, whereas montmorillonite is most stable in an alkaline environment (Millot, 1949). The distribution of the clay minerals seems to meet with the environmental conditions as given by Millot. Kaolinite is dominant in the acidic environment of the mangrove swamp, whereas montmorillonite and illite dominate the alkaline environments of the lagoons and the open Gulf. These clay assemblages may be of some help in future interpretations of such environments. However, further study of the clay minerals would be necessary to determine what effects will occur during diagenesis.

Cores

In an attempt to give a three dimensional aspect to the study, cores ranging from two to four feet in length were taken at representative sites. The core stations were chosen to give the most complete cross section possible of the environments of the region. The cores were for the most part devoid of internal structure such as has been reported in other sediment studies (Scruton and Moore, 1956). In a few cores peat layers and some sand lenses

were found.

Texturally the cores maintained the same mean grain size and sorting with depth. The carbon-nitrogen ratio increased with depth, giving some indication of the alteration of the plant and animal material in the sediment. The carbonate percentage showed neither an increasing nor decreasing trend with depth. It is believed that the carbonate is being leached from the sediment especially in the swamp area. Evidence for this is given by the pH which decreases with depth, and the absence of calcareous micro-organisms with depth. The shells that were found in the cores were badly corroded, indicating chemical attack in the acidic environment.

SUMMARY

The sediments of the Ten Thousand Islands overlie the wave-eroded surface of the Tamiami formation. These sediments combine with the mangroves and underlying ancient shell bars to form the low-lying islands. The build-up of the islands is due to the entrapment of the inorganic material in the quiet water around the mangroves and also to the many mollusks which inhabit the area.

There are four physiographic divisions discernible in the area. The mangrove barrier extends through the central portion of the study area. This mangrove barrier, which

is dissected by many tidal channels, separates the open Gulf from the bay chain. The bay chain, a group of bays, is connected by small inlets cutting across what is believed to have been old oyster bars. The bay chain is bounded on the northeast by the fourth physiographic province, the mangrove swamp.

The shoreline is very irregular and difficult to delineate. There is a diagnostic feature which could be used to determine the modern shoreline. This is the presence of the "worm rock", which is found only on the outer edge of the islands and is limited to the littoral zone. The rock forms ledges which seem to be restricted by the tidal range. The "worm rock" is present throughout the entire area from Coon Key to Lopas River 35 miles to the south. From Hog Key to Indian Key the "worm rock" ledges are covered by sand in the north and by shell hash in the south. South of Coon Key the rock forms spits which extend out into Gullivan Bay. South of Indian Key the rock hugs the fringes of the islands. Off some of the islands the "worm rock" forms ledges below the low tide water level. These ledges may indicate the tidal range at a lower stand of the sea.

The predominant transporting agent in the Ten Thousand Islands is the tide. The tide in this region is the mixed type and ranges from four feet at Pavilion

Key to two feet at Marco Pass. Wind-generated waves play only a minor part in the distribution of sediment, and probably act only as an agitating force.

The highest tidal range in this section of the Gulf occurs at Pavilion Key. The reason for this is that the concavity of the coast causes a tidal bulge. The high tide in this region is believed to be the cause of the strong tidal currents.

Both the total texture and the non-carbonate texture define environmental conditions. The presence of the large carbonate particles in the total sediment sample defines one environment not discernible from the non-carbonate fraction. This environment is the shoal bar, generally marked by a great deal of oysters and other carbonate secreting organisms. In general the fine material is located in the protected regions of the mangrove barrier and the mangrove swamp. Coarse material is found in the open Gulf on the fringe of the islands, in the channel bottoms and in the northern swamp area near the old shoreline. The sediments in the lagoons and bays are, according to the classification used in this paper, medium grained in size and poorly sorted. In the southern section of the mangrove barrier around Rabbit Key, the sediment is composed of fine, poorly sorted material.

The calcium carbonate in the islands and bays was derived from oyster shells and other carbonate-secreting organisms. Most of these organisms are restricted to the Gulf side of the bays. A small percentage of calcium carbonate is found in the channels adjacent to the bays, due to the presence of a few oyster bars. The relatively high percentage of calcium carbonate found on the Gulf side of the islands is due to the presence of the worm rock and shell fragments.

The carbon content of the sediments is high as compared to normal marine sediments. The highest carbon percent is found in the fine grained sediment of the mangrove swamp and the mangrove barrier. The carbon-nitrogen ratio is large indicating a high percentage of plant material.

The pH in the region shows that acidic conditions prevail in the mangrove swamp and slightly basic conditions are present throughout the rest of the area. The clay minerals present in the region are kaolinite, montmorillonite, illite, and an interlayered montmorillonite-chlorite. The kaolinite predominates in the acidic protected areas, whereas montmorillonite predominates in the more normal marine environments. Illite is present only in the southern end of the study area and in the open Gulf.

CONCLUSIONS

Observations pertinent to the objectives of this paper as stated in the introduction have been discussed in various sections. The conclusions of these observations are discussed here.

The Ten Thousand Islands is a region of low physical energy as is manifested by the swampy shoreline. The tidal high created in the area is responsible for the strong tidal currents. These currents produce the tidal lag and scour effect which accounts for the distribution of most of the sediments of the region. With the predominant wind offshore, the tidal range is lower than it might otherwise be.

Ground swells derived from storms in the Gulf create an onshore movement of sediment. The presence of the shoals refracts these waves so that there is always a frontal attack on the islands. These waves, however, have lost most of their energy because of the refraction of the shoal and the gentle shoaling. Waves, due to local variable winds, are only of minor importance, but they do serve as an agitating agent in stirring up the

fine material for distribution by the tidal currents.

The quartz sand in the study area is derived from two different sources. The coarse quartz sand is derived from the ancient shoreline in the north. This sand is transported and deposited in the rivers as bars, and at the mouths of the rivers as deltas. Finer quartz sand, as the result of the longshore drift from the north, is deposited on Cape Romano and in the Cape Romano Shoals. These two sand populations become mixed in the region behind Cape Romano.

The carbonate content of the samples is a function of the amount of shell hash, shells and micro-organisms. The distribution of the carbonate is due to the migration of calcium-secreting organisms, to the lag effects of the currents and to the population of numerous shell bars.

The formation of the islands is due to four major factors: the ancient surface, the migration of the mangroves, the formation of the shoals, and subsequent strong tidal currents. The history of formation of the islands may have been somewhat as follows: On the broad shelf of southern Florida, during a somewhat high stand of the sea, the old shoreline was formed. Off this shoreline there were many shell bars in the form of patch reefs all

trending along the shoreline. With a lowering of the sea level these shell bars became shoal bars, and conditions became right for the mangroves to take root on these bars. The lowering of the sea also caused the longshore drift of sand to change to a more southerly direction. This change resulted in the formation of the Cape Romano Shoals.

The shoals formed a protective setting for the mangrove forest to take root and grow. These shoals also produced conditions which caused strong tidal currents to flow into the region behind them. These currents kept the inlets between the original shell bars open, and the result of the currents and the mangrove growth is the dissected region of the Ten Thousand Islands.

If the area of study were lithified, there would be a zone of fossiliferous limestone, overlain by sand beds in the north-central part on the outer edge of the study area. In an inter-zone there would be beds of carbonaceous silty material and peat (some form of coal). This zone would be dissected by channels filled with coarse shell fragments and sand. The lagoon and bay zones would be represented by fine silt with biostromes present on the edges. The swamp region would be represented by coal and coarse sand in the north. If the calcium carbonate were all leached away, only the

carbonaceous material and the quartz sand would be left for interpretation. The quartz sand would give an investigator some clue to the energy conditions, and the carbonaceous material would be a good clue to the swamp conditions. The clay mineral assemblages might also be good indications to the environments of the region.

In a study such as this there are many features overlooked at the time as unimportant, which later appear as important in understanding the history or geology of a region. One of the features which was only given a cursory study was the worm rock. More work needs to be done on this feature to find its exact relation to the area, and to find how it effects the sediment distribution of the region. More work needs to be done on the chemical processes controlled by pH and on the clay mineral distributions. These data would give valuable information about the processes at work in such an area and would be of great value in the study of areas which are suspected to be similar in environment and formation.

Appendix I

Sample No.	Total Texture		Non-Carbonate Texture	
	Mean	Sorting	Mean	Sorting
1	1.78	0.68	1.77	0.66
2	2.17	0.57	2.17	0.56
3	3.28	3.42	4.15	2.98
4	2.29	1.48	2.41	1.34
5	6.27	2.30	6.27	2.30
6	2.20	0.61	2.18	0.58
7	3.23	2.88	4.76	2.64
8	2.71	1.71	2.86	1.57
9	5.39	3.75	7.17	2.48
10	5.39	3.75	7.17	2.48
11	5.14	3.18	5.58	3.03
12	6.26	3.98	7.54	2.73
13	2.44	1.91	2.68	1.81
14	6.80	2.88	6.96	2.72
15	3.56	2.16	3.77	2.07
16	5.28	3.23	5.40	3.19
17	2.68	2.15	3.00	1.87
18	2.30	1.15	2.53	0.64
19	2.89	2.39	2.99	2.36
20	2.96	2.31	3.15	2.26
21	2.06	0.76	2.14	0.64
22	2.25	1.39	2.66	0.68
23	3.68	2.97	4.00	2.69
24	1.39	3.17	3.30	2.65
25	3.48	2.83	4.02	2.78
26	6.86	3.93	7.96	3.06
27	2.41	1.10	2.59	0.88
28	3.38	3.55	4.32	3.41
29	2.69	3.64	4.64	3.23
30	0.45	3.42	6.33	3.25
31	0.04	1.76	2.69	0.91
32	2.23	0.78	2.31	0.47
33	4.36	2.89	4.46	2.88
34	7.36	3.20	7.80	3.11
35	2.78	2.38	3.05	2.36
36	3.77	3.63	5.36	2.81
37	7.98	3.19	8.00	3.11
38	3.69	2.81	4.16	2.46
39	3.09	2.99	3.85	2.16
40	3.60	3.77	5.29	3.29
41	1.89	4.61	6.16	3.02
42	0.55	3.29	5.15	3.09
43	1.25	4.06	5.25	3.77
44	3.61	3.11	4.37	2.88
45	-1.74	1.52	2.66	0.92
46	5.83	3.28	6.00	3.23
47	0.63	1.74	2.04	0.54

Appendix I (cont.)

Sample No.	Total Texture		Non-Carbonate Texture	
	Mean	Sorting	Mean	Sorting
48	0.53	2.16	2.46	1.64
49	6.61	3.76	7.93	3.04
50	2.29	0.31	2.30	0.51
51	5.11	3.31	5.47	2.97
52	3.74	2.36	3.95	2.17
53	8.27	2.47	8.27	2.47
54	4.03	2.21	4.28	2.04
55	2.17	2.09	2.59	1.89
56	-0.67	2.63	2.93	2.49
57	4.26	3.35	4.87	2.26
58	--	--	--	--
59	3.99	1.99	4.17	1.98
60	-1.33	2.11	2.89	1.14
61	5.18	3.21	5.47	3.02
62	4.93	2.96	5.09	0.91
63	-0.42	1.47	1.68	0.49
64A	2.03	0.86	2.12	0.63
64	5.09	2.95	5.49	2.73
65*	5.63	2.96	6.19	2.76
66	2.53	2.04	2.77	1.97
67	4.32	2.46	4.48	2.39
68	4.17	2.85	4.38	2.87
69	2.66	2.35	4.14	2.33
70	4.36	2.53	4.82	2.65
71	2.84	1.90	2.86	1.75
72	3.32	1.87	3.46	2.15
73	2.84	0.91	2.85	0.89
74	3.20	1.86	3.37	1.81
75	2.71	1.69	2.86	1.63
76	4.26	2.77	4.41	2.78
77	5.21	3.46	5.74	3.16
78	5.76	3.38	6.26	3.01
79	2.06	1.16	2.38	0.68
80	2.33	1.52	2.78	1.26
81	4.36	3.13	4.59	3.11
82	2.33	2.28	3.06	1.96
83	3.09	2.75	3.58	2.85
84	3.26	2.41	3.69	2.43
85	4.07	2.73	4.35	2.71
86	4.39	2.66	4.55	2.64
87	3.67	2.77	4.03	2.76
88	2.93	2.51	3.27	2.41
89	2.51	2.55	3.33	2.53
90	3.33	2.54	3.62	2.43
91	4.32	3.06	4.47	2.96
92	1.02	2.93	3.64	2.05
93	3.39	2.43	4.09	2.49
94	5.36	3.19	5.86	2.88

Appendix I (cont.)

Sample No.	Total Texture		Non-Carbonate Texture	
	Mean	Sorting	Mean	Sorting
95	3.96	2.69	4.73	2.97
96	3.35	2.34	3.40	2.35
97	3.36	2.59	3.79	2.44
98	4.98	3.67	5.79	3.24
99	4.37	3.15	4.86	2.93
100**	1.63	0.47	1.65	0.47
1CT	2.23	1.52	2.48	1.25
1CB	1.68	4.44	6.43	2.84
2CT	5.12	2.71	5.28	2.64
2CM	8.15	2.60	8.68	1.82
2CB	5.05	2.83	6.07	2.83
3CT	4.61	3.63	4.85	2.62
3CM	5.09	3.37	6.41	2.64
3CB	4.57	3.04	5.26	2.87
4CT	6.09	2.12	6.09	2.12
4CM	3.42	1.26	3.42	1.26
4CB	6.29	2.41	6.30	2.32
5CT	2.36	0.91	2.39	0.86
5CM	2.01	1.20	2.03	1.11
5CB	2.56	1.50	2.60	1.46
1WT	2.75	0.94	2.86	0.69
1WB	2.71	0.96	2.73	0.95
2WT	5.32	3.66	6.18	3.91
2WB	3.55	2.58	3.89	2.45
3WT	4.92	3.37	5.48	3.11
3WB	3.43	2.41	3.81	2.27
4WT	4.14	3.88	5.88	3.12
4WB	4.48	3.59	5.93	2.87
5WT	4.37	3.66	4.41	3.63
5WM	5.96	3.34	5.96	3.32
5WB	6.11	3.67	6.11	3.65
1HT	5.52	3.09	5.82	2.99
1HM	5.46	3.91	7.16	2.70
1HB	5.29	3.77	6.56	2.82
2HT	7.08	2.71	7.43	2.24
2HM	5.17	3.43	6.30	2.45
2HB	6.32	3.15	7.64	2.55
3HT	4.12	3.56	5.58	2.78
3HM	4.38	3.21	5.48	2.83
3HB	5.16	3.16	5.86	2.64
4HT	4.03	2.97	4.62	2.59
4HM	6.89	3.37	7.07	3.23
4HB	6.63	3.67	7.41	2.89
5HT	5.93	3.23	4.68	3.03
5HM	2.83	2.60	3.79	2.42
5HB	2.07	2.23	1.07	1.13

Appendix II

Sample No.	CaCO ₃ %	CaCO ₃ X	C%.	N%	C/N
1	6.79	1.85	0.37	0.03	12.46
2	0.06	----	0.53	0.05	11.19
3	17.92	0.70	16.17	0.16	98.59
4	3.64	-0.63	2.36	0.03	97.60
5	----	----	21.81	0.77	28.00
6	1.91	3.22	0.41	0.03	15.76
7	44.11	1.27	9.41	0.17	48.91
8	19.55	2.07	8.41	0.12	70.00
9	28.44	0.91	2.63	0.11	24.16
10	6.40	0.54	10.64	0.33	32.60
11	11.91	1.88	2.03	0.06	32.20
12	15.96	0.46	8.23	0.16	50.49
13	14.76	1.03	0.39	0.38	10.40
14	2.86	1.24	7.64	0.21	36.04
15	10.98	1.82	1.43	0.06	24.67
16	3.57	1.89	1.88	0.09	19.61
17	9.26	-0.47	2.55	0.08	31.09
18	19.10	1.38	21.31	0.26	81.96
19	4.23	0.66	1.09	0.08	12.90
20	7.91	0.86	1.37	0.06	24.50
21	4.56	0.59	0.83	0.06	13.50
22	15.62	0.02	9.09	0.05	27.90
23	9.88	0.00	2.72	0.04	75.58
24	44.28	-1.02	0.78	0.05	14.69
25	19.42	1.27	0.89	0.06	15.94
26	15.07	0.68	8.47	0.21	40.75
27	17.30	1.52	0.16	0.03	4.70
28	27.49	0.92	17.46	0.24	72.14
29	39.93	-0.38	1.66	0.09	19.03
30	81.93	-0.85	0.88	0.06	14.33
31	94.02	-0.13	0.82	0.07	11.92
32	1.69	-2.41	0.12	0.01	17.71
33	4.10	2.20	9.04	0.31	29.15
34	3.11	-0.36	21.31	0.77	27.34
35	13.45	1.00	2.21	0.19	11.82
36	28.93	-0.15	1.52	0.15	9.74
37	0.36	0.00	20.96	0.77	27.18
38	9.92	-0.61	23.69	0.46	51.30
39	21.69	0.38	3.56	0.23	15.41
40	36.89	0.71	3.56	0.57	6.15
41	54.44	-1.68	4.56	0.09	48.45
42	76.57	-0.85	2.47	0.12	24.05
43	62.41	-1.16	1.46	0.05	27.47
	18.91	0.36	1.25	0.04	35.57
	94.05	-2.01	3.74	0.14	26.48
46	4.96	2.62	3.62	0.08	43.66
47	51.33	-0.71	0.56	0.01	40.40
48	62.73	-0.62	0.46	0.03	15.93

Appendix II

Sample No.	CaCO ₃ %	CaCO ₃ X	C%	N%	C/N
49	22.03	2.28	22.96	0.94	23.00
50	1.61	1.58	0.45	0.04	10.50
51	6.20	-0.31	9.68	0.38	25.10
52	5.65	-0.21	4.25	0.24	17.86
53	0.00	----	23.75	0.14	16.00
54	8.74	1.38	8.66	0.44	10.81
55	15.24	-0.18	1.26	0.04	30.68
56	74.94	-1.86	1.68	0.06	27.67
57	17.19	1.32	3.65	0.08	4.50
58	100.00	-6.00	----	----	----
59	15.72	2.55	2.38	0.00	23.70
60	88.60	-1.87	6.77	0.03	22.56
61	6.48	1.00	9.25	0.04	32.68
62	5.96	2.23	2.46	0.08	31.22
63	77.91	-1.01	0.11	0.02	8.29
64A	12.28	1.38	0.45	0.00	----
64	9.91	1.42	8.78	0.16	54.20
65*	15.39	2.53	5.52	0.12	46.80
66	13.78	1.05	1.05	0.03	35.00
67	5.68	1.69	1.45	0.06	23.40
68	10.57	2.58	2.76	0.02	137.75
69	53.72	1.39	1.46	0.04	36.50
70	22.94	2.83	4.09	0.09	44.00
71	7.54	2.52	2.97	0.03	102.30
72	35.34	3.05	1.03	0.04	24.97
73	5.61	2.78	0.13	0.01	10.20
74	13.46	2.11	0.77	0.02	32.00
75	8.16	1.06	0.47	0.33	14.15
76	6.45	1.06	2.83	0.06	44.22
77	10.04	0.42	4.03	0.05	75.60
78	8.71	0.49	5.64	0.12	46.40
79	14.67	0.18	0.12	0.03	3.34
80	21.03	0.61	1.15	0.05	24.50
81	11.95	1.78	2.03	0.05	41.40
82	23.14	-0.12	2.18	0.05	44.40
83	25.77	1.68	1.91	0.05	40.70
84	24.08	1.90	2.04	0.07	26.57
85	11.36	1.91	4.57	----	----
86	7.58	2.56	1.70	0.05	32.75
87	14.36	1.56	2.95	0.09	32.41
88	12.36	0.51	1.66	0.08	21.03
89	29.01	0.51	2.39	0.11	22.50
90	10.42	0.92	3.69	0.03	131.92
91	3.71	0.44	2.59	0.04	53.90
92	61.72	-0.60	2.59	0.04	73.90
93	20.21	1.66	4.62	0.04	113.61
94	9.63	0.65	9.03	0.14	64.52

Appendix II (cont.)

Sample No.	CaCO ₃ %	CaCO ₃ X	C%	N%	C/N	pH
95	33.64	2.43	1.09	0.05	20.98	
96	5.96	1.67	2.50	0.05	51.08	
97	11.85	0.30	4.97	0.06	73.10	
98	14.68	0.28	6.26	0.08	75.40	
99	11.54	0.62	2.53	0.19	24.30	
100**	18.62	1.51	----	----	----	
1CT	17.54	1.03	10.84	0.11	99.50	7.2
1CB	61.91	-1.23	8.34	0.12	70.07	7.0
2CT	4.51	1.55	6.34	0.14	45.30	7.2
2CM	8.84	2.58	10.22	0.14	72.24	7.1
2CB	32.93	2.98	6.89	0.08	63.00	7.2
3CT	10.01	2.46	3.15	0.04	68.19	6.9
3CM	24.89	1.08	3.12	0.04	82.15	7.2
3CB	20.21	1.84	3.22	0.03	94.60	6.8
4CT	00.00	----	10.69	0.11	96.70	7.9
4CM	00.00	----	11.73	0.06	195.50	6.8
4CB	0.15	----	15.28	0.07	219.29	6.7
5CT	2.49	0.89	1.81	0.03	62.20	7.6
5	5.64	1.81	2.84	0.04	81.05	7.0
5C	2.27	0.95	2.85	0.01	237.50	6.9
1WT	6.35	1.00	1.07	0.03	38.00	7.1
1WB	1.95	1.53	6.29	0.06	98.20	7.2
2WT	15.59	0.63	9.84	0.13	76.30	7.1
2WB	7.52	0.63	6.90	0.05	153.35	6.8
3WT	11.59	0.70	10.13	0.04	215.46	7.1
3WB	13.83	1.03	6.95	0.07	103.73	6.9
4WT	29.29	0.07	6.91	0.17	50.42	7.1
4WB	27.36	0.63	5.56	0.11	32.89	6.8
5WT	0.69	0.00	0.91	0.07	26.31	7.2
5WM	0.00	----	12.44	0.05	243.30	6.8
5WB	0.00	----	6.84	0.04	171.00	6.0
1HT	8.04	2.07	14.04	0.04	127.50	7.3
1HM	28.06	0.10	13.96	0.16	84.60	7.1
1HB	18.68	-0.20	18.76	0.15	112.00	6.9
2HT	4.88	0.34	18.88	0.11	174.00	7.1
2HM	17.44	-0.21	10.33	0.04	215.00	7.1
2HB	16.91	-0.15	8.91	0.01	43.10	7.3
3HT	27.60	0.29	6.76	0.05	130.00	6.9
3HM	26.28	1.27	4.44	0.05	98.70	6.8
3HB	12.56	0.29	4.86	0.04	107.70	7.1
4HT	13.66	0.27	3.13	0.07	41.20	7.2
4HM	2.76	0.61	0.75	0.08	9.50	6.8
4HB	10.37	-0.08	1.39	0.03	42.00	6.6
5	16.93	0.51	6.91	0.34	20.32	6.9
5C	37.27	1.21	4.85	0.13	38.30	6.8
5HB	00.00	----	6.53	0.18	40.70	6.6

Appendix III
Sediment Types

Sample No.	% Shell	% Sand	% Silt	% Clay	Sed. Types
1	00.00	100.00	00.00	00.00	Sand
2	00.00	100.00	00.00	00.00	Sand
3	9.12	64.23	19.74	6.94	Silty Sand
4	1.97	93.38	2.34	0.28	Sand
5	0.17	7.84	77.04	15.04	Silt
6	0.02	99.98	00.00	00.00	Sand
7	6.05	70.49	18.72	4.74	Silty Sand
8	2.64	87.23	9.67	0.44	Sand
9	4.54	26.78	51.45	17.45	Sandy Silt
10	00.00	11.04	86.32	2.62	Silt
11	0.78	57.82	36.39	14.96	Silty Sand
12	5.57	26.97	60.37	23.87	Silt
13	1.95	94.24	3.23	2.52	Sand
14	00.00	11.95	63.87	24.18	Silt
15	1.91	80.34	15.55	2.19	Sand
16	0.14	54.34	26.66	15.82	Silty Sand
17	4.69	83.80	10.11	1.38	Sand
18	4.34	95.66	00.00	00.00	Sand
19	0.73	86.59	7.59	4.84	Sand
20	0.62	86.75	8.85	3.76	Sand
21	0.42	99.57	0.08	00.00	Sand
22	5.17	95.92	0.91	00.00	Sand
23	4.41	71.51	17.51	6.59	Silty Sand
24	28.76	63.33	2.92	4.97	Shelly Sand
25	3.41	71.94	18.18	5.73	Silty Sand
26	3.02	21.37	29.34	39.24	Sandy Silt
27	1.05	97.28	1.57	0.07	Sand
28	8.99	65.28	14.51	11.21	Silty Sand
29	13.83	62.69	15.25	8.23	Sh Si Sand
30	47.81	40.70	6.77	4.51	Sandy Shell
31	32.91	66.33	0.76	00.00	Shelly Sand
32	1.58	98.32	00.00	00.00	Sand
33	0.32	67.16	17.76	12.86	Silty Sand
34	00.00	17.34	42.03	40.63	Silt
35	2.21	68.70	26.81	2.91	Silty Sand
36	11.61	50.51	30.22	7.66	Sh Si Sand
37	00.00	18.39	30.54	51.06	Silty Clay
38	4.28	51.87	25.87	1.83	Silty Sand
39	6.81	71.90	13.97	7.31	Silty Sand
40	13.84	55.01	20.04	11.15	Sh Si Sand
41	41.59	25.59	21.94	10.88	Sd Si Shell
42	38.59	48.69	9.18	3.04	Sh Si Sand
43	37.53	47.41	6.14	8.92	Silty Sand
44	3.38	76.89	17.41	3.58	Silty Sand
45	81.52	18.48	00.00	00.00	Shell
46	0.05	45.16	30.29	24.54	Sandy Silt

Appendix III (cont.)
Sediment Types

Sample No.	% Shell	% Sand	% Silt	% Clay	Sed. Type
47	25.88	74.11	00.00	00.00	Shelly Sand
48	26.91	57.89	14.45	0.76	Sh Si Sand
49	00.00	24.45	50.93	34.72	Sandy Silt
50	0.07	99.83	00.00	00.00	Sand
51	3.07	24.99	59.02	12.92	Sandy Silt
52	2.49	72.67	21.06	4.38	Silty Sand
53	00.00	00.00	73.64	26.37	Clay Silt
54	00.00	66.49	28.46	5.03	Silty Sand
55	5.89	87.56	4.06	2.49	Sand
56	60.83	35.78	1.60	1.79	Sandy Shell
57	1.06	69.37	13.05	16.55	Silty Sand
58	100.00	00.00	00.00	00.00	Shell
59	0.74	56.33	39.04	4.00	Silty Sand
60	0.41	52.15	30.09	17.34	Silty Sand
61	73.35	26.65	00.00	00.00	Sandy Shell
62	0.64	61.51	22.72	15.15	Silty Sand
63	41.32	58.68	00.00	00.00	Shelly Sand
63A	1.30	98.70	00.00	00.00	Sand
64	1.78	48.27	49.94	10.13	Silty Sand
65*	1.68	39.70	46.13	12.50	Sandy Silt
66	2.26	89.59	5.88	2.27	Sand
67	0.49	66.59	27.74	5.23	Silty Sand
68	0.87	69.56	21.83	7.74	Silty Sand
69	5.59	77.33	15.92	1.15	Silty Sand
70	0.16	64.43	31.21	5.23	Silty Sand
71	0.16	89.71	8.59	1.58	Sand
72	1.15	85.60	10.58	2.74	Sand
73	0.08	99.92	00.00	00.00	Sand
74	1.36	87.03	6.36	3.35	Sand
75	0.69	92.66	3.71	0.94	Sand
76	0.25	59.23	30.99	9.59	Silty Sand
77	0.36	44.17	40.53	14.94	Sandy Silt
78	2.56	31.57	65.89	00.00	Sandy Silt
79	3.26	95.58	1.15	00.00	Sand
80	2.98	86.67	12.36	00.00	Sand
81	1.89	66.82	22.23	9.85	Silty Sand
82	7.00	78.32	13.77	0.90	Silty Sand
83	3.56	75.73	23.71	5.84	Silty Sand
84	1.70	80.53	13.32	4.44	Sand
85	00.00	69.94	21.85	8.21	Silty Sand
86	0.29	57.91	31.96	9.84	Silty Sand
87	1.11	76.89	16.14	6.96	Silty Sand
88	3.81	82.73	8.23	5.21	Sand
89	2.53	78.39	15.25	3.84	Silty Sand
90	1.68	81.56	11.19	5.58	Sand
91	0.89	50.19	28.27	11.64	Silty Sand
92	19.82	69.54	7.33	3.31	Sh Si Sand

Appendix III (cont.)
Sediment Types

Sample No.	% Shell	% Sand	% Silt	% Clay	Sed. Type
93	1.15	74.97	20.73	5.15	Silty Sand
94	00.00	39.19	52.17	8.64	Sandy Silt
95	0.40	72.14	19.19	7.57	Silty Sand
96	0.39	79.73	16.29	3.59	Silty Sand
97	1.97	71.52	23.00	3.53	Silty Sand
98	5.16	45.46	31.46	17.93	Silty Sand
99	3.19	55.12	33.17	8.49	Silty Sand
100**	0.09	99.91	00.00	00.00	Sand
1CT	1.78	98.22	00.00	00.00	Sand
1CB	43.37	27.83	25.19	3.54	Sd Si Shell
2CT	00.00	56.89	32.73	10.38	Silty Sand
2CM	00.00	10.69	89.41	27.59	Silt
2CB	1.04	47.63	38.81	12.55	Sandy Silt
3CT	0.16	61.48	32.06	6.31	Silty Sand
3CM	00.00	37.75	53.44	8.80	Sandy Silt
3CB	3.43	51.39	35.62	9.56	Silt
4CT	00.00	00.00	89.86	10.19	Silt
4CM	00.00	95.39	4.61	00.00	Sand
5CT	00.00	11.19	73.94	14.86	Silt
5CB	0.16	98.09	1.67	0.07	Sand
5CM	0.28	97.63	1.67	0.41	Sand
5CB	0.09	94.07	4.71	1.13	Sand
1WT	1.64	96.64	1.73	00.00	Sand
1WB	00.00	95.65	4.23	0.13	Sand
2WT	4.24	45.51	31.12	19.13	Silty Sand
2WB	1.83	68.57	24.49	5.11	Silty Sand
3WT	2.87	54.10	27.64	17.38	Silty Sand
3WB	2.39	80.88	11.17	5.53	Sand
4WT	8.62	44.78	35.38	11.22	Silty Sand
4WB	7.06	44.69	35.79	12.45	Silty Sand
5WT	0.13	68.05	12.86	18.96	Silty Sand
5WM	00.00	40.31	28.62	31.07	Sandy Silt
5WB	00.00	48.49	14.93	36.57	Sandy Silt
1HT	0.20	42.04	39.87	17.88	Sandy Silt
1HM	4.66	31.82	45.07	18.42	Sandy Silt
1HB	7.26	42.34	36.27	14.13	Sandy Silt
2HT	1.07	8.49	77.78	12.66	Silt
2HM	2.79	22.92	61.29	9.88	Sandy Silt
2HB	6.15	15.17	53.60	25.18	Sandy Silt
3HT	9.32	44.91	39.30	6.46	Sh Si Sand
3HM	3.32	48.92	37.95	9.81	Silty Sand
3HB	3.62	30.21	54.22	11.94	Sandy Silt
4HT	4.67	55.61	30.03	9.69	Silty Sand
4HM	0.87	25.15	32.03	41.99	Sandy Silt
4HB	4.72	21.48	45.25	28.55	Sandy Silt
5HT	00.00	65.55	26.51	8.91	Silty Sand

Appendix III (cont.)
Sediment Types

Sample No.	% Shell	% Sand	% Silt	% Clay	Sed. Types
5HM	5.65	72.68	20.46	1.21	Silty Sand
5HB	00.00	100.00	00.00	00.00	Sand

Key:

- * Samples taken on the offshore grid
- ** Sample taken on the beach of Tiger Key
- T Top of core
- M Middle of core
- B Bottom of core

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