FLORIDA STATE UNIVERSITY

RECENT SEDIMENTARY HISTORY OF ST. JOSEPH BAY, FLORIDA

By
RICHARD A. STEWART

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fulfillment of the requirements for
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Approved:

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Dean of the Graduate School

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INTRODUCTION

Purpose of the Study

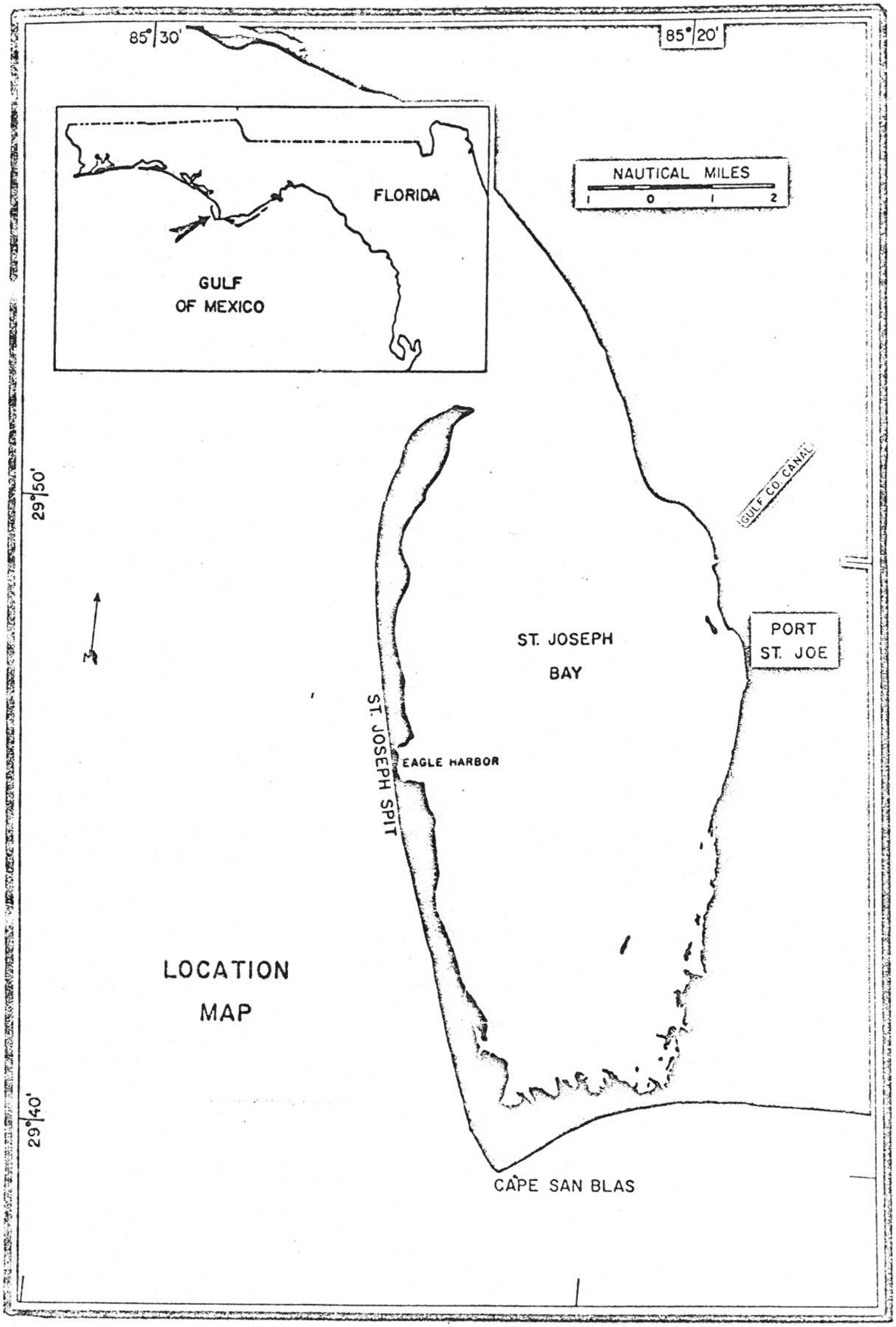
Marine strata contribute by far the largest percentage of the sedimentary rocks in the geologic column and in great part these are of shallow water origin. Only in recent years have near-shore environments begun to receive the attention necessary for adequate description and interpretation of the factors determining the sedimentary patterns and characteristics developed.

St. Joseph Bay is unique in being the only sizable body of water along the eastern portion of the Gulf Coast not of estuarine origin or markedly influenced by the influx of fresh water. It is the hope of the writer that the study of recent sedimentation in this bay may furnish useful information on yet another type of environment encountered along our present coastline.

Location and Extent

St. Joseph Bay, or more properly St. Joseph Lagoon, is located on the panhandle portion of the Florida West Coast in Gulf County (Fig. 1). The bounding spit encloses a body of water about eleven miles long and three to five miles wide opening to the north. This study includes a

Figure 1. - Location map of St. Joseph Bay, Florida.


85°30'
85°20'
FLORIDA
GULF
OF MEXICO
NAUTICAL MILES
1 0 1 2
GULF CO. CANAL
29°50'
PORT
ST. JOE
ST. JOSEPH
BAY
ST. JOSEPH SPIT
EAGLE HARBOR
LOCATION
MAP
29°40'
CAPE SAN BLAS

roughly rectangular area of approximately 140 square miles, extending from five miles southwest of Cape San Blas north and east to the mainland. About forty-six square miles lie within the lagoon.

Previous Investigations in the Area

The gross characteristics and shoreline features of this portion of the Gulf Coast have been well described by Price (1954). For the past several years members of the faculty and their graduate students at Florida State University have been engaged in near-shore studies along the west coast of the state, with special emphasis on the northern panhandle. W. F. Tanner (1959, 1960, 1961) has described the morphology and sediment-energy relationships of the coastal area and summarized the work of Brenneman (1957), Waskom (1958), Vause (1959), Mullins (1959), and others. Two studies have been completed recently on bays immediately to the east and to the west of St. Joseph Bay (Kofoed and Gorsline, 1962; Waller, 1961). A beach profile study along the panhandle coastline is presently in progress under the direction of D. S. Gorsline.

Works defining the bottom characteristics of the continental shelf and slope off this coast have been presented by Gould and Stewart (1955) and Jordan (1951).

A preliminary hydrographic survey of St. Joseph Bay by Plutchak, Trotts, Hambleton, and Milligan (1961) is the only work of this nature in the immediate study area. Offshore circulation and hydrography have been described by Austin (1955) and Chew (1955). Gorsline (1962) has recently completed a description of the oceanography of Apalachicola Bay, twenty miles to the east.

Procedures

Field Methods

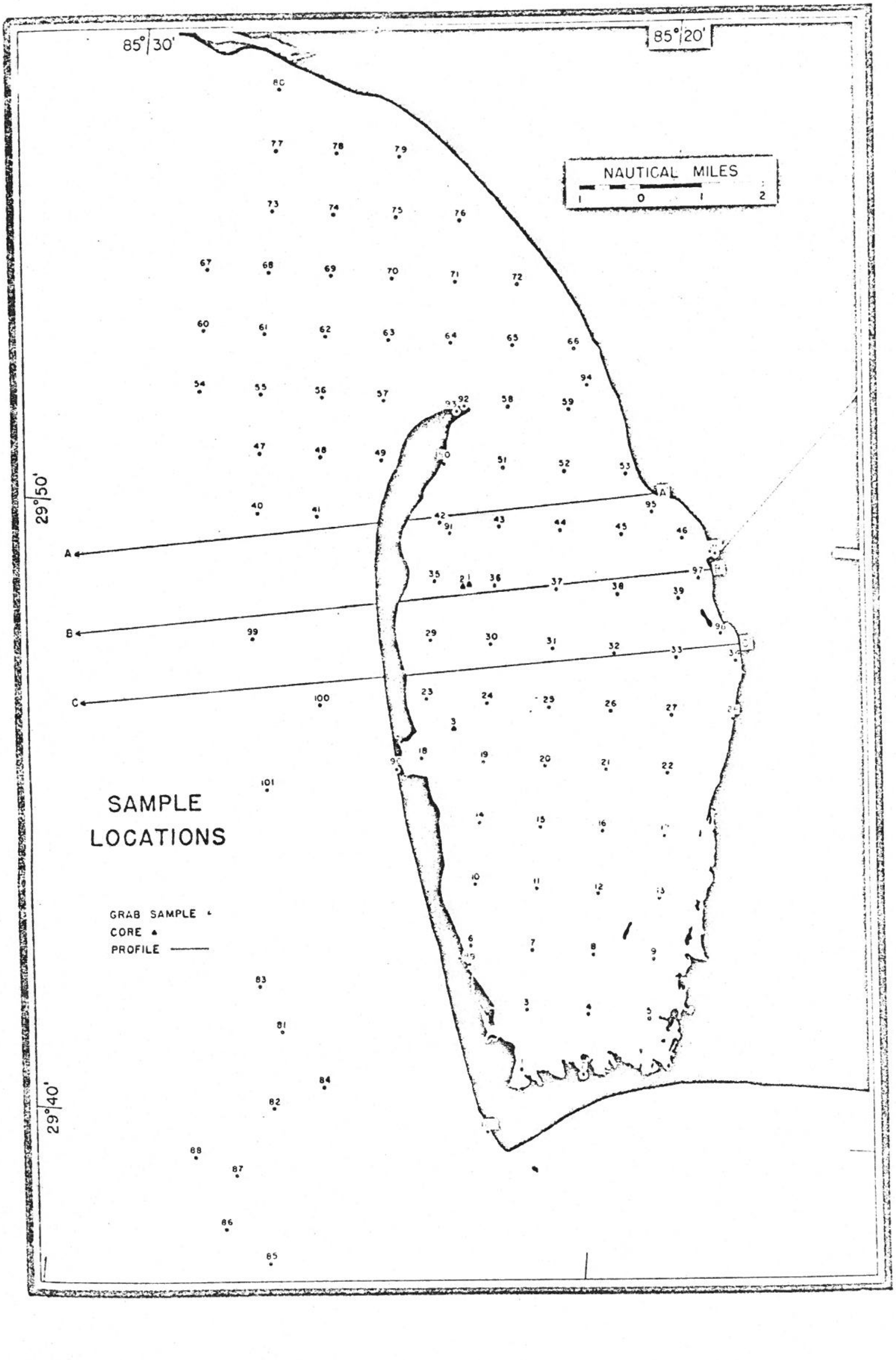
Eighty samples were taken on a grid dividing the bay into square-mile units oriented north-south (Fig. 2), using a Rigosha "Seki" grab sampler with a 500 c.c. capacity. Twenty-two additional samples were taken in areas of special interest. The sediments were stored untreated in ice cream containers. Surface water samples were also taken for salinity determination to supplement previous work in the area. Three cores obtained with an Emery-Dietz type gravity corer were measured, described, and sealed in aluminum foil for laboratory analysis.

Laboratory Methods

In the laboratory, determinations were made of the textural, mineralogical, and some chemical characteristics of each sample. These data were analyzed statistically with the aid of an IBM 709 Computer.

On arrival in the laboratory all samples were oven dried at a low temperature of 45° C. A representative portion was powdered for use in chemical analyses. Another portion of approximately fifty grams was washed free of

Figure 2. - Sample and profile locations in the study area.


85°30'
85°20'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
A
B
C
SAMPLE
LOCATIONS
GRAB SAMPLE
CORE
PROFILE

salts and wet sieved with dilute calcium hexametaphosphate solution through a 0.062 mm. screen. The coarse fraction was sieved and the fine fraction pipetted using standard procedures outlined by Krumbein and Pettijohn (1938) and utilizing the Wentworth size grade classification (Wentworth, 1922).

Upon completion of each pipette analysis a sample was drawn off and a slide made for determination of the clay minerals present by use of the X-ray diffractometer.

Coarse fractions in each size grade were examined individually under a binocular microscope to determine composition, relative percentages of components, and shape characteristics. The fractions of each sample were then mixed and split, and the heavy minerals separated from the total by centrifuging with tetrabromoethane. Heavy minerals were mounted on glass slides and examined under a petrographic microscope.

Analyses of the carbonate, organic carbon, and organic nitrogen content were made on the powdered portion of the samples. Carbonate percentages were determined by the insoluble residue method (Goforth, 1962). The Allison method (Allison, 1935) was utilized for organic carbon determinations, and the micro-Kjeldahl method (Nierderl and Nierderl, 1947) was used for measuring organic nitrogen content.

Cores obtained were divided at 8 cm. intervals, split, and analyses run on texture, organic carbon, and organic nitrogen according to the above described procedures.

Salinities were determined by titration with silver nitrate solution after the procedure outlined by Knudsen (1901).

SETTING

Regional and Local Geology

The study area lies in the Gulf Coastal Plain, a thick accumulation of Cretaceous to Recent sediments abutting upon and initially derived from the Appalachian region to the north. These sediments dip generally southward about four feet per mile, extending an undertermined distance off the present shoreline beneath the Gulf of Mexico. The youngest identified formation, the Citronelle of Pleistocene-Pliocene age (Doering, 1960), outcrops fifty miles north of the coast. From this point southward a series of Pleistocene terraces, four to seven in number according to various authors (MacNeil, 1949; Cooke, 1945), have been tentatively correlated with interglacial stages.

Fluvial deposition by the Apalachicola River and its tributaries, a major drainage system extending from the Piedmont in Georgia and Alabama southward to the coast and covering an area of approximately 18,000 square miles, has obscured the terraces in the immediate area. A sizable delta has been developed in Late Pleistocene to Recent time, formerly extending from the vicinity of Panama City eastward to the Ochlockonee River, a distance of 100 miles, and northward for fifty miles. The modern delta is limited to a distance of about eight miles above the present river mouth (Kofoed and Gorsline, 1962). The river has shown evidence of an eastward shift to its present location since the establishment of the delta (Moore, 1955).

Along the shore and seaward, sediments are for the most part of Recent marine origin. Outcrops of limestone, possibly of Miocene Tampa age, have been found in water about 100 feet deep to the east in Apalachee Bay and to the west off Panama City (Tanner, 1959). No outcrops occur in the study area but a similar limestone has been noted in a well at Port St. Joe at a depth of 610 feet (Doering, 1960). It is not known at present whether the explanation for this unusual depth lies in facies change or structural deformation.

Cultural Features

A thriving cotton port, St. Joseph, occupied a site just south of the present city of Port St. Joe in the early 1800's. It's prosperity was short-lived, however, and economic failure, followed by an epidemic of yellow fever and a disastrous hurricane, destroyed the town in 1843.

It was not until the 1900's that the forest industry brought new life to the area. The St. Joe Pulp and Paper Mill, the bulwark of the local economy, was started in 1937. This plant, expanded in 1952, uses approximately thirty million gallons per day (MGD) of fresh water obtained from an open canal from the Chipola River, sixteen miles to the east, and recycles 14.5 MGD of salt water. An adjacent organic chemical plant utilizes extracts obtained from the paper mill. In 1938 the Gulf County Canal was constructed, linking the lagoon to the Intracoastal Waterway to the northeast. The canal was widened and dredged to its present depth of nine feet in 1943. A magnesium extraction plant, located one-half mile from the coast on the canal, was completed in 1959. This plant obtains approximately fifteen million gallons of seawater daily from a pipe-line opening at the paper mill wharf and, after precipitating the magnesium, returns this water via the canal.

Commercial fishing catches in this area consist mainly of shrimp, mackerel, and mullet. Shell fish are not important although some clams and scallops are taken.

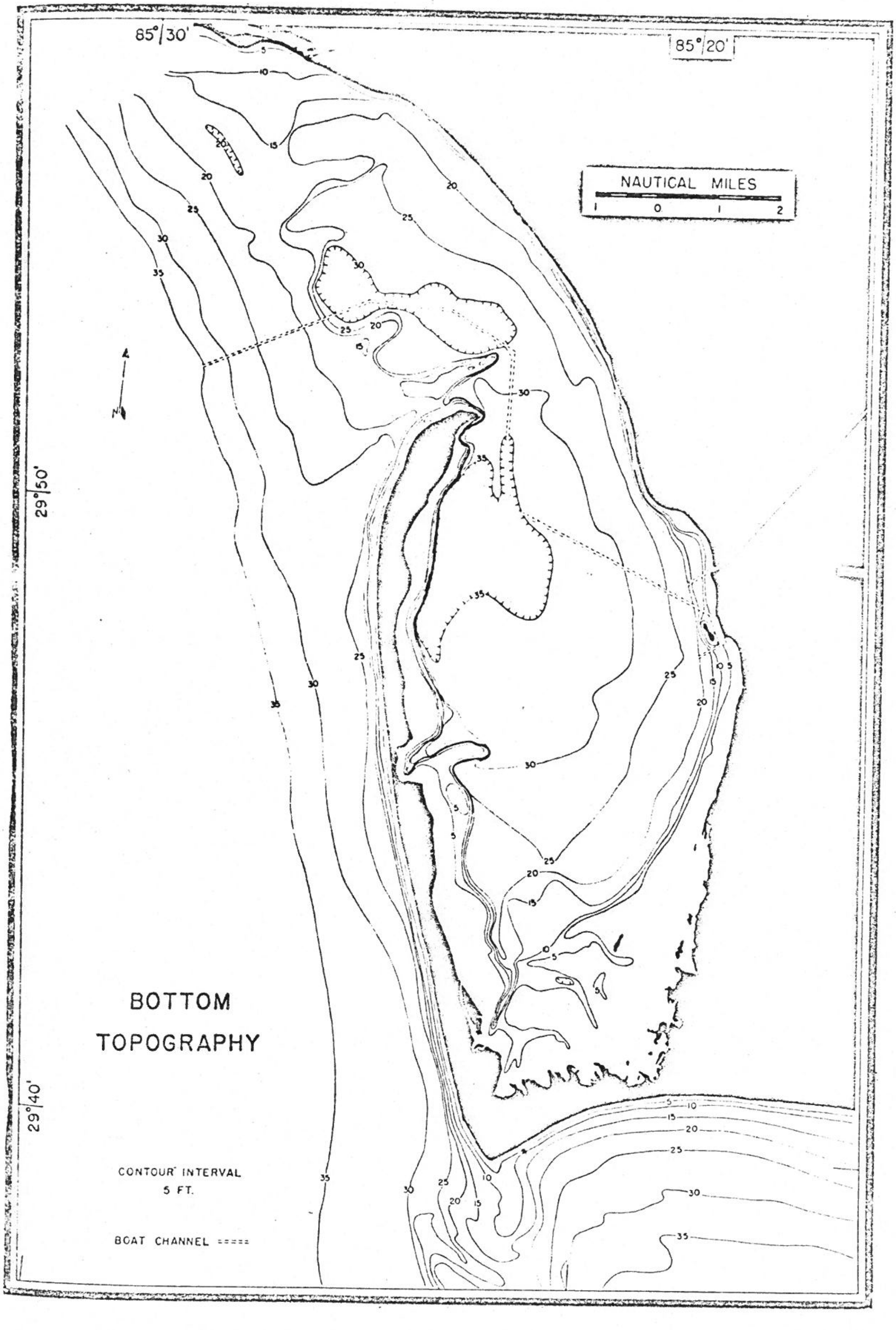
Terrestrial Physiography and Bathymetry

Inshore from the study area the land is typically low-lying with numerous swamps and marshes developed on the old delta surface. A series of old beach ridges parallel the entire mainland shore and extend about one mile inland. An old stream channel is clearly seen on aerial photographs, arriving at the beach ridges at the right angle bend of the coast from Lake Wimico, a bayou extension of the Apalachicola River, at which point it turns sharply north following the last ridge. Just north of the lagoon it appears to break through a low point in the ridges and its trace is obliterated.

The coastal morphology in this area has been classified as a "cuspate foreland" by Shepard (1960). The spit, connected to the mainland at the southern shore, extends three miles westward to Cape San Blas, at which point it bends sharply north (Fig. 3). A large shoal is developed from the cape southward for about four miles. Shepard has postulated a prior existence of this shoal to account for the configuration of the later developed spit. Current gyrals set up on either side would favor deposition in the present form. From the configuration of the spit it seems certain that such gyrals were responsible. Detailed submarine contours give evidence of an old series of beach ridges trending southwest from the lower end of the lagoon through the shoal area. The existence of these ridges would provide the barrier necessary for the establishment of the gyrals.

Physiographically the study area may be subdivided into five major types: spit, offshore terrace, shoal, outer basin, and lagoon. A large shoal extending from the tip of the spit northwest to the mainland forms the seaward boundary of the outer basin (Fig. 3). The shoal averages twenty feet in depth along the crest with a minimum of ten feet near the spit. A tidal channel separates the spit and shoal. The offshore terrace has an average slope of about four to five feet per mile in the study area and attains a maximum depth of between forty and fifty feet. Beyond this

Figure 3. - Chart of bottom topography.



85°30'
85°20'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
BOTTOM
TOPOGRAPHY
CONTOUR INTERVAL
5 FT.
BOAT CHANNEL

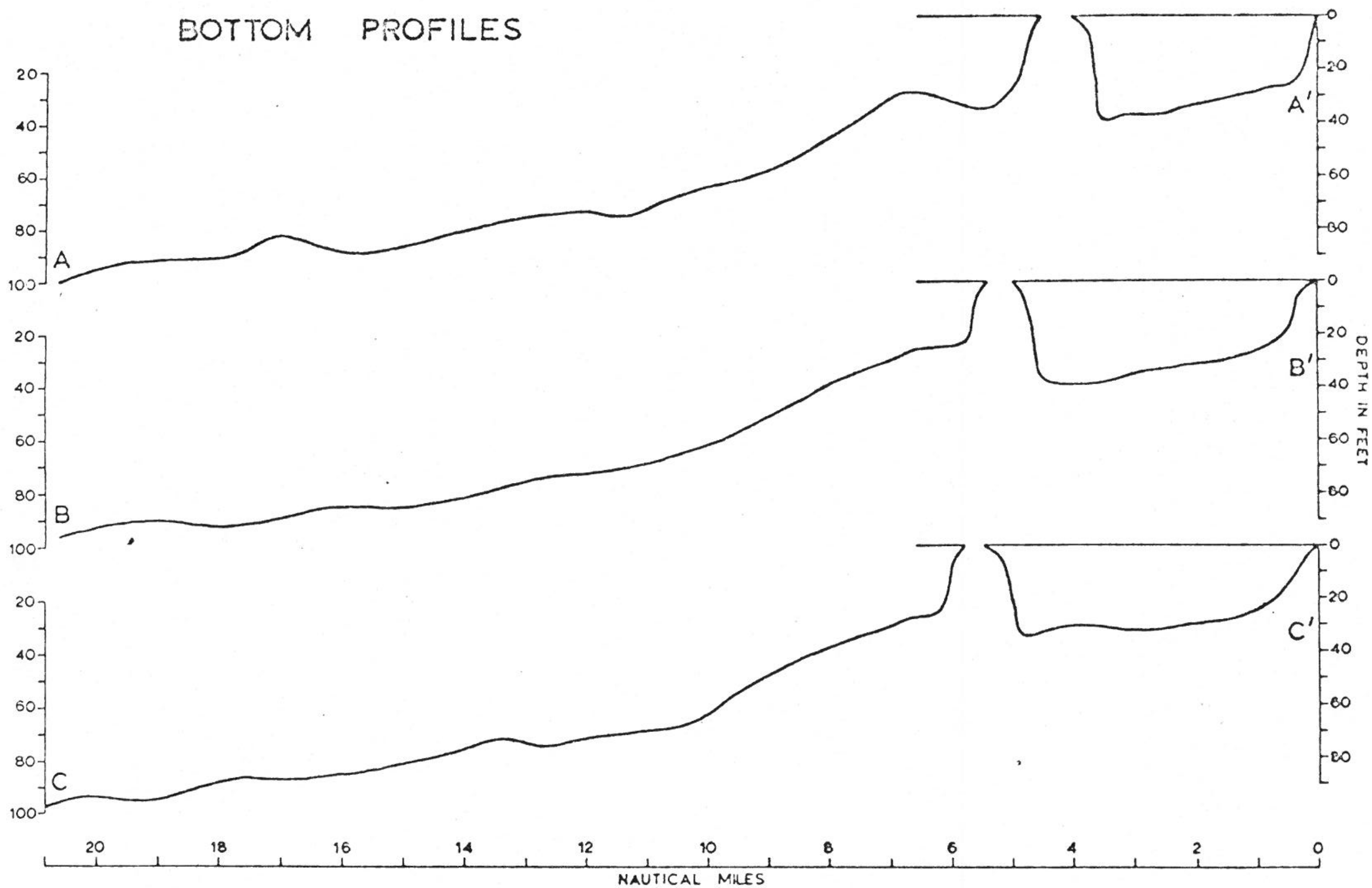
point the gradient decreases somewhat.

Profiles across the area (Fig. 4) show that the spit represents an accumulation of sediments above the surface of the terrace on the order of 9×10^8 cubic meters, only a small portion of which lies above sea level. On the connecting arm, sand ridges average ten to fifteen feet in height. Two miles north of Cape San Blas the ridges increase in height from twenty to thirty-five feet with a maximum of fifty-one feet (Bruun, Chiu, Gerritsen, and Morgan, 1962), trending north-northwest across the surface of the spit.

The lagoon is basinal in character, attaining a depth of forty feet close to the northern portion of the spit. Basin depth and slope show good correlation with the offshore terrace gradient (Fig. 4) and apparently little deposition has taken place since this portion was cut off by spit development. Extremely shallow in the southern third of the lagoon, the floor slopes gradually toward the basin, except along the flank of the spit where steep declinations occur. The entire lagoon has a mean depth of twenty-one feet. Several old tide channels cut the shallow southern end, their depths decreasing with probable age. Another channel extends into Eagle Harbor half way up the spit. marking with its accompanying protruding shoal a former extension of the barrier. A depth of twenty-five to thirty feet has been maintained in this channel. Man-made fea-

Figure 4. - Bottom profiles across St. Joseph Bay.
(see Figure 2 for locations)

BOTTOM PROFILES



tures in the bay include a boat channel dredged to a depth of thirty-five feet extending from offshore around the spit to a boat basin located at the paper mill. Spoil from the basin has been dumped just to the west, forming a small island. Two shorter channels have been constructed, one south of the spoil area and the other extending from the mouth of the Gulf County Canal.

The outer basin to the north reaches a maximum depth of thirty-two feet. It is probable that this basin was once part of the one immediately to the south and has been cut off and partially filled by sedimentation.

The bottom topography presented in Fig. 3 was taken from the latest U. S. Coast and Geodetic Smooth Sheets of the area published in 1875 (Series H-1265) and corrected where necessary from present navigational charts and personal observation. Surprisingly few corrections were found to be necessary and these were based primarily on man-made features such as the channels, boat basin, and spoil areas. Even more striking is a comparison of the earliest survey made by the Navy in 1841 with the present features. Virtually no appreciable change has taken place during that period of 122 years either in the length and configuration of the spit and northern shoal or in depths throughout the area. In those areas such as the basins and old tide channels, especially at Eagle Harbor, where some filling might be expected no significant changes of depth have occurred.

The sole area of dynamic change lies in the southern shoal off Cape San Blas which has fluctuated appreciably in both length and depth. In 1841 this shoal was extended far south of its present location. By 1875 much of the sediment had been removed and the shoal lay much closer inshore, while at present a period of building has resumed and extension is being repeated.

Climate

The climate of panhandle Florida is classed as humid sub-tropical. Rainfall in the study area averages fifty-seven inches but this generous amount is not evenly distributed throughout the year. Prolonged dry periods occur, occasionally during the normal summer rainy season. Torrential downpours are common during the summer months and exceptionally heavy rainfall sometimes occurs in connection with tropical storms in late summer and early fall. Despite the heavy rainfall only about nineteen inches is available as runoff in the immediate vicinity of St. Joseph Bay (Gillespie, 1951). The remainder penetrates the porous sand on the delta surface, is taken up by the lush plant growth, or is returned to the atmosphere through evaporation.

The annual temperature average for the area is about 65° Fahrenheit, with a winter average of 50° and a summer average of 80°.

Hydrography

Salinity and Temperature

Salinity measurements in the lagoon range from 33.5 to 16.9 o/oo (Plutchak, Trotts, Hambleton, and Milligan, 1961). Low values are confined to the surface in areas in close proximity to the paper mill and canal. Water in the canal is generally brackish to saline and the flow is tidal at the mouth. No streams of consequence enter the bay and fresh water influx is confined primarily to discharge from the paper mill. Below the five-foot level the salinity ranges from 28.9 to 33.5 o/oo, identical to values given by Chew (1955) for the open gulf. Water temperatures for the period covered, March and April, ranged from 26.5° to 17.2° Centigrade. Again variations occurred in the upper five to ten feet with the exception of the bay mouth; below this level the water is essentially isothermal.

Data obtained by Institute personnel during beach profile surveys at Cape San Blas and Mexico Beach, four miles north of the lagoon, over a five month period from January through June, 1962, show a salinity range of 28.8 o/oo to 34.3 o/oo and a temperature range of 13.5° C. to 29.5° C. for these open coastal areas.

Circulation

Currents in St. Joseph Bay show a response to the tidal cycle of ebb and flood. During the flood a moderately strong flow measured at a maximum of one-and-one-half knots sweeps into the lagoon around the point. This current has directed the growth of the spit causing it to bend inward at the point. It seems apparent that a counter-clockwise gyral is established in the central portion of the lagoon for a northward movement of water is maintained close in along the eastern shore, disrupted only during the maximum flood. At ebb tide currents flow from the lagoon and outer basin via the channel at the point and across the shoal in the vicinity of the boat channel. Current movement is essentially surficial throughout the major portion of the lagoon, diminishing rapidly below five feet, and is negligible in the shallow southern end.

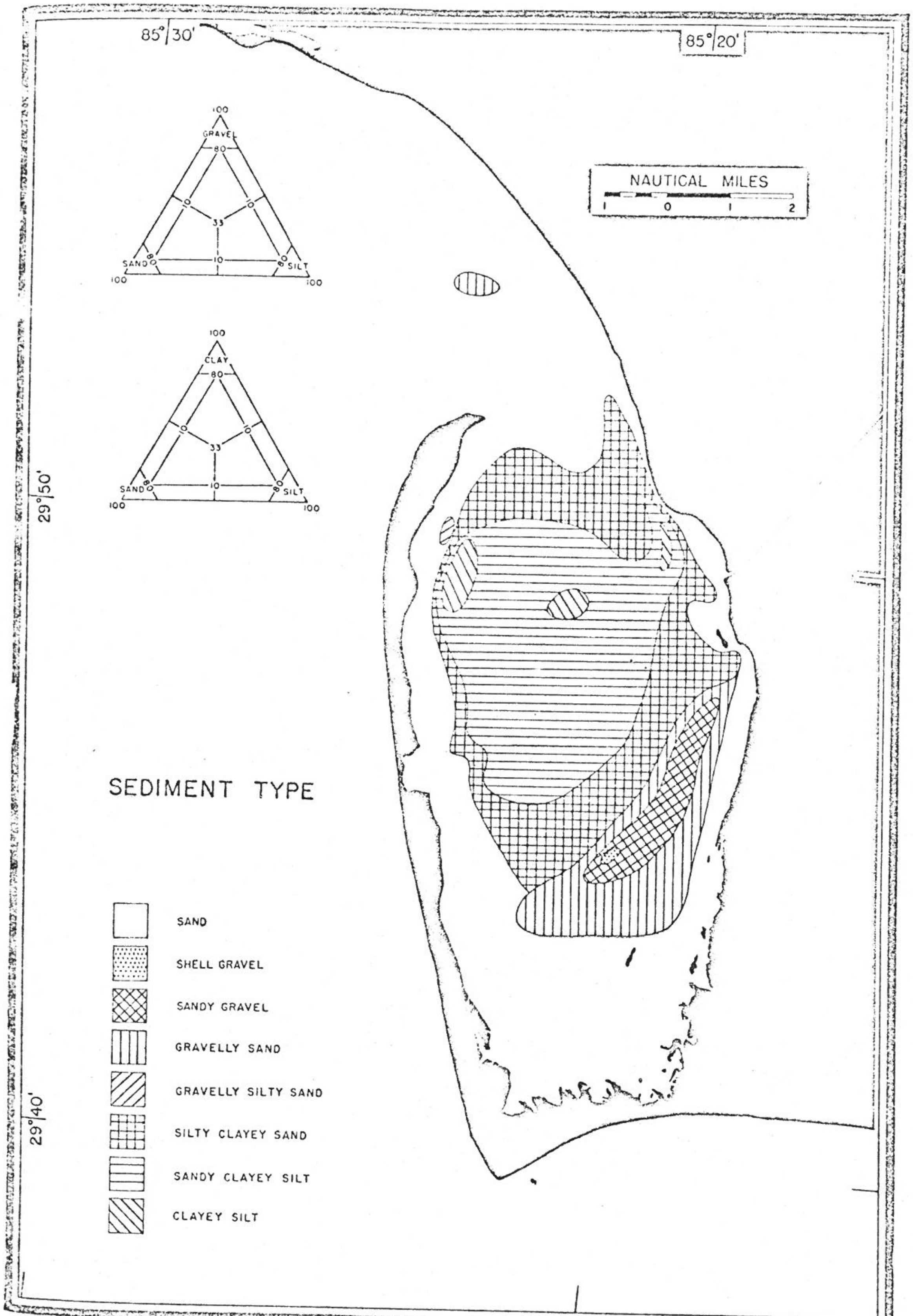
From consideration of the hydrographic factors it is apparent that circulation is low in the deeper portions of the lagoon and reducing conditions might be expected. Sediment observations have shown this to be the case in the basin and deeper old tide channels.

SEDIMENTS

Classification

Any classification of sediments requires the establishment of purely arbitrary boundaries between the selected classes, but clarity of presentation demand that some such system be utilized. The reader should keep in mind however, that no sharp discontinuity between the established classes is intended. The end-member concept has seen wide use in sediment work and it has been found that the triangle or tetrahedron generally provides an adequate basis for classification. Shepard (1954) has reviewed several such systems and presented his own views. The classification adopted for this study is a modification of Shepard's diagram derived by Gorsline for use with sediments along the South Atlantic Coast (Moore and Gorsline, 1960). The sediment types are determined by the relative percentages of Wentworth size divisions represented in each sample, particles of granule size being included with the gravels. Sediment type therefore carries a purely textural connotation and compositional characteristics are excluded. Two faces of the tetrahedron were found adequate to describe sediments in the St. Joseph Bay area (Fig. 5). In no case was a fourth component present in percentages large

Figure 5. - Distribution of sediment types.


85°30'
85°20'
NAUTICAL MILES
1 0 1 2
GRAVEL
SAND
SILT
CLAY
29°50'
29°40'
SEDIMENT TYPE
SAND
SHELL GRAVEL
SANDY GRAVEL
GRAVELLY SAND
GRAVELLY SILTY SAND
SILTY CLAYEY SAND
SANDY CLAYEY SILT
CLAYEY SILT

enough to necessitate the use of the complete three-dimensional figure.

Source Areas and Mode of Transport

The immediate source of the major portion of sediment contribution of the St. Joseph area is the Apalachicola River which empties into the Gulf twenty miles to the east. Only a minor part of these sediments are presently contributed by the initial provenance of the Piedmont and Folded Appalachians. By far the greatest amount is derived from the reworked Cretaceous to Recent deposits of the Coastal Plain. As a result the few unstable minerals initially supplied decrease rapidly in importance toward the coast. Feldspars are virtually non-existent in the coastal sands and the heavy mineral suite becomes increasingly more mature with distance. Quartz grains, by far the dominant component, show a general trend from well-rounded in the coarser sizes to sub-angular in the fines, although a few highly angular grains are present in all grades.

Tanner (1961) has estimated the amount of bed load delivered yearly by the Apalachicola River at 5×10^5 cubic meters. Evaluation of coastal energy shows it normally to be capable of handling approximately 2×10^4 cubic meters of this supply, the excess going into the building of barriers, beach ridges, and shoals. Medium to fine sand and some coarse silt is delivered to the St. Joseph area via the westward longshore drift, the finer materials being trapped in Apalachicola Bay and the basin to the east of Cape San Blas (Kofoed and Gorsline, 1962).

The free movement of sand past Cape San Blas is a function of shoal development in this area which in turn appears to be dependent on the frequency of intense tropical storms. Development, as previously pointed out, has undergone cycles of expansion and destruction. In the absence of detailed study it appears that increased wave refraction resulting from shoal expansion causes erosion of the shoreline immediately north of the cape, furnishing load for the northward drift. In the face of this active erosion the Coast Guard lighthouse located at this point was moved a quarter of a mile inshore in 1948. At that time its former site was still well above high water while today it is awash at high tide. Erosion will probably continue until destructive storm activity removes the barrier sufficiently to reduce wave attack and allow replenishment of sand supply. Such a series of events probably occurred in the early 1800's. The disastrous hurricane of late 1843 which destroyed the town of St. Joseph may well have provided the necessary force for reduction of the shoal. In any event periodicity of the cycles seems to have been sufficiently frequent to establish a near equilibrium condition to the north during recorded history, confining notable change to the immediate vicinity of the cape.

Eolian transport across the spit is greatly diminished by a heavy growth of trees and shrubs. This growth is continuous to a point just south of the tip where dunes are small but active. As a result sediment supply through this agency is greatly reduced.

Shells and shell fragments form the entire gravel size constituent of the sediments and locally contribute substantial amounts to the coarse sand fraction. Areas of greatest production lie within the lagoon, isolated from currents capable of transporting the material. As a consequence large accumulations have developed and the shells have been broken down in situ by boring organisms and larger predators capable of crushing the shells. In the southern portion of the lagoon an extensive bed of shells some three and one-half miles long dominates the detrital material. Smaller carbonate particles in the form of foraminiferal and ostracod tests, sponge spicules, and fine shell material constitute substantial amounts of the very fine sand and silt fractions in the area. These particles are for the most part winnowed by currents and deposited under low energy conditions present within the lagoon, where in the absence of fine-grained quartz they dominate the silt fraction.

Little clay material is being introduced into the study area at the present time. Virtually none arrives with the major detrital contribution via longshore drift. The only alternative source, the Gulf County Canal, can, with its low discharge rate and short period of existence, be responsible for little of the clay found within the lagoon. This problem will be discussed in the following section.

A major source of organic material at present, the paper mill, complicates discussion of the natural contribution. The weekly BOD (biochemical oxygen demand) average of 17,400 pounds per day in mill discharge (Smith, Wakefield, Bevis, and Philps, 1954) is sufficient to allow heavy accumulation of organic matter in sediment types of normally low content. This along with several other environmental factors calls for a more lengthy discussion which will also be postponed for a later section.

Texture

Sediment Type

The distribution of sediment types may be seen in Fig. 5. In view of the sampling techniques used, the patterns shown represent a composite of the first few centimeters of sediment, the depth varying somewhat with the character of the sediment sampled.

The most apparent feature is the oval pattern conforming to the bathymetric configuration of the lagoon in which sand is succeeded by silty sand, sandy silt and clayey silt in that order toward the central basin. Such a pattern might at first thought be attributable to the basinal character of the lagoon until energy relationships and present sediment supply are recalled. If clay materials were presently being contributed in amounts sufficient to produce the observed situation, some accumulation might be expected in the shallow southern portion of the lagoon where under present low energy conditions the tidal mechanism described by van Straaten and Kuenen (1958) might be an important factor. Such accumulation does not occur; on the contrary, this area is represented by sands markedly free of clay content.

Areas of greatest accumulation of clay occur south of the opening to the Gulf and are not uniformly consistent with current activity. One area in particular just south of the bulge in the eastern shoreline lies beneath the north moving current and appears to have been protected rather than deposited by this flow. To account for these peculiarities it seems necessary to postulate an earlier period of sedimentation preceding the present sedimentary accumulations. It has previously been noted that an old stream channel is present with an exit in the outer basin just north of the lagoon. This channel has the dimensions of a sizable river and appears to have once been a distributary of the Apalachicola, utilized in periods of flood. Such a flow would have carried considerable amounts of fine materials into the basin from the north and a large accumulation could be expected. With time sand has covered the northern area and extended into the lagoon, evidenced by the lobate pattern at the mouth. A line connecting the areas of greatest clay accumulation forms a crescent before this encroaching tongue. Eventually sands will cloak these finer sediments. Unfortunately, failure of the coring device to penetrate the sand lobe prevented adequate verification of this hypothesis. Recovery in the soft silts at core locations 1 and 2 (Fig. 2) was poor and the sediments were disrupted so that layering could not be ascertained. The longest core of forty-six centimeters, core 2, displayed a marked change in composition at sixteen centimeters with clay content increasing from 15 per cent to 41 per cent over the next eight centimeters and to a maximum of 50 per cent at forty centimeters. Clearly an abundance of clay has been contributed in the past. It appears, therefore, that the bulk of the fine-grained materials are relict from a time immediately prior to the present period of sand deposition.

Since the conclusion of this study, U. S. Navy divers, investigating the recently dredged boat channel north of the lagoon, have verified the existence of a clay and silt wedge underlying sand at a depth of 37 feet, in good accord with exposures in the lagoon (George A. Dowling, U. S. Navy Mine Defense Laboratory, personal communication).

A second curious pattern is exhibited on the south-eastern flank of the central oval trend. A large accumulation of shell gravel has formed on the moderate slope of the basin between the five and twenty-five foot contours, with maximum values following the twenty to twenty-five foot interval. The shells consist chiefly of mollusk remains, including principally clams, pectens and the oyster, Ostrea equestris. This oyster should not be confused with the common commercial species, Crassostrea virginica, which forms large beds in brackish waters along the coast and is found here only in very limited numbers in the small area of fresh water influx. Much of this material shows the effects of age, however biological remains are continually being contributed in the area. Evidently this site has provided optimal conditions for growth of these sedentary organisms. Again the lack of fine-grained material in this area attests to the absence of a present day supply.

The protruding lobe of sand at the paper mill south of the canal is not of natural origin, but results from the dumping of spoil in this area.

The averages of the characteristics measured and their ranges for each sediment type encountered in the area are given in Table 1.

Grain Size and Sorting

All means of evaluating sediment texture in use at present fall somewhat short of a true and easily discernible description of the sample. Computations based on

TABLE 1

CHARACTERISTICS OF ST. JOSEPH SEDIMENTS BY SEDIMENT TYPE

Sediment Type / No. of Samples	Mean Diam. Ave. / Range mm.	Std. Dev. Ave. / Range phi units	Carbonate Ave. / Range %	Org. Carbon Ave. / Range %	Org. Nit. Ave. / Range %	C/N Ave.
Sandy Gravel (2)	1.425 1.094-1.765	5.00 4.73-5.26	54.3 52.8-55.8	0.192 0.158-0.226	0.082 0.082	2.3
Gravelly Sand (5)	0.429 0.243-0.616	2.24 1.82-3.01	22.7 7.4-40.3	0.504 0.178-1.321	0.037 0.016-0.070	13.6
Sand (52)	0.216 0.088-0.423	0.94 0.45-2.48	4.5 0.5-18.2	0.291 0.048-1.633	0.017 0.005-0.077	17.1
Si Cl Sand (8)	0.028 0.019-0.050	3.36 2.94-3.70	20.8 12.9-31.8	3.479 1.782-4.625	0.151 0.081-0.239	23.0
Sa Cl Silt (12)	0.009 0.006-0.017	3.02 2.62-3.53	27.1 19.7-34.5	3.951 2.595-4.617	0.219 0.148-0.277	18.0
Clayey Silt (3)	0.004 0.003-0.004	2.57 2.48-2.62	30.6 25.0-34.1	5.520 4.554-7.067	0.257 0.225-0.275	21.5

graphic interpretation of cumulative curves utilize only a portion of the total sediment range. Statistical evaluation as outlined by Krumbein and Pettijohn (1938) has, with greater accessibility of computers, provided a more rapid and accurate means of description and for that reason has been used in this study.

The distribution of mean grain sizes in the area is displayed in Fig. 6. The overall pattern is closely correlated with sediment type and shows a correspondingly wide range from 26 to 0.003 millimeters. Grain size decreases slightly seaward and rapidly into the lagoon. The pattern of encroachment is readily apparent, as is the barrier effect established along the eastern shore by current circulation. The southern shell bank is delineated by the coarse mean diameter values.

Sorting, as defined by the standard deviation (Fig. 7), shows response to the variation in sediment sources and to the modal character of the sediments. As might be expected in a coastal environment, sands exhibit the best sorting, the bulk of the sample falling into less than two size grades about the mean. As applied energy decreases in the outer basin and lagoon the addition of carbonate silt particles creates a secondary mode, increasing the deviation. Similar modes occur in each textural class and as more classes are represented, notably in the shelly area, sorting values become increasingly larger. Of necessity a

Figure 6. - Distribution of mean grain size.

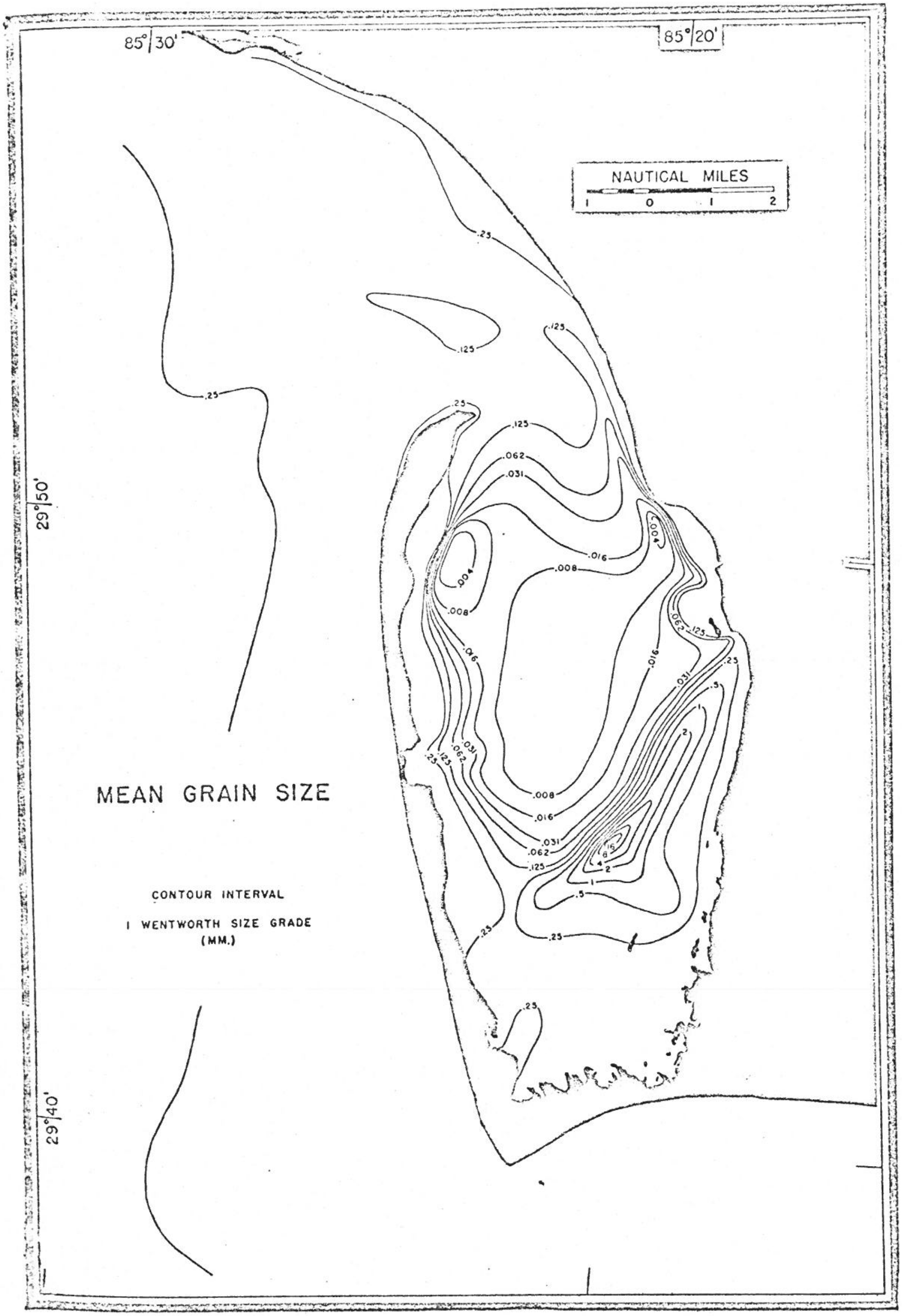
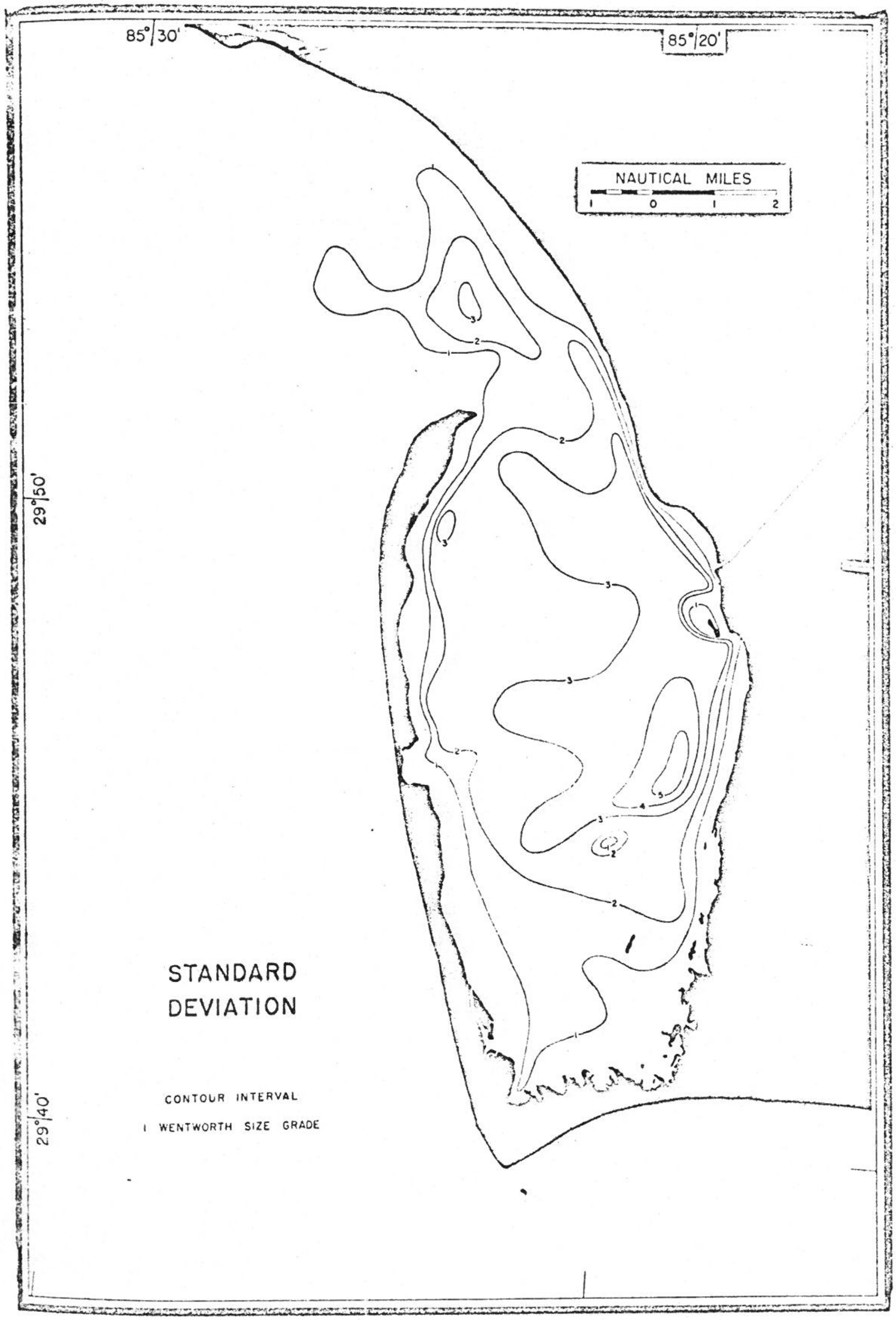

85°30'
85°20'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
MEAN GRAIN SIZE
CONTOUR INTERVAL
1 WENTWORTH SIZE GRADE
(MM.)
.25
.125
.062
.031
.016
.008
.004
.5
1
2
4
8
16

Figure 7. - Distribution of standard deviation.



85°30'
85°20'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
STANDARD DEVIATION
CONTOUR INTERVAL
1 WENTWORTH SIZE GRADE

mode occurs in the clay fraction when significant amounts are present. Computation techniques require the lumping of all clay particles into one size grade despite some variation in the true size. Flocculation may well cause clay minerals to follow the hydrodynamic characteristics of silt particles in the marine environment. Thus the presence of clay tends to increase calculated sorting values beyond what might be dictated by the energy conditions present.

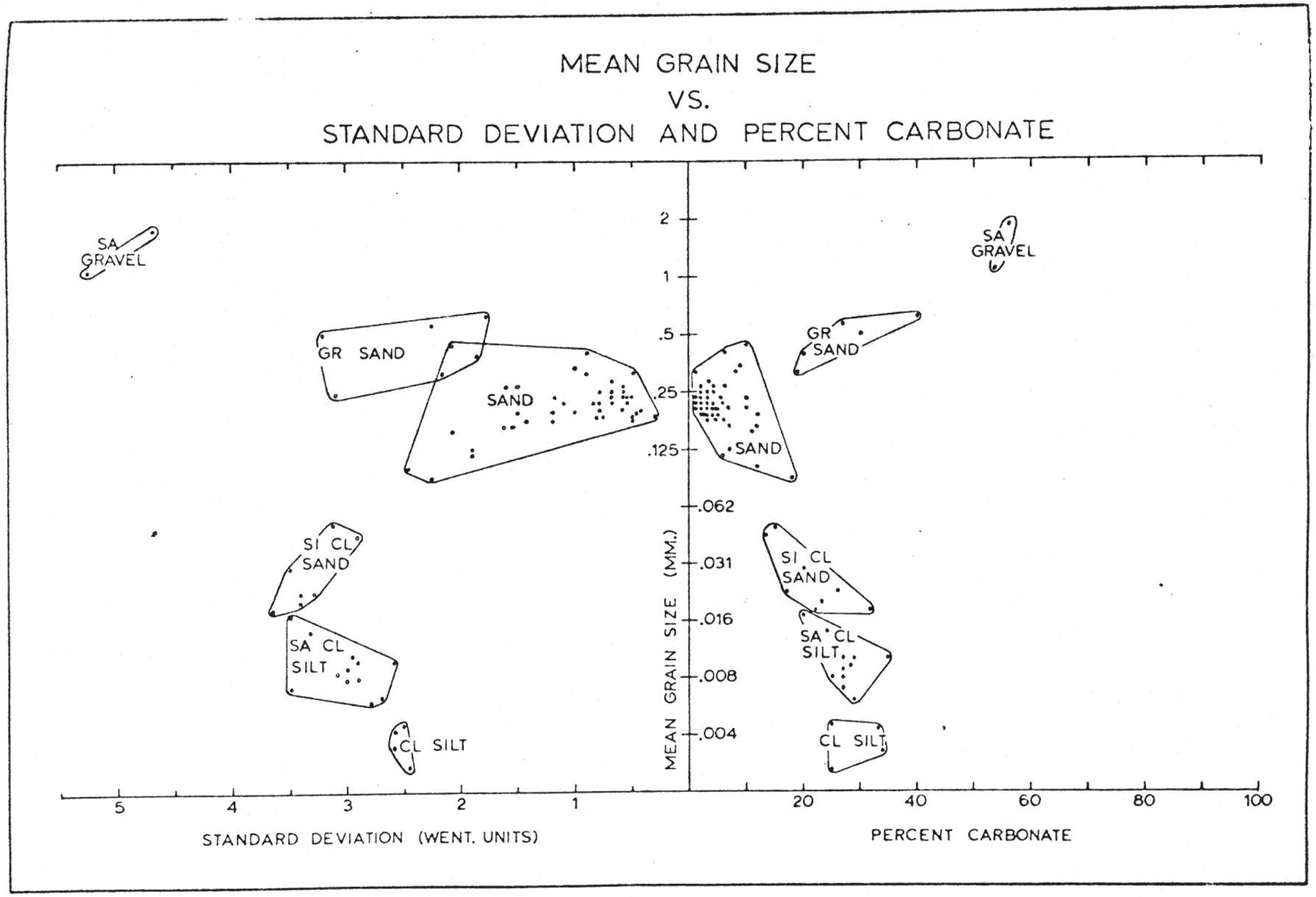
A better picture of the association of mean grain size and standard deviation in the various sediment types may be seen in Fig. 8. Inman (1949) has pointed out that the best sorting occurs in sand with a diameter of 0.18 mm. in response to the relationship between settling and threshold velocities, and frictional stresses. Poorer sorting is exhibited with increase or decrease in diameters from the 0.18 mm. minimum. This V-shaped distribution is illustrated in Fig. 8. Present deposition extending over previously deposited fine-grained material accounts for the wider deviation of sandy silts and silty sands as compared with that of the virtually uneffected clayey silt samples. The wide deviation in gravel types might be expected because of the residual nature of the biologic contribution.

Chemical Analyses

Calcium Carbonate

The high percentages of carbonate in the study area

Figure 8. - Diagram of mean grain size versus standard deviation and percent carbonate according to sediment type.


MEAN GRAIN SIZE
VS.
STANDARD DEVIATION AND PERCENT CARBONATE
SA GRAVEL
GR SAND
SAND
SI CL SAND
SA CL SILT
CL SILT
MEAN GRAIN SIZE (MM.)
2
1
.5
.25
.125
.062
.031
.016
.008
.004
5
4
3
2
1
20
40
60
80
100
STANDARD DEVIATION (WENT. UNITS)
PERCENT CARBONATE

are entirely of biological origin. With the absence of substantial amounts of fine quartz particles, organic tests and spicules winnowed from the outer coastal sands increase the carbonate dominance of the contemporary silt fraction as energy decreases into the lagoon. Highest carbonate percentages outline the limits of penetration of present fine detrital sedimentation into the basin (Fig. 10). Beyond this penetration, in the central portion of the lagoon, quartz particles supplied by the ancient river to the north predominate in the silt sizes and a lower carbonate content is therefore present.

Mollusk remains contribute heavily to the carbonate content of sediments along the southern slope of the lagoon; the carbonate contours in Fig. 10 outline the extensive bed of shell gravel.

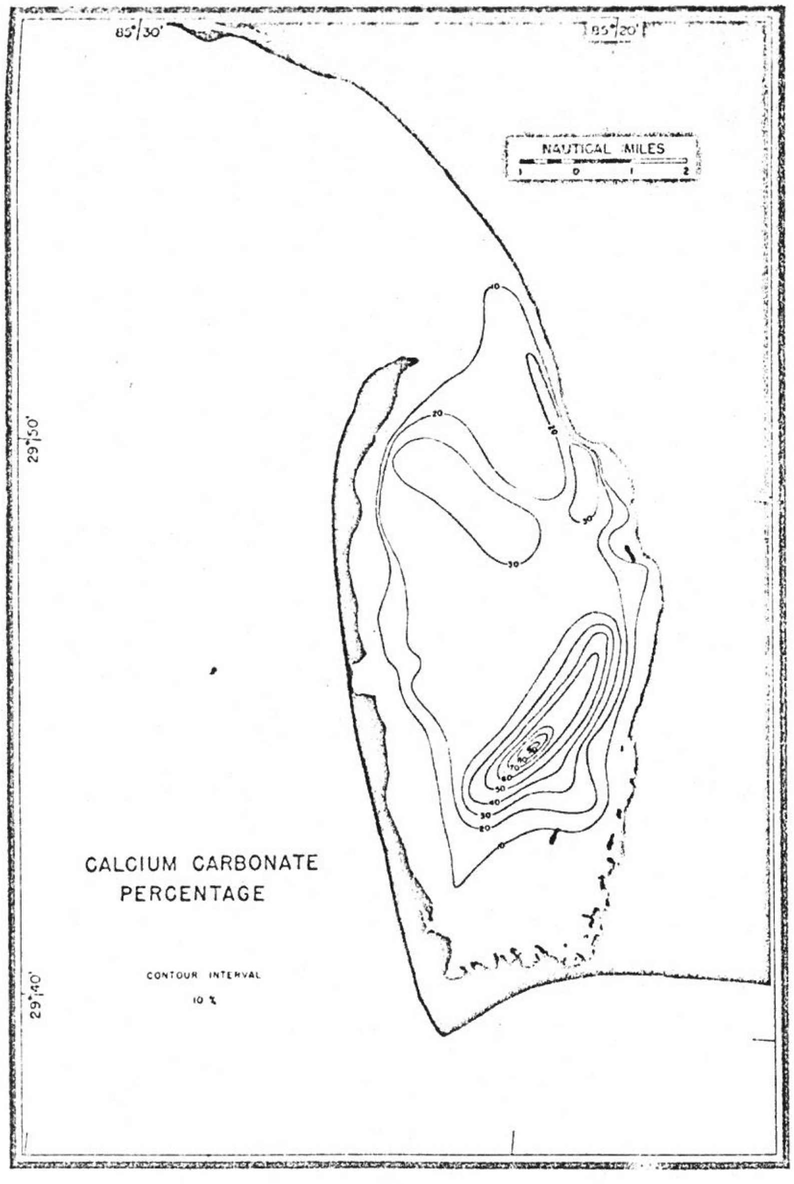
The relationship of mean grain size and carbonate percentage with the various sediment types is illustrated in Fig. 8. Carbonate content, low in the sand sediment type, increases in both coarse and fine grain sizes.

Organic Constituents

Analyses of organic carbon and organic nitrogen content have been made in order to determine the total organic contribution to the sediments. The distribution of these two constituents may be seen in Figs. 9 and 12. Strikingly similar patterns are evident in all areas with the exception of the northeastern portion of the lagoon where the

Figure 9. - Distribution of organic nitrogen content.

Figure 10. - Distribution of carbonate content.


85°30'
85°20'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
CALCIUM CARBONATE
PERCENTAGE
CONTOUR INTERVAL
10 %

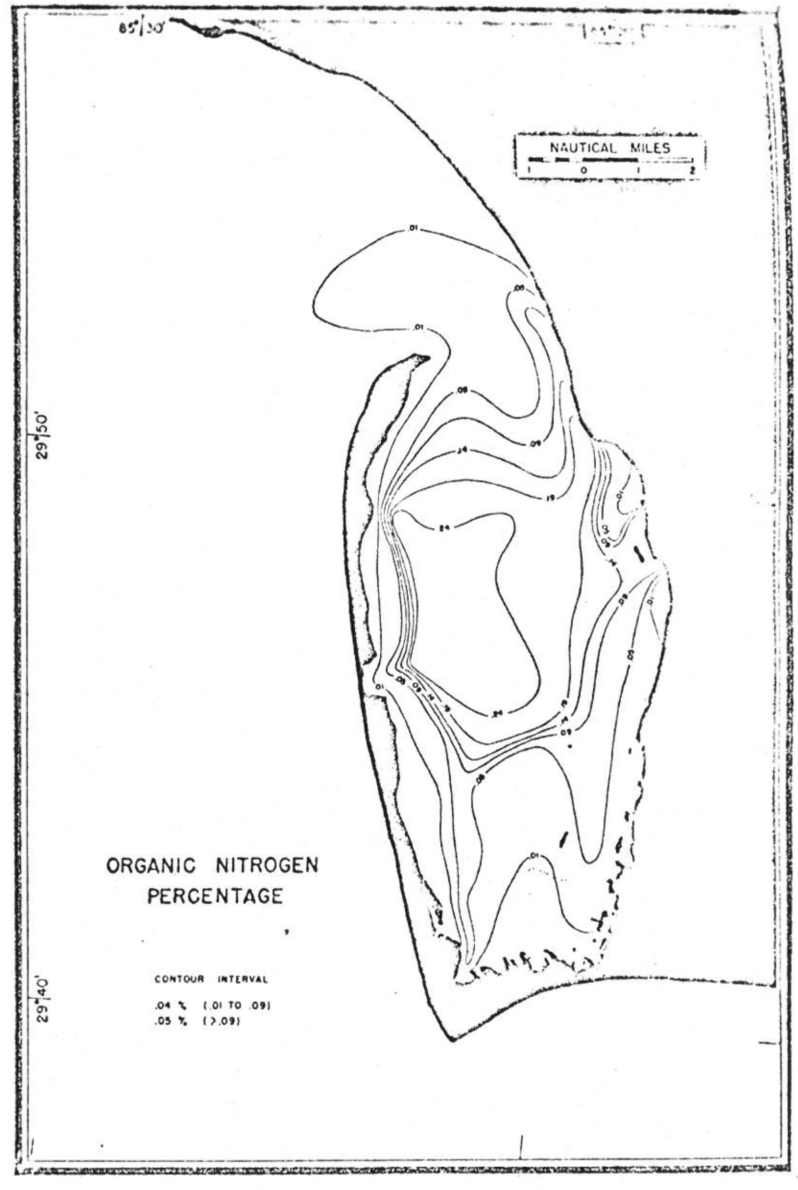
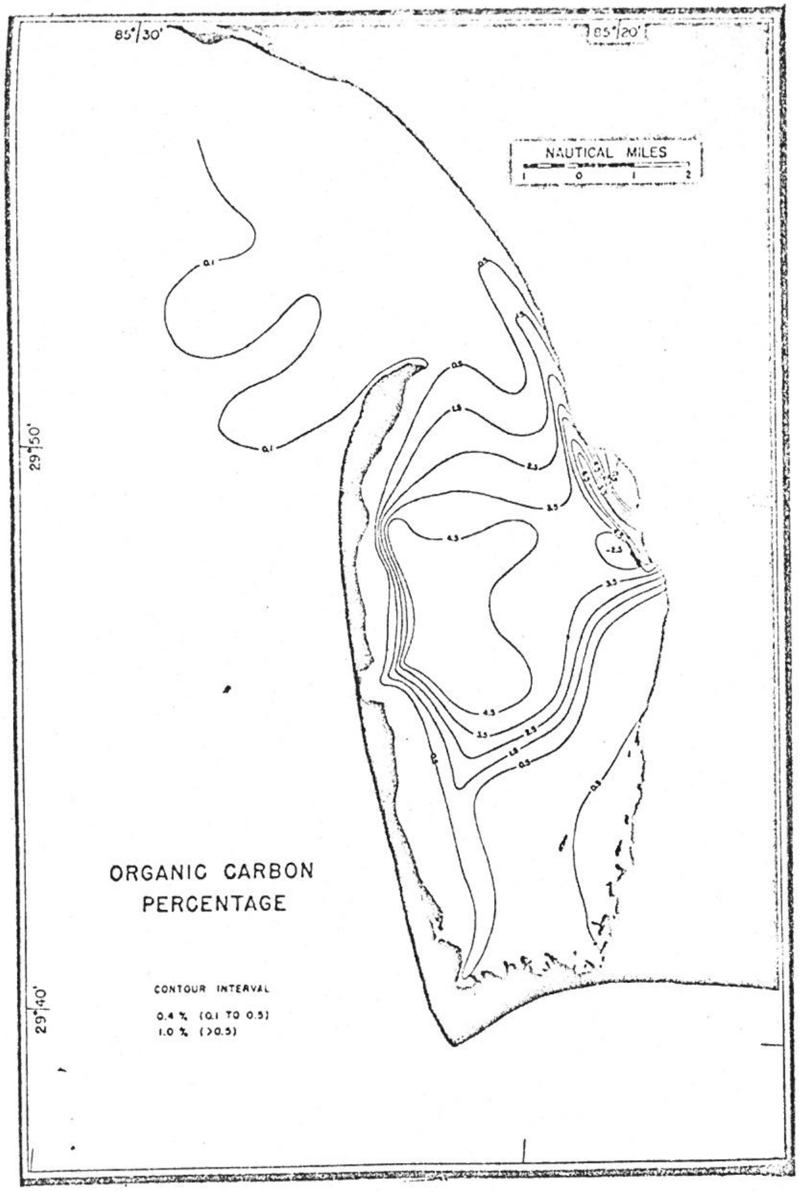
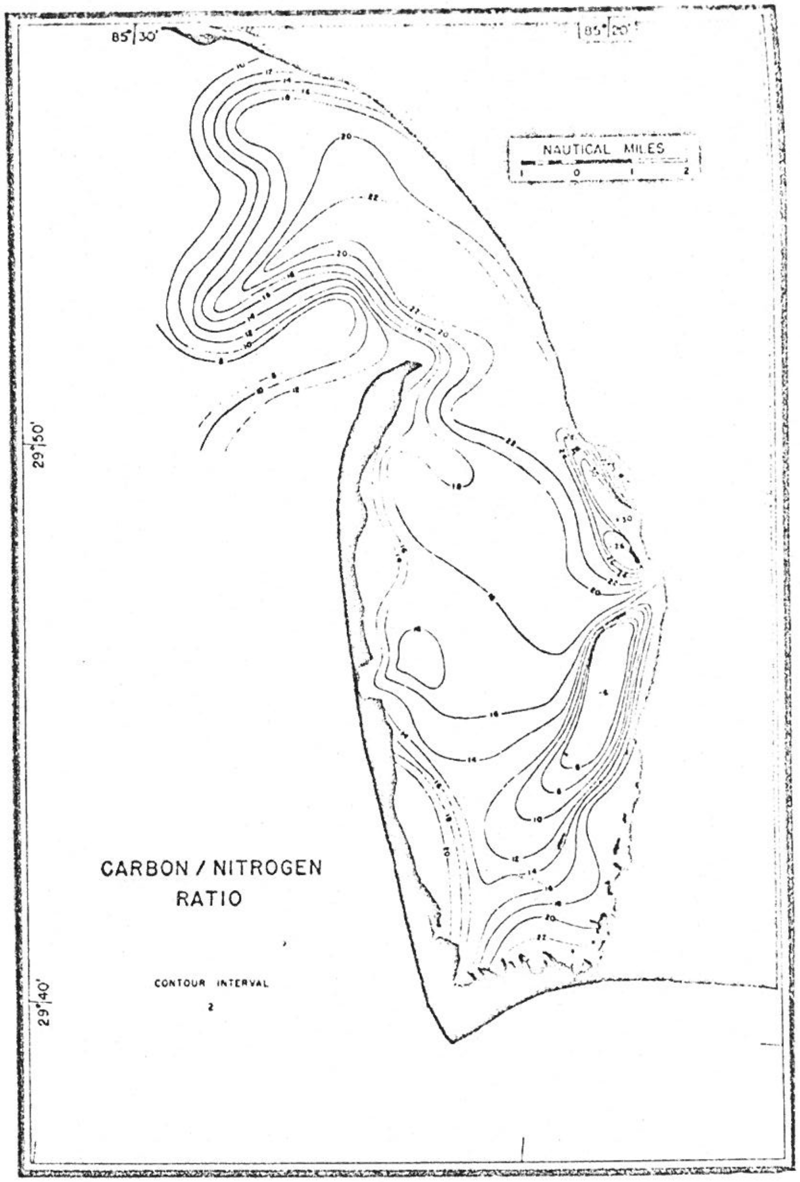

85°30'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
ORGANIC NITROGEN
PERCENTAGE
CONTOUR INTERVAL
.04 % (.01 TO .09)
.05 % (>.09)

Figure 11. - Distribution of C/N ratio.

Figure 12. - Distribution of organic carbon content.


85°30'
85°20'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
ORGANIC CARBON
PERCENTAGE
CONTOUR INTERVAL
0.4 % (0.1 TO 0.5)
1.0 % (>0.5)

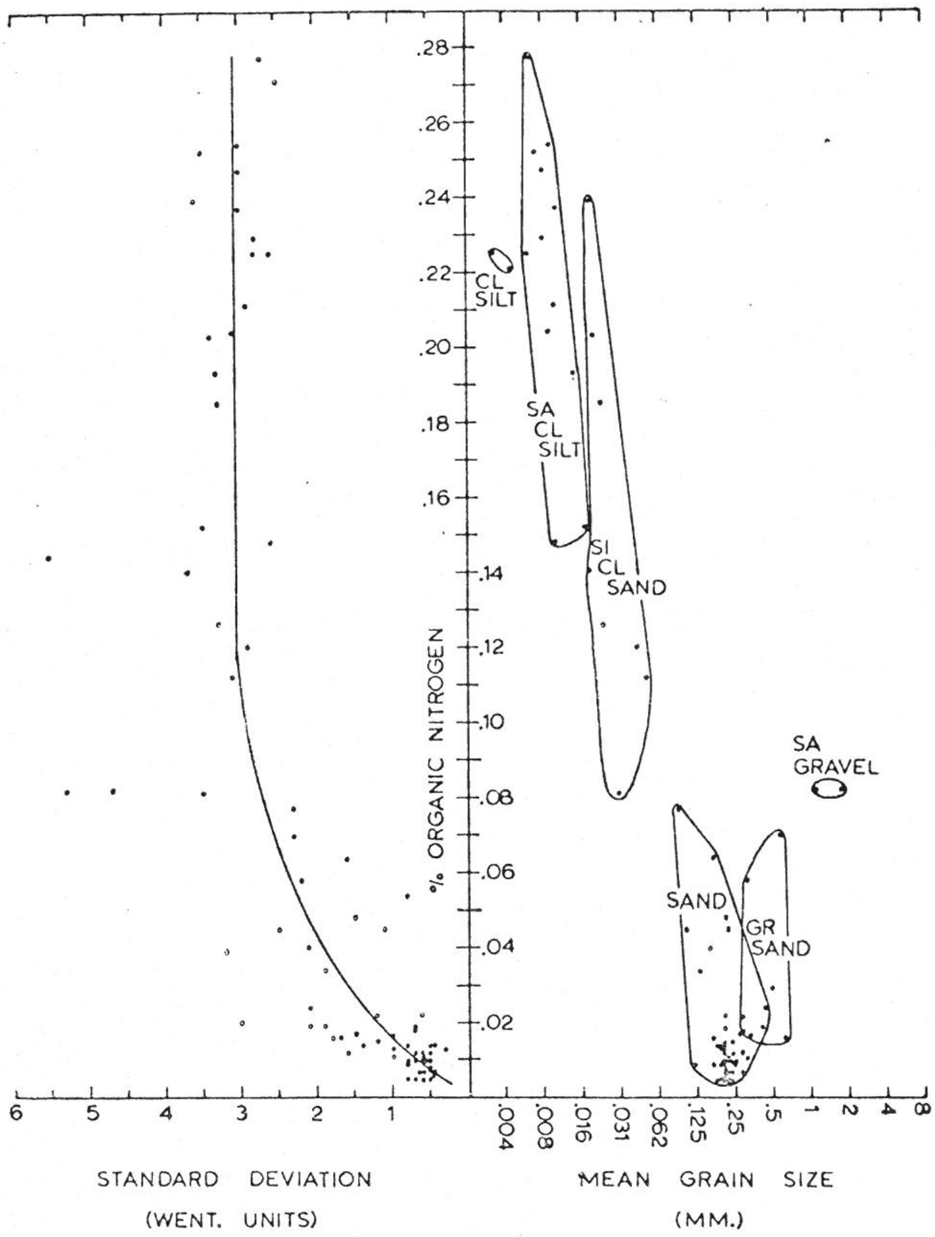

85°30'
85°20'
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
CARBON / NITROGEN
RATIO
CONTOUR INTERVAL
2

heavy influence of paper mill discharge gives high organic carbon contents to sediments normally low in organics. In view of this influence the nitrogen values probably present a better estimate of organic contribution from natural sources. The average nitrogen content is 0.071 per cent by weight, giving an average total organic content of 1.4 per cent using a conversion factor of twenty. In contrast, organic carbon averages 1.34 per cent by weight, giving a total organic content of 2.7 per cent using a conversion factor of two. These conversion factors are slightly larger than those previously presented by Trask (1939), Waksman, Carey, and Renszen (1933), and Emery (1960), but rounded figures appear to be in order in view of the uncertainty surrounding these factors and the precision of measurements. Organic content shows a strong relationship to present bottom topography. Reducing conditions characterizing sediments in the deeper basin and channels restricts bacterial decomposition and permits substantial accumulation. As might be expected offshore sands contain the lowest amounts of organics, less than 0.2 per cent, with a steady increase into the basin. The encroaching lobate pattern previously discussed is again clearly evident.

Comparison of organic nitrogen percentage to mean grain size and standard deviation is presented in Fig. 13. The V-shaped distribution with mean grain size is again evident. Nitrogen content increases in both directions

Figure 13. - Diagram of organic nitrogen versus mean grain size and standard deviation.

ORGANIC NITROGEN VS. STANDARD DEVIATION AND MEAN GRAIN SIZE

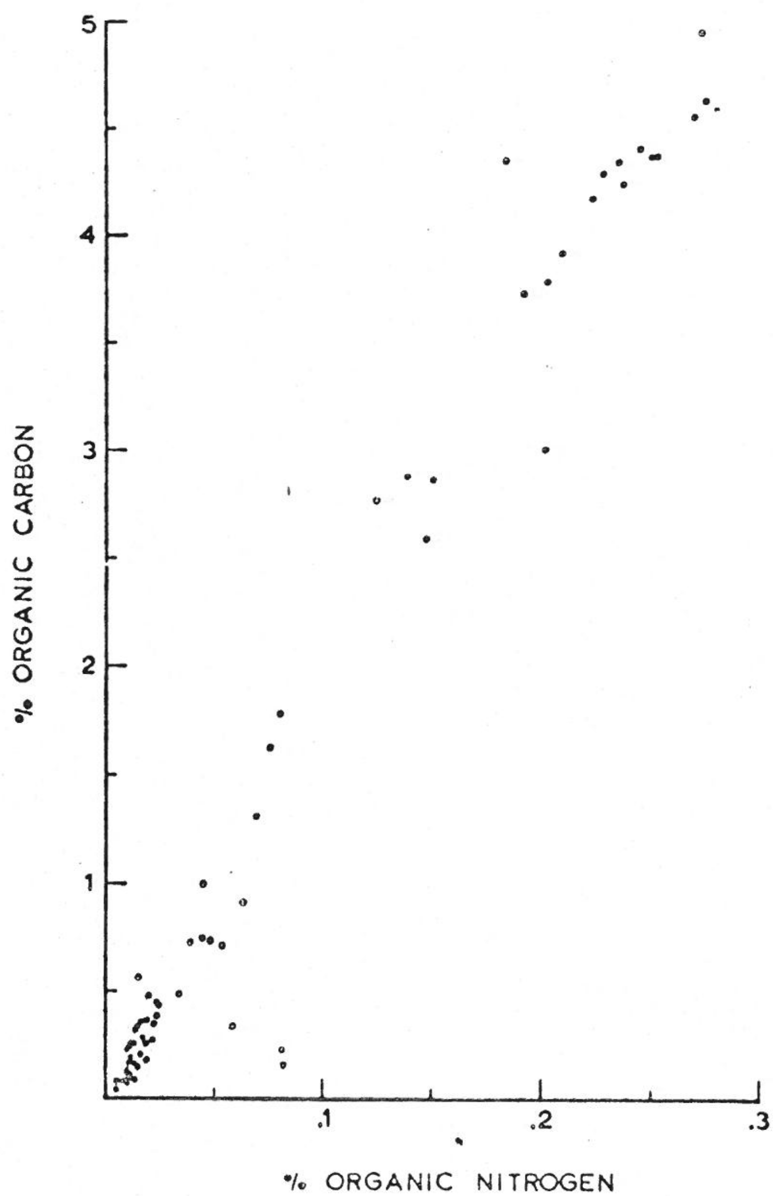


from a minimum in sands, a reflection of the normally increasing percentage in fine-grained sediments and the proteinaceous content of shells in the gravels. The curve of nitrogen content versus sorting increases steadily to a standard deviation of three, the normal maximum deviation of the fine-grained sediments.

The ratio of organic carbon to organic nitrogen for the study area are presented graphically in Fig. 14. The best-fit line through the points has a slope of 18.2. While this average illustrates present conditions it is unfortunately influenced strongly by carbonaceous material discharged from the paper mill. This influence is apparently confined by current flow to the northern portion of the study area, its extent outlined by the configuration of the contours in Fig. 11. If this northern area is eliminated from consideration an average ratio of 15.4 is obtained. While this average represents a considerable increase in carbon content over normal offshore sediments, which have an average ratio of about 8 to 12 (Emery, 1960), it is somewhat less than the ratio of 19 previously encountered in the even more restricted environment of San Quintin Bay in Baja California (Gorsline and Stewart, 1962). The excess in carbon is apparently due to the accumulation of highly carbonaceous plant debris under low energy conditions. Under these conditions values depart from what might normally be expected in a given marine sediment type.

Figure 14. - Organic carbon / organic nitrogen diagram.

CARBON - NITROGEN PLOT



Lower than average ratios are encountered in the extensive bed of shell gravel in response to the high protein content of the shell material.

The average carbon-nitrogen ratios for the various sediment types, given in Table 1, increase in response to average particle size, interrupted only in the silty clayey sands. If four highly contaminated samples in the immediate vicinity of the paper mill are eliminated, a ratio of 17.9 is obtained for that class and the trend is then continuous.

The carbon-nitrogen ratio over the forty-seven centimeter length of core 3, obtained in the old channel off Eagle Harbor, increases steadily with depth from 17.1 to 19.1, despite the uniform character of the sediment. A corresponding reduction is seen in nitrogen content, from 0.321 to 0.267 per cent, which might be attributed to anaerobic bacterial action. The strong presence of hydrogen sulfide marked the reducing character of the sediments throughout the length of the core. Possibly the ratio increase was established prior to the establishment of the reducing environment. Certainly little sediment has been added under the present slow rate of deposition.

Mineralogy

Light Minerals

The characteristics and source of quartz and calcite, the only light minerals present in this area with the exception of the clays, have been covered in previous sections and need little further discussion. Some aragonite is also present in the form of shell material. A moderate percentage of the quartz grains in the range from 0.5 to 0.062 mm. shows considerable frosting and has probably been contributed from eolian dune deposits along the coast and inland. The variable sources and distance of travel of the quartz is evident in the variation of surface texture and particle shape.

Heavy Minerals

The study area lies in the East Gulf heavy mineral province as defined by Goldstein (1942) and described at length by Van Andel and Poole (1960) and Hsu (1960). The "kyanite-staurolite" suite along this coast is characterized by abundant ilmenite, staurolite, kyanite, zircon, tourmaline and sillimanite, and by low magnetite, amphiboles, and pyroxenes. This assemblage is well illustrated in the average percentages encountered in St. Joseph Bay, given in Table 2.

Recycling of older sediments accounts for part of the maturity of the suite but loss of unstable heavies is also apparent in present transport by the Apalachicola River and its tributaries and coastal currents. Cazeau (1955) found a steady decrease downstream in the hornblende and epidote, which dominate the suite in the upper reaches. These min-

TABLE 2

HEAVY MINERAL AVERAGES
(based on 20 samples in per cent
of heavy fraction by weight)

Mineral	%	Mineral	%
Ilmenite	28.0	Rutile	4.8
Kyanite	13.1	Magnetite	3.6
Sillimanite	7.4	Epidote	1.4
Staurolite	14.1	Hornblende	3.1
Zircon	8.7	Leucoxene	7.3
Tourmaline	8.5		

erals are reduced to minor importance by the time they reach the present study area. On the other hand the percentage of leucoxene increases in response to increased weathering of ilmenite. A curious and interesting note is the disappearance of garnet, present in Apalachicola sediments in amounts of one or two per cent of the heavy fraction. The answer certainly does not lie in the stability of the mineral and does not appear to be connected with particle size or density since minerals exhibiting similar size and density, such as zircon, remain fairly constant in percentage.

Heavy mineral content is low throughout the St. Joseph Bay area, amounting to less than one per cent in all examples analyzed and averaging 0.3 per cent. Highest concentrations occur along the outer shore of the spit and in the shoal to the north, percentages decreasing seaward and into the basins.

Clay Minerals

Kaolinite, montmorillonite, and illite make up the clay mineral suite in St. Joseph Bay sediments and occur in fairly constant proportions throughout the area. Quantitative estimates based on the areas under the fifteen, seven, and ten angstrom peaks result in the following average percentages: kaolinite 66%, montmorillonite 26%, illite 8%. These figures are in good agreement with the composition and relative percentages of clays in the terrestrial deposits of this region as given by Griffin (1962). Griffin's estimated ranges for marine clays in the Apalachicola area, based on relative peak heights, are kaolinite 60-80%, montmorillonite 0-20%, illite 0-5%. The slight variation between these results and those obtained by this writer are very likely due to the differing techniques for making quantitative estimates from diffractogram patterns.

Segregation of clay minerals on the basis of particle and floccule sizes has been described by Whitehouse and Jeffrey (1955). Montmorillonite, which develops smaller floccules in seawater than either kaolinite or illite is kept in suspension for a longer time and increases in percentage with distance. If the clays of St. Joseph Bay had been transported over the distance traveled by the present detrital sediments, a resulting increase in montmorillonite might reasonably be expected. The fact that the relative percentages are comparable to the clay mineral content in

Apalachicola Bay strengthens the argument for a more immediate and consequently older source of fine-grained material in the study area.

Trends of Sedimentation

The procedures involved in the application of regression surfaces to sedimentary parameters have been thoroughly covered by Krumbein (1956) and Miller (1956) and the reader is referred to these sources for a more complete explanation. In brief, a surface is fit statistically through the raw data and the differences between this surface and the original values are contoured as residuals. Positive residuals occur when original values are higher than the surface, negative residuals when these values are lower. Ideally these residuals should outline those areas which are anomalous to the general trend and which require an explanation for their presence.

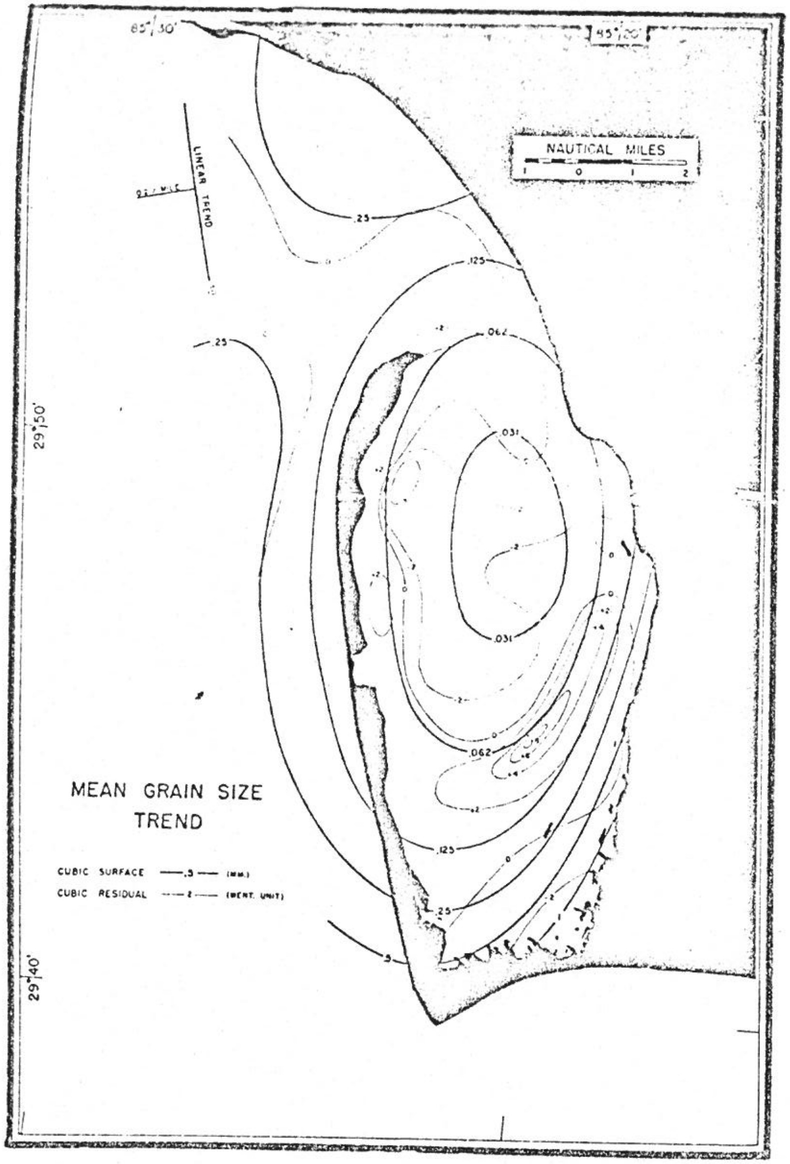
Surfaces up to the fifth degree have been programmed for the 709 IBM Computor at Florida State and were applied to the data obtained for mean grain size, standard deviation, carbonate, and carbon percentages in the study area. The linear surface appeared to give the best representation of the larger regional trend and the strike and dip of this surface is included in the following figures. In the case of mean diameter, standard deviation, and organic carbon content the strike of the linear surface is north-northwest, paralleling the shoreline. The one exception is the carbonate trend which is offset to a north-south position, probably as a result of the linearity of the extensive shell bank. In every case the surfaces slope seaward, values decreasing away from shore. On a regional scale, however, the study area is itself anomalous and for this reason the cubic surface which better represents the localized trend of sedimentation was applied. The resulting patterns are presented in Figs. 15 through 18.

The response of the surface in all cases to the basinal character of the area is at once apparent. Since the trend reflects the summation of all factors involved, residual contours on these surfaces represent areas in which individual factors dominate and may be explained on that basis. In Fig. 16 positive residuals outline the encroaching sand lobe and the shell bank to the south, while the fine-grained sediments of the central portion of the lagoon show up as a negative anomaly. Comparison of the mean grain size residuals to the contoured raw data (Fig. 6) show a striking similarity of patterns, emphasizing the fact that no single uniform mode of sedimentation can be accepted to account for the observed situation. Comparisons of standard deviation, carbonate, and organic carbon content show the same to be true of these parameters. The residual maps might easily be substituted for maps contoured on raw data.

In view of the above discussion it appears that

Figure 15. - Standard deviation trend and residual map.

Figure 16. - Mean grain size trend and residual map.


MEAN GRAIN SIZE
TREND
CUBIC SURFACE —.3— (MM.)
CUBIC RESIDUAL ---2--- (WENT. UNIT)
LINEAR TREND
NAUTICAL MILES
1 0 1 2
85°30'
85°20'
29°50'
29°40'

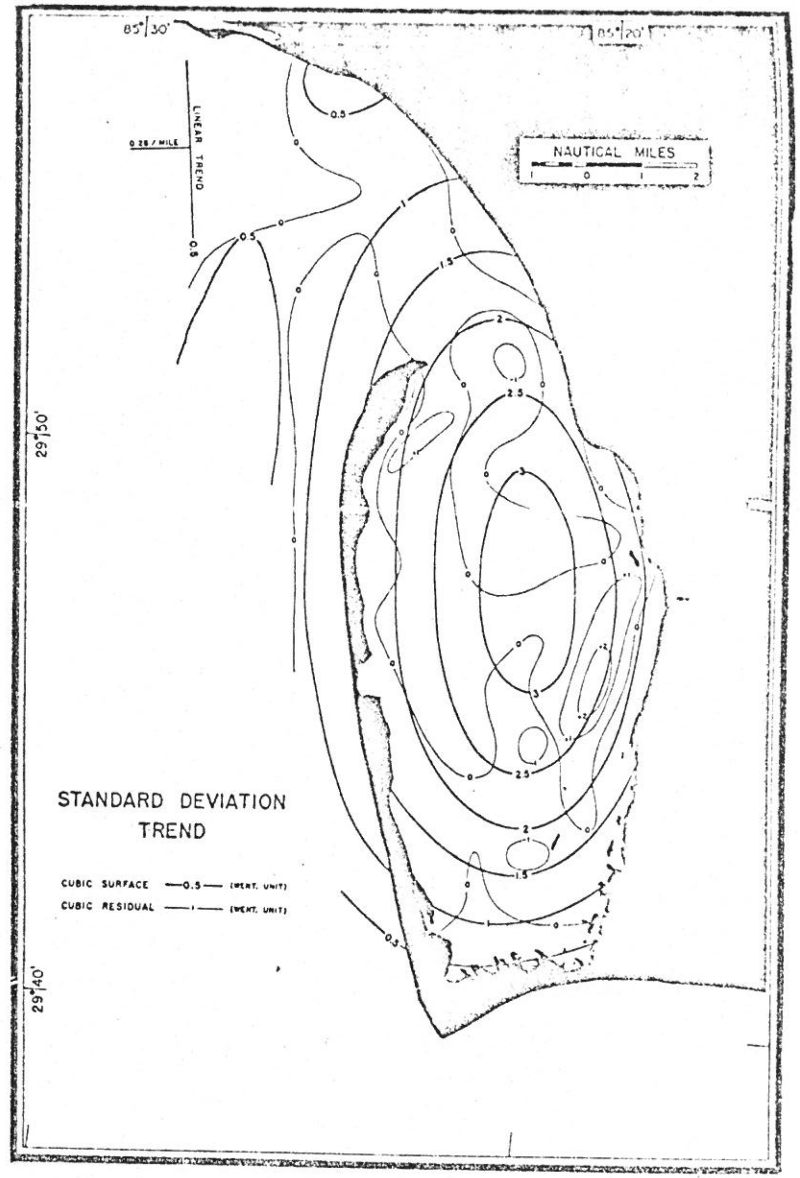
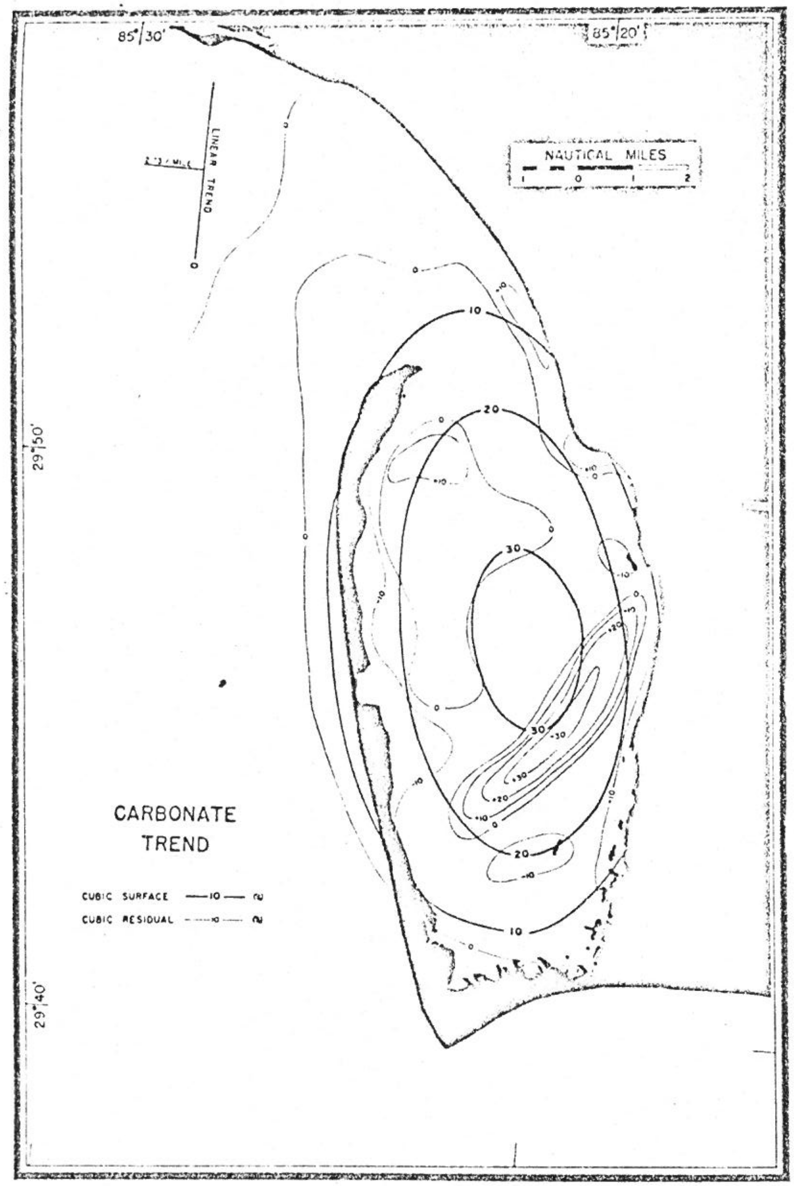
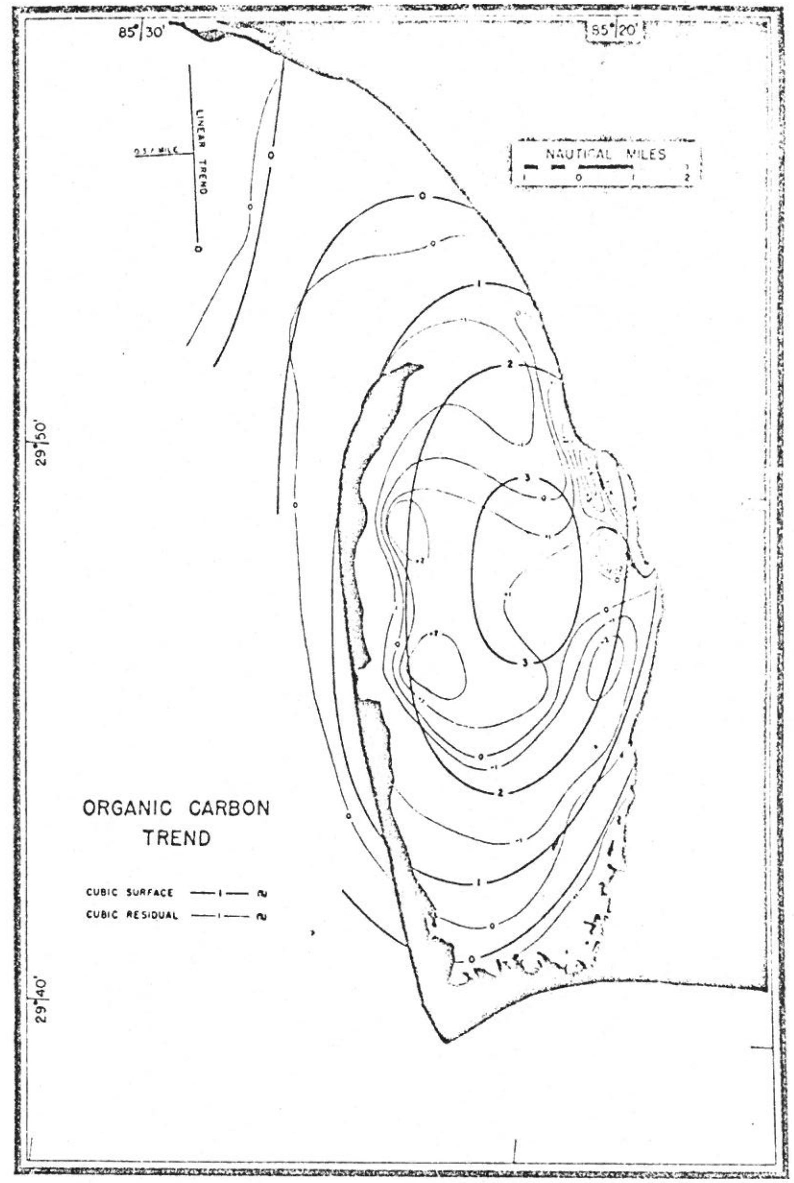

STANDARD DEVIATION
TREND
CUBIC SURFACE —0.5— (WENT. UNIT)
CUBIC RESIDUAL —1— (WENT. UNIT)
LINEAR TREND
0.28 / MILE
NAUTICAL MILES
1 0 1 2
85°30'
85°20'
29°50'
29°40'

Figure 17. - Organic carbon trend and residual map.

Figure 18. - Carbonate trend and residual map.


85°30'
85°20'
LINEAR TREND
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
CARBONATE
TREND
CUBIC SURFACE —10—
CUBIC RESIDUAL ---10---


85°30'
85°20'
LINEAR TREND
NAUTICAL MILES
1 0 1 2
29°50'
29°40'
ORGANIC CARBON
TREND
CUBIC SURFACE —1—
CUBIC RESIDUAL ---1---

little is gained by the application of trend surfaces to modern sediments where observation of the present relationship between energy, source, and sediment patterns permit adequate interpretation. In ancient sediments, however, this relationship is rarely so apparent and the employment of trend surfaces might greatly facilitate recognition of factors in operation in a given environment. For this reason the application of trend surfaces to modern environments can be of great aid in establishing identifying patterns for recognizing similar situations encountered in the geologic record.

SUMMARY AND CONCLUSIONS

Present day sedimentation in the St. Joseph area may be ascribed to two dominant factors, the coastal transport of clean quartz sand from the east and biological activity within the area itself. In the absence of substantial amounts of silt size quartz, carbonate tests and shell fragments increase in importance as the applied energy of the environment decreases into the lagoon from the north. Residual shell gravels dominate a sizable portion of the southern slope of the lagoon removed from active deposition of detrital material.

The slow rate of deposition which has followed since the construction of the enclosing spit has allowed the preservation of depth and gradient in the central portion of the lagoon in close agreement with that of the offshore slope. The large accumulation of clay in the central basin, well beyond that accounted for by present minor sources, has led to the conclusion that these fine sediments represent a relict surface produced by the discharge of an old distributary of the Apalachicola River. The presence and location of this distributary have been established from aerial photographs.

Mineralogically the sediments of this area are what might be expected from the character of the Coastal Plain source. Small differences can be attributed to attrition and loss in transport. The typical East Gulf "kyanite-staurolite" suite of heavy minerals is present in amounts of less than one per cent. Kaolinite, montmorillonite, and illite comprise the clay minerals present, with kaolinite dominating the suite.

In view of the conditions established by this study, the following sequence of events appears to be in order in the development of modern St. Joseph Bay.

1. Following the last sea level rise, about 5000 years B. P., a series of north-south trending beach ridges were formed and an open coast profile established offshore. A still older set of ridges was submerged and subjected to marine attack, resulting in the formation of a shoal trending south-southwest from the mainland through the Cape San Blas area.

2. A large distributary of the Apalachicola River, its course controlled by beach ridge development, debouched about five miles north of the present lagoon and deposited a wedge of fine-grained material over the terrace surface. At approximately the same time gyral currents established by the presence of the southern shoal initiated spit growth from the east.

3. Rapid spit development segregated a large portion of the older surface and prevented substantial filling of

the bypassed area. At this time the supply of detrital material by the distributary had ceased and sand supplied by long-shore drift and biologic carbonate formed the major contribution.

4. Development of stronger tidal currents in recent times controlled spit growth and furnished an agency for the transport of sand into the basins. Sand has completely covered the fine-grained material to the north. Under the lower energy conditions of the lagoon, sand encroachment has been slow and limited, and a large portion of the older surface remains relatively unobscured.

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APPENDIX

TABLE 3

TEXTURAL DATA

Sample No.	Mean Diameter millimeters	Standard Deviation phi units	Sediment Type
1	0.206	1.48	sand
2	0.221	0.60	sand
3	0.321	1.00	sand
4	0.207	1.01	sand
5	0.203	0.52	sand
6	0.232	0.72	sand
7	0.168	1.56	sand
8	0.190	0.34	sand
9	0.218	1.08	sand
10	0.304	0.97	sand
11	0.616	1.82	gravelly sand
12	0.406	1.92	gravelly sand
13	0.582	2.28	gravelly sand
14	0.129	1.91	sand
15	0.019	3.43	si cl sand
16	25.992	0.78	gravel
17	0.299	2.16	gravelly sand
18	0.283	0.74	sand
19	0.010	2.96	sa cl silt
20	0.006	2.69	sa cl silt
21	0.018	3.59	si cl sand
22	1.094	5.26	sa si gravel
23	0.423	2.08	sand
24	0.008	3.00	sa cl silt
25	0.007	3.53	sa cl silt
26	0.009	3.14	sa cl silt
27	1.765	4.73	sandy gravel
28	0.207	0.59	sand
29	0.181	1.21	sand
30	0.009	2.96	sa cl silt
31	0.008	2.83	sa cl silt
32	0.014	3.34	sa cl silt
33	0.018	3.70	si cl sand
34	0.213	0.56	sand
35	0.004	2.48	clayey silt
36	0.009	2.86	sa cl silt
37	0.004	2.60	clayey silt
38	0.006	2.82	sa cl silt
39	0.240	1.19	sand
40	0.277	0.65	sand
41	0.229	0.58	sand
42	0.486	3.21	gr si sand

TABLE 3 - Continued

Sample No.	Mean Diameter millimeters	Standard Deviation phi units	Sediment Type
43	0.010	2.62	sa cl silt
44	0.017	3.53	sa cl silt
45	0.023	3.31	si cl sand
46	0.274	1.48	sand
47	0.235	0.56	sand
48	0.196	0.48	sand
49	0.206	0.45	sand
50	0.237	0.52	sand
51	0.030	3.48	si cl sand
52	0.104	2.48	sand
53	0.022	3.29	si cl sand
54	0.207	0.51	sand
55	0.252	0.64	sand
56	0.202	0.48	sand
57	0.205	0.45	sand
58	0.168	1.67	sand
59	0.209	1.22	sand
60	0.222	0.55	sand
61	0.232	0.63	sand
62	0.221	0.54	sand
63	0.245	0.71	sand
64	0.120	1.92	sand
65	0.170	2.10	sand
66	0.088	2.28	sand
67	0.224	0.54	sand
68	0.227	0.57	sand
69	0.178	1.38	sand
70	0.192	0.80	sand
71	0.243	3.01	gravelly sand
72	0.196	0.81	sand
73	0.209	0.46	sand
74	0.216	0.57	sand
75	0.247	0.86	sand
76	0.277	1.66	sand
77	0.200	0.45	sand
78	0.195	0.67	sand
79	0.216	0.84	sand
80	0.200	0.48	sand
81	0.184	0.73	sand
82	0.196	0.82	sand
83	0.198	0.85	sand
84	0.187	0.70	sand
85	0.221	0.72	sand
86	0.206	0.54	sand

TABLE 3 - Continued

Sample No.	Mean Diameter millimeters	Standard Deviation phi units	Sediment Type
87	0.193	0.52	sand
88	0.174	0.56	sand
89	0.224	0.54	sand
90	0.238	0.51	sand
91	0.003	2.45	clayey silt
92	0.395	0.93	sand
93	0.314	0.58	sand
94	0.152	2.13	sand
95	0.003	2.62	clayey silt
96	0.203	0.45	sand
97	0.050	3.10	si cl sand
98	0.043	2.94	si cl sand
99	0.235	0.58	sand
100	0.203	0.53	sand
101	0.209	0.64	sand
102	0.209	0.51	sand

TABLE 4

SEDIMENT COMPOSITION DATA

Sample No.	% $CaCO_3$	% Org. Carbon	% Org. Nitrogen	% Heavy Minerals
1	4.5	0.738	0.048	0.28
2	2.1	0.235	0.010	0.26
3	8.8	0.276	0.017	0.22
4	4.4	0.262	0.013	0.13
5	2.8	0.366	0.019	0.09
6	3.1	0.257	0.012	0.32
7	11.5	0.918	0.064	0.21
8	2.5	0.166	0.013	0.03
9	6.1	0.745	0.045	0.13
10	7.0	0.245	0.011	0.73
11	40.3	0.206	0.016	0.11
12	20.0	0.178	0.019	0.18
13	27.2	0.321	0.070	0.04
14	7.1	0.493	0.034	0.16
15	22.9	3.006	0.203	0.20
16	90.3	0.706	0.054	0.00
17	18.7	0.336	0.058	0.19
18	2.9	0.256	0.018	0.12
19	28.8	4.347	0.237	0.17
20	29.0	4.617	0.277	0.07
21	31.8	4.239	0.239	0.18
22	52.8	0.158	0.082	0.09
23	9.9	0.385	0.024	0.12
24	24.8	4.401	0.247	0.06
25	27.0	4.374	0.252	0.12
26	27.2	3.767	0.204	0.10
27	55.8	0.226	0.082	0.06
28	2.3	0.351	0.022	0.09
29	5.7	0.277	0.022	0.12
30	27.9	4.361	0.254	0.06
31	27.0	4.286	0.229	0.07
32	23.5	3.726	0.193	0.13
33	21.7	2.882	0.140	0.13
34	3.8	0.166	0.011	0.09
35	25.0	4.554	0.271	0.03
36	27.4	3.906	0.211	0.10
37	32.6	4.941	0.275	0.04
38	28.7	4.168	0.225	0.08
39	10.1	0.158	0.015	0.23
40	2.4	0.092	0.007	0.09
41	1.6	0.092	0.007	0.26
42	30.4	0.731	0.039	0.21
43	34.5	2.592	0.148	0.19

TABLE 4 - Continued

Sample No.	% $CaCO_3$	% Org. Carbon	% Org. Nitrogen	% Heavy Minerals
44	19.7	2.862	0.152	0.15
45	16.7	2.768	0.126	0.16
46	5.8	0.358	0.017	0.10
47	1.8	0.119	0.012	0.11
48	2.0	0.140	0.010	0.54
49	2.5	0.096	0.007	0.58
50	3.2	0.196	0.012	0.04
51	20.1	1.782	0.081	0.19
52	11.5	0.999	0.045	0.18
53	25.6	4.347	0.185	0.08
54	1.8	0.078	0.010	0.27
55	2.2	0.105	0.010	0.16
56	2.1	0.092	0.014	0.67
57	4.9	0.139	0.014	0.75
58	6.5	0.570	0.016	0.18
59	10.4	0.338	0.015	0.24
60	1.9	0.130	0.010	0.40
61	5.5	0.099	0.005	0.58
62	1.8	0.097	0.007	0.94
63	3.1	0.146	0.019	0.62
64	5.7	0.431	0.019	0.33
65	7.4	0.445	0.019	0.36
66	18.2	1.633	0.077	0.92
67	1.4	0.048	0.005	0.31
68	1.8	0.079	0.005	0.46
69	4.5	0.330	0.014	0.44
70	3.1	0.195	0.009	0.41
71	7.4	0.477	0.020	0.41
72	4.2	0.313	0.014	0.33
73	2.4	0.146	0.012	0.26
74	2.8	0.192	0.010	0.29
75	4.4	0.214	0.010	0.22
76	4.1	0.233	0.012	0.51
77	2.5	0.130	0.007	0.56
78	3.2	0.188	0.010	0.61
79	2.5	0.199	0.010	0.21
80	2.2	0.102	0.008	0.13
81	2.8	0.086	0.005	0.22
82	4.6	0.079	0.005	0.39
83	3.8	0.086	0.005	0.41
84	11.7	0.081	0.005	0.38
85	3.5	0.073	0.005	0.12
86	3.1	0.108	0.007	0.24
87	2.1	0.081	0.005	0.24
88	2.8	0.079	0.005	0.38

TABLE 4 - Continued

Sample No.	% $CaCO_3$	% Org. Carbon	% Org. Nitrogen	% Heavy Minerals
89	1.0			0.22
90	0.6			0.40
91	25.0			0.25
92	5.7			0.01
93	1.2			0.10
94	11.4	0.950	0.040	0.62
95	34.1	7.065	0.225	0.15
96	0.5	0.056	0.006	0.08
97	14.8	4.179	0.112	0.46
98	12.9	4.625	0.120	0.70
99				0.10
100				0.26
101				0.29

TABLE 5

TEXTURAL CLASS PERCENTAGES

Sample No.	% Gravel	% Sand	% Silt	% Clay
1	3.04	93.24	3.33	0.39
2	0.24	99.52	0.24	-
3	4.62	95.33	0.05	-
4	4.26	95.04	0.04	-
5	0.17	99.77	0.06	-
6	0.38	99.35	0.27	-
7	4.24	90.63	4.36	0.77
8	0.01	99.94	0.05	-
9	3.77	94.95	1.28	-
10	4.89	94.86	0.25	-
11	14.21	85.69	0.10	-
12	14.02	85.92	0.06	-
13	23.59	74.55	1.86	-
14	0.87	90.83	5.00	3.30
15	0.22	48.58	28.64	22.56
16	100.00	-	-	-
17	13.90	83.91	1.82	0.37
18	1.09	98.91	-	-
19	0.28	20.03	61.33	18.36
20	0.06	10.20	66.39	23.35
21	1.92	41.28	31.80	25.00
22	55.93	23.85	11.78	8.44
23	13.87	86.03	0.10	-
24	0.22	19.63	58.07	22.08
25	0.09	12.53	64.30	23.08
26	0.38	19.88	54.57	25.17
27	65.04	19.81	8.35	6.80
28	-	99.50	0.50	-
29	1.74	94.65	2.77	0.84
30	0.13	18.19	60.86	20.82
31	0.27	14.12	65.10	20.51
32	0.14	27.42	56.39	16.05
33	1.22	43.27	29.22	26.29
34	0.30	99.36	0.34	-
35	-	8.71	59.99	31.30
36	0.18	14.91	63.31	21.60
37	0.30	8.02	57.73	33.95
38	0.13	10.67	59.23	29.97
39	5.14	94.37	0.49	-
40	0.16	99.79	0.05	-
41	0.17	99.77	0.06	-
42	26.24	61.90	10.58	1.28
43	0.06	25.94	52.69	21.31
44	0.20	39.21	40.14	20.45

TABLE 5 - Continued

Sample No.	% Gravel	% Sand	% Silt	% Clay
45	0.72	49.50	32.07	17.71
46	6.00	90.90	3.10	-
47	0.04	99.87	0.09	-
48	0.02	99.84	0.14	-
49	-	100.00	-	-
50	0.01	99.99	-	-
51	2.44	46.51	35.42	51.63
52	1.49	80.63	13.78	4.10
53	0.55	43.00	40.61	15.84
54	0.04	99.90	0.06	-
55	0.05	99.88	0.07	-
56	0.06	99.84	0.10	-
57	0.07	99.72	0.21	-
58	2.92	89.74	6.17	1.17
59	2.75	95.72	1.52	-
60	0.20	99.77	0.03	-
61	0.27	99.66	0.07	-
62	0.19	99.81	-	-
63	0.91	99.09	-	-
64	0.79	88.33	6.77	4.11
65	3.76	88.30	4.47	3.47
66	1.41	83.30	9.49	5.80
67	0.02	99.96	0.02	-
68	0.05	99.92	0.03	-
69	0.59	96.09	2.44	0.88
70	0.79	97.89	1.32	-
71	15.68	76.08	4.35	3.89
72	0.31	98.05	1.64	-
73	-	100.00	-	-
74	-	99.76	0.24	-
75	0.20	99.23	0.57	-
76	8.12	91.20	0.68	-
77	-	100.00	-	-
78	0.08	99.25	0.67	-
79	1.04	95.78	3.18	-
80	0.10	99.80	0.10	-
81	1.02	95.89	3.09	-
82	3.37	96.62	0.01	-
83	2.06	96.69	1.25	-
84	1.89	98.11	-	-
85	1.08	97.98	0.94	-
86	0.39	99.01	0.60	-
87	0.74	99.26	-	-
88	0.79	96.61	2.60	-
89	0.28	99.72	-	-

TABLE 5 - Continued

Sample No.	% Gravel	% Sand	% Silt	% Clay
90	-	100.00	-	-
91	-	6.98	48.33	44.69
92	5.64	94.36	-	-
93	0.15	99.85	-	-
94	2.09	88.44	5.86	3.61
95	-	9.65	49.32	41.03
96	0.07	99.93	-	-
97	2.65	60.83	24.87	11.65
98	0.30	70.75	15.89	13.06
99	0.07	99.91	0.02	-
100	0.03	99.95	0.02	-
101	0.25	99.71	0.04	-
102	-	100.00	-	-

TABLE 6

HEAVY MINERAL SUITE PERCENTAGES

Sample No.	Kyanite	Sillimanite	Zircon	Staurolite	Rutile
1	19	3	5	13	3
3	20	3	6	21	3
5	18	7	8	17	7
6	12	11	13	14	1
13	12	9	8	14	6
18	11	12	4	16	5
28	18	5	14	15	6
30	14	2	11	11	8
41	9	8	10	13	4
46	16	5	13	19	3
50	11	12	8	12	2
53	9	8	6	8	3
57	15	7	2	22	1
58	12	12	3	13	2
62	8	11	17	9	7
68	8	5	10	13	6
72	12	10	10	17	8
79	12	7	7	16	11
80	11	8	6	8	8
83	15	3	13	11	1

TABLE 6 - Continued

Tourmaline	Ilmenite	Leucoxene	Magnetite	Epidote	Hornblende
8	35	2	9	-	3
3	30	3	6	3	2
12	11	8	3	2	7
5	26	5	3	3	7
5	32	7	5	1	1
19	22	3	4	2	2
10	20	3	4	2	3
5	36	7	4	-	2
11	31	7	2	2	3
7	25	8	2	-	2
9	23	8	4	3	8
5	38	19	2	1	1
7	30	10	4	1	1
4	29	13	5	2	5
8	31	5	1	1	2
15	28	7	3	2	3
6	23	9	2	1	2
12	29	4	1	-	1
9	33	10	-	2	5
10	28	8	8	-	3