THE DISTRIBUTION AND ORIGIN OF BOTTOM SEDIMENTS IN TIMBALIER BAY, LOUISIANA, AND THE ADJACENT OFFSHORE AREA

by James I. Jones and Sam E. Williams

ABSTRACT

Sediment samples from Timbalier Bay, Louisiana, and the adjacent offshore area were analyzed for grain size distribution, percentage of organic carbon, percentage of carbonate, and selected elements. The observed sediment distribution in the study area was characterized by a naturally occurring transition between sand and mud. These sediments originate from the Mississippi River, from old submerged Mississippi River deltaic lobes, and from drill cuttings. The observable and documentable effects of drilling were generally limited to surface sediments within three miles of the drilling platform. Coarse, medium, and fine sand fractions were greatest adjacent to the platform because of the addition of drill cuttings to the naturally occurring sediment. In Timbalier Bay the organic and carbonate values increased shoreward from the barrier islands. Offshore, the carbon and organic carbon values were generally low. The carbonate values correlate well with the distribution pattern found for the granule size fraction. The most common clay minerals found, in decreasing abundance, were montmorillonite, illite, and kaolinite. With few exceptions, the measured elements demonstrated lower values in the sandy sediments and higher values in finer sediments and at the bottom of the cores. Of the measured elements only barium demonstrated values significantly greater than those measured from naturally occurring sediments reported in the literature. The high barium values may be attributed to the introduction of barite, a major component of

At the time of this investigation James Jones and Sam Williams were with the Department of Oceanography, Florida State University, Tallahassee, FL.

drilling mud, into the sediment. The results of this study indicate that no significant sedimentary alterations have occurred in Timbalier Bay or in the adjacent offshore area as a result of drilling activities. With the single exception of increased barium concentrations, no significant elemental concentrations of those elements measured have occurred as a result of drilling operations in this region.

INTRODUCTION

Timbalier Bay is a large, shallow, semi-enclosed bay located approximately 90 kilometers to the west of the present Mississippi River delta near Grand Isle, Louisiana. The bay has historically been influenced by at least two deltaic lobes of the Mississippi River (Coleman 1966). Since 1938, when the first producing offshore oil well was discovered here, the bay has been continuously drilled. Today it contains about 400 wells (Morgan 1973). The offshore area adjacent to Timbalier Bay in south central Louisiana was also studied. This area extends from the shoreline offshore to about the 30 meter depth contour, and covers an area of approximately 1000 square kilometers. The sediments in this area are influenced by the old Mississippi River deltaic lobes, the sediment presently transported by the Mississippi River, and the drill cuttings and drilling mud produced during the drilling of the offshore oil and gas wells.

The deep subsurface geology of the area is well known as a result of this drilling, but very little has been published about the surface and shallow subsurface geology. Baseline data for the recent sediments of this region prior to drilling are, therefore, not available. A previous study of the surface sediments of Timbalier Bay was conducted by the Louisiana Wildlife and Fisheries Commission in 1968 (Louisiana Wildlife and Fisheries Commission 1971).

The present study was undertaken to describe the sediments of Timbalier Bay and its adjacent offshore area, to determine the distribution and origin of these sediments, and to measure the effects, if any, of oil production and drilling on these sediments.

METHODS

Sediment samples were obtained by coring, grab sampling, and underway bottom sampling. Gravity cores were collected using a 60 cm core barrel with a 3.8 cm outside diameter core liner. Diver-collected hand cores consisted of a section of 6.4 cm OD core liner, which was pushed into the substrate. The advantage of hand coring over gravity coring is that the substrate maintains its structural integrity with little sample compaction, a significant problem with gravity cores. Each core was marked with an identifying number and an arrow to indicate the horizontal orientation of the core. Cores were refrigerated or frozen to retard bacterial action and were handled and stored vertically to minimize structural disturbance in the sample.

Grab samples were collected with a 0.25 square meter Van Veen bottom grab. Two subsamples of each Van Veen grab were taken for later analysis.

The scoopfish-underway bottom sampler was designed to obtain a sample without stopping the vessel. Its capacity is 164 cubic centimeters of bottom sediment. This sampling method was not used at speeds over 15 knots.

Each sample was labeled with an identifying number, position, date of collection, type of sample, water depth, and supplemental remarks. Sampling locations are shown in figure 1 for the offshore area and in figure 2 for Timbalier Bay.

ANALYTICAL PROCEDURES

Size analysis

Two methods of grain size analysis have been used in this study: standard sieve analysis, in which a nest of sieves and a rotap are used, and settling tube analysis. The method to be used was determined by the size of the collected sample. If the total sample size was less than 25 grams, the settling tube method was used.

Sieve Method. Samples to be used for grain size analysis were washed three times with tap water to remove salts. Twenty-four hours after the final wash a subsample was taken and placed into a pre-weighed beaker and dried in an oven at 75° C. While drying, the sample was checked for salt deposits on the surface of the sediment. If a deposit appeared, the sample was rewashed. When the sample was dry, it was placed into a desiccator for 8 hours to cool to room temperature. The sample was then removed from the desiccator and weighed to 3 decimal places. A dispersant was then added to the sample and it was allowed to sit for 24 hours. The sample was stirred occasionally or placed on an ultrasonic cleaner during this period to aid the dispersant process. The sample was then wet sieved through a 62.5 micron screen. That portion of the sample which remained on the screen after wet sieving was dried in an oven. After drying, the sample was placed in a nest of sieves, which ranged from −1 to 4 phi, at 0.5 phi intervals, and rotapped for 20

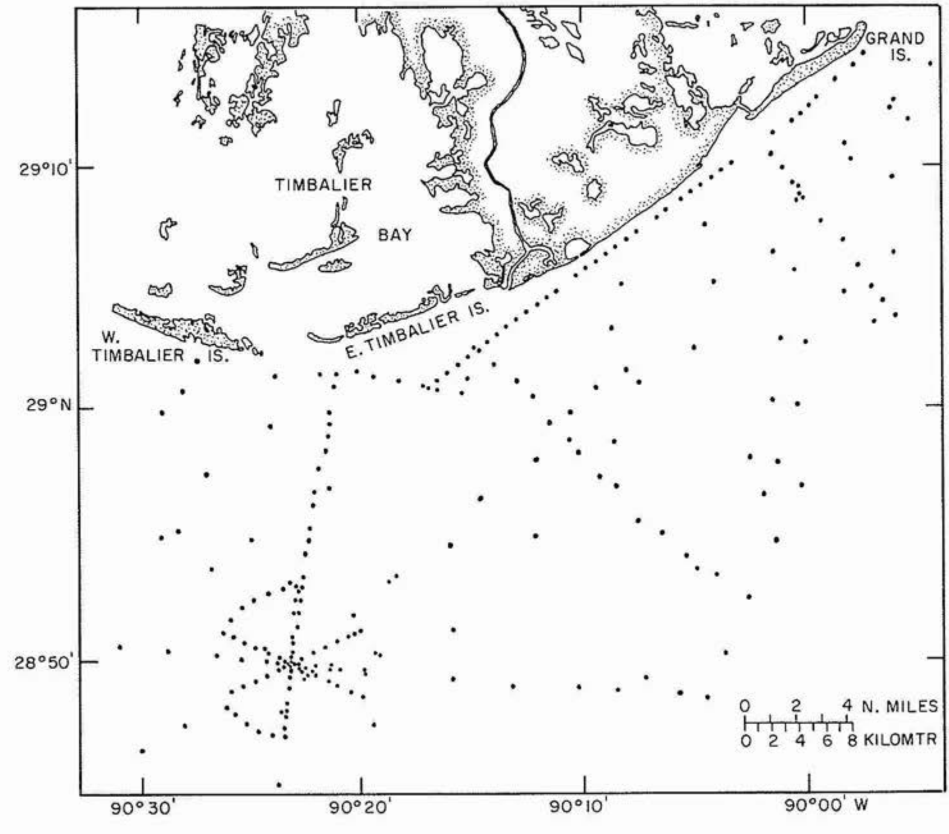

FIG. 1. SAMPLE LOCATIONS—OFFSHORE LOUISIANA.

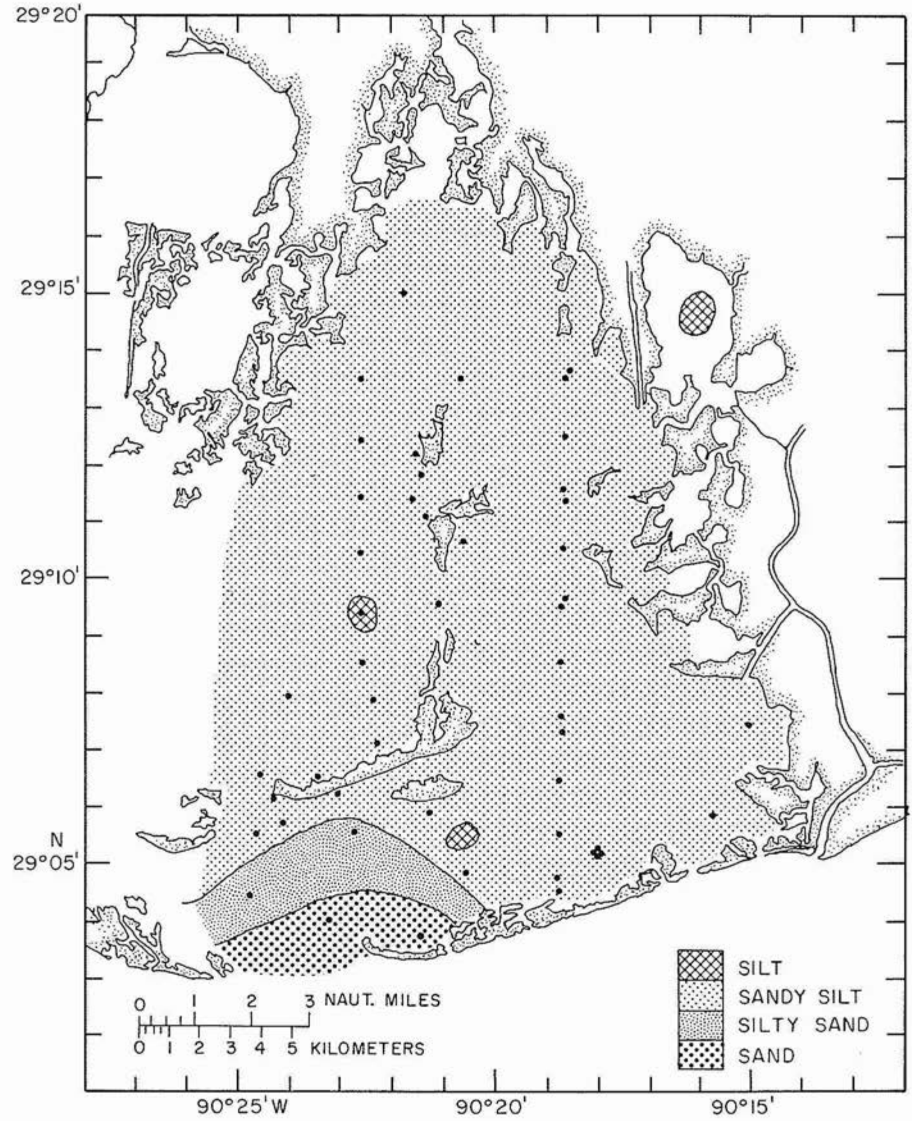

FIG. 2. SAMPLE LOCATIONS AND GENERAL SEDIMENT TYPES—TIMBALIER BAY.

minutes. Each fraction removed from the sieves was placed into a pre-weighed beaker and weighed.

Settling Tube Method. To determine the grain-size distribution for a sediment sample by use of the settling tube, the dispersed sediment sample was first wet-sieved through a 37 micron mesh screen, using tap water and a soft rubber spreader (policeman). That portion of the sample which remained on the screen was placed into a pre-weighed beaker, put into an oven at 75° C until it was dry, transferred to a desiccator for 8 hours to cool to room temperature, and then weighed to 3 decimal places. The grain-size analysis of the sedimentary material was done utilizing a UCLA settling tube (Ziegler et al. 1960; Schlee 1966; Felix 1969). This tube was one meter in length and equipped with a Cahn automatic electro balance and a chart recorder. Approximately 800 milligrams of sample were spread in a thin layer over the lower side of the lid of the settling tube and the lid placed over the settling tube just above the water level in the tube. When the unit was started, the lid was dropped the short distance to the water, where the sample washed off the lid and began to settle in the water column, at which time the chart recorder was started. The sample settled on a plane, and the weights were continuously recorded on the chart. The recorder continued to run until all the sample had settled out of the water column. The information recorded on the chart determined the percentage of the sample weight over the time of the run for the sample. From the information on the chart and the relationship between sphere size and settling velocity (Gibbs et al. 1971), the weight percentages at 0.25 phi size intervals were determined. These values were then used to calculate the statistical sediment parameters from the moments of frequency distribution of clastic sediments. The statistical sediment parameters included mean grain size, variance, standard deviation, degree of skew, and kurtosis. The formulas used in these calculations were those of Friedman (1961) and modified to fit the original moment method of Krumbein (1939).

Carbonate analysis

The percentage of carbonate in each sample was determined by weight loss after acidification (Carver 1971). A portion of the washed sample was dried and powdered and placed into a desiccator. Approximately 2 grams of powdered sample were placed into a pre-weighed beaker and weighed to 3 decimal places. Dilute HCl was added to the powdered sample. After the initial reaction had ceased, additional acid was added and the sample allowed to sit for 8 hours. Then, if no further reaction was observed and pH paper indicated an acidic condition, the excess acid was decanted off the sample. The sample was then washed with distilled water to remove $CaCl_2$ until pH paper indicated a neutral condition. The sample was then dried in an oven, placed in a desiccator for 8 hours and weighed, after which the necessary calculations were performed.

Organic analysis

The percentage of organic matter in each sample was determined by weight loss after ignition (Carver 1971). Approximately 1 gram of dried powdered sediment was placed in a pre-weighed crucible. The crucible was then placed in a muffle furnace and the sample heated to 550° C for 1 hour. Upon its removal from the furnace, the sample was partially cooled in air, and then placed in a desiccator to cool to room temperature. The sample was reweighed and the necessary calculations completed.

Microscopic analysis

The portion of any sample that was larger than 62.5 microns was examined through a binocular microscope to determine whether drill cuttings were present and to identify the minerals that were present.

X-ray analysis

The identification and relative abundance of clay minerals were determined by X-ray diffraction techniques. X-ray mounts were prepared by coating glass slides with several thin layers of suspended material, using those fine particles which had passed through the 37-micron screen during the wet sieving process. This produced a translucent coating on the slide. The slides were then X-rayed, using a K-alpha radiation and a G.E. XRD-5 diffractometer. Supplementary glycol and heat treatments were used as necessary to characterize the clay minerals. The patterns obtained were interpreted according to procedures previously published (Griffin 1971).

Elemental analysis

Elemental concentrations were measured by emission spectrography. The sample, as a dry powder, was mixed in a 1:1.3 ratio with an internal standard containing Lu, Pd, and Sr in a carbonate matrix, with powdered graphite. The prepared sample (30 μg) was loaded into a graphite electrode and ashed at 500° C for 15 minutes, and then burned in the emission spectrograph arc in a Stallwood jet, in an atmosphere of argon (90%) and oxygen (10%).

The detection limits were as follows: 3 μg/g for Sc and Y; 5 μg/g for B, Co, Cr, Cu, Ni, and V; 10 μg/g for La, Ti, and Zr; and 30 μg/g for Ba and Mo. The accuracy for elements present on the level of 3-4 times the detection limit is about ± 10%, and it is ± 20-25% for elements present in lower concentrations.

Al, Fe, Mn, and Si were determined by atomic adsorption with accuracies of 2% for these elements.

RESULTS

Timbalier Bay area

The dominant sediment type in Timbalier Bay was sandy silt, i.e., sand with >50% silt. Very fine sand (62.5-125.0 microns) was the dominant sand size in Timbalier Bay. The highest values for this sediment type occurred in the western part of the bay and near the pass (figure 2). Fine sand (125-250 microns) values were high near the pass, comprising 40-80% of the total. The remaining sand fractions had markedly lower values, usually less than 1% of total, with the higher values generally farthest from the pass. This size fraction was almost totally shell hash material. For comparison, figure 3 shows the sediment distribution reported by the Louisiana Fish and Wildlife Commission.

Drill cuttings, i.e., particles $>125\mu$, were found in the ranges of fine to very coarse sand. The fine sand fraction was most common.

Maximum carbonate values in the bay generally occurred farthest from the pass in the barrier islands. The organic values follow this same pattern, with the highest values occurring farthest from the pass.

The most abundant element measured in the bay was silica (SiO_2), which ranged from 42% to 85% of total, with an average value of 57%. Al_2O_3 ranged from 7% to 16.5%, with an average of 10%. The average value for iron showed a tendency for lower values in the sandy areas. The values for iron at the bottom of the cores were slightly higher than those from the top of the cores.

TiO_2 ranged from 0.27% to 0.70%, with an average value of 0.6%. The lower values occurred in the sandy area. P_2O_5 values ranged from 0.08% to 0.17%, with an average of 0.12%. MnO ranged from 0.02% to 0.16% and had an average value of 0.08%. Both P_2O_5 and MnO exhibited values that were reasonably uniform throughout the Timbalier Bay area.

Barium values were generally high throughout the bay. These values ranged from 370 to 1400 μg/g with an average value of 861 μg/g. The higher values occurred in those sediments with a higher concentration of silt size materials. Although still high, the values at the bottom of the cores were significantly lower than those near the top. The average value at the bottom of the cores was 600 μg/g.

Chromium exhibited a range of 20-85 μg/g, with an average value of 55 μg/g. Boron ranged from 45 to 130 μg/g with an average value of 80

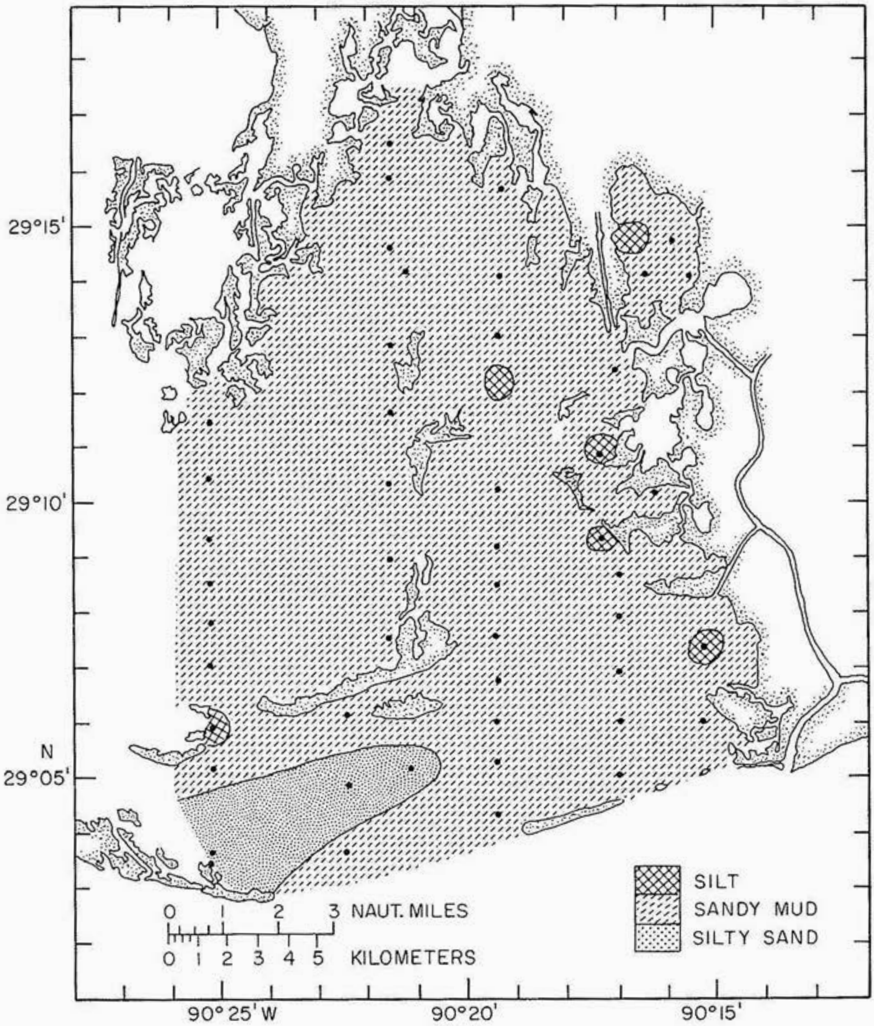

FIG. 3. GENERAL SEDIMENT TYPES—TIMBALIER BAY, 1968-69 (Louisiana Wildlife and Fisheries Commission 1971).

μg/g. Cobalt ranged from 5 to 25 μg/g and averaged 11 μg/g. These three elements all exhibited lower concentrations in the sandy areas of the bay. Nickel had relatively uniform values throughout the bay and in the cores, exhibited a range of 26-56 μg/g, and averaged 32 μg/g.

Copper had a range of 3-35 μg/g with an average of 13 μg/g. Vanadium ranged from 30 to 170 μg/g with an average value of 87 μg/g. Zirconium had a range from 90 to 410 μg/g, averaging 260 μg/g. The lowest values for each of these trace elements occurred in the sandy sediments near the pass. Unlike copper and vanadium, which showed higher values at the bottom of the core, zirconium exhibited highest values near the top of the cores.

Lanthanum values ranged from 12 to 45 μg/g and averaged 31 μg/g. They remained fairly uniform throughout the study area and did not exhibit any discernible distribution pattern. Both scandium and yttrium, which exhibited ranges of 3-15 μg/g and 6-30 μg/g, and average values of 7 μg/g and 21 μg/g respectively, exhibited a distribution pattern with the lower values in the sandy areas of the bay.

Area offshore Louisiana adjacent to Timbalier Bay

The dominant sediment types found in this area were silt, sandy silt, silty sand, and sand, as defined on the Wentworth Scale (Folk 1968). In the eastern portion, that area to the south of Grand Isle, Louisiana, west to a line running south from the mouth of Bayou Lafourche, the sediment types are generally sandy silt and silt. The only variation, a silty sand, occurred next to an oil well. The sandy portion of these sediments was generally a very fine sand (62.5-125 microns). In the western portion of the area sediment types ranged from silt to sand. The area with the greatest variety of sediment types was that around Exxon Platform 54A (figure 4). The entire range of sediments, from silt to sand, was found within a 1.6 kilometer radius of the platform. North of the platform the sediments were mostly sandy silt. Sand and silty sand were major sediment types to the southeast, south, and southwest of the platform.

The most common clay minerals in the area were, in relative abundance, montmorillonite, illite, and kaolinite. No general distribution pattern could be established.

The granule size fraction (2-4 mm) consisted of shell hash, drill cuttings, pieces of wood, and other organic matter. Shell hash was by far the dominant member of this size fraction, generally over 95% of the total. This fraction exhibited maximum values at the near-shore stations.

The coarse sand fraction (0.5-1.0 mm) was generally found within 4 kilometers of the platform and highest values occurred next to the platform (figure 5).

The only material found larger than a coarse sand was shell hash, although very coarse sand and some pieces of shale were found using a more selective sampling method. Some of the shale particles (drill cuttings) were larger than 4 mm, and found within a 6.4 kilometer radius of the platform, but never in large quantities. Just to the south of the eastern end of Timbalier Island a piece of material (larger than 4 mm) consisting of sand grains in an asphalt-like matrix was found. This was the only petroleum-base conglomerate material found in the whole study.

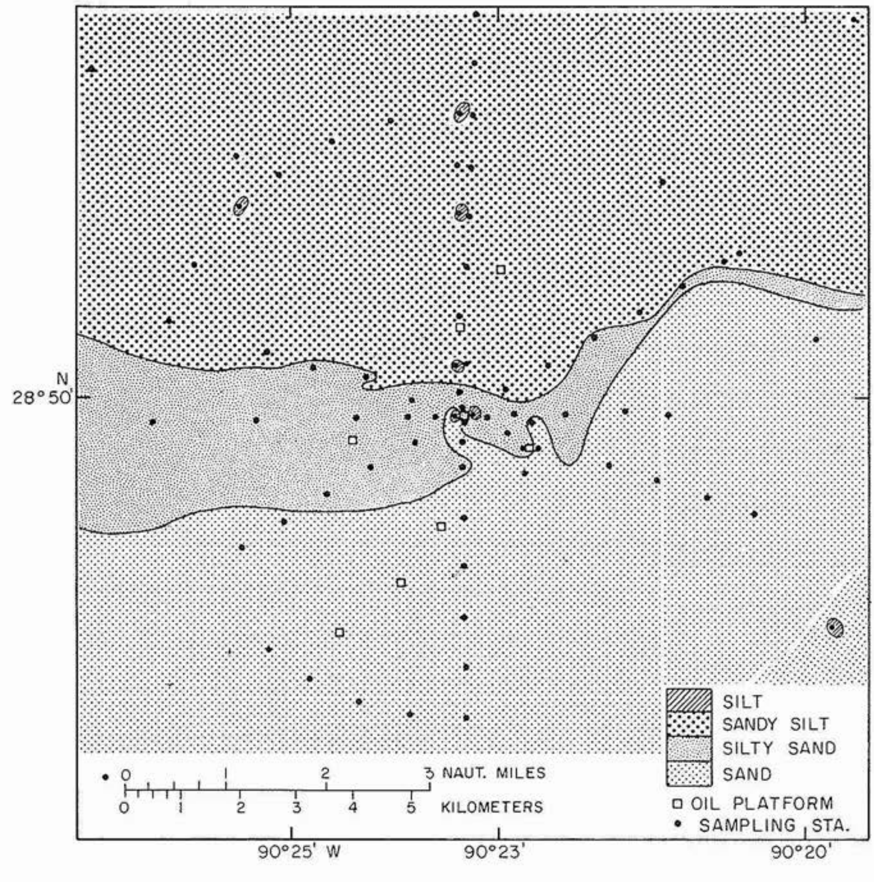

FIG. 4. GENERAL SEDIMENT TYPES AROUND EXXON PLATFORM 54A.

Cores collected from around Exxon Platform 54A, out to a distance of 4.8 kilometers, show a sediment distribution pattern at the surface in which there is a narrow band of silty sand running generally east-west across the platform location. To the north of this band, about 0.8 kilometers north of 54A, the sediment types are sandy silt and silt. To the south of this band, about 1.6 kilometers south of 54A, the sediments are sandy (see figure 4). Around the platform there is a complete range of sediment types from silt to sand, with the majority being silty sand or sand. At the 10 cm and 20 cm depth levels the sediment types are sandy silt and silt. The sediment distribution pattern found at the surface was not observed at depth, although the silty sediments generally occur north of 54A or next to a platform.

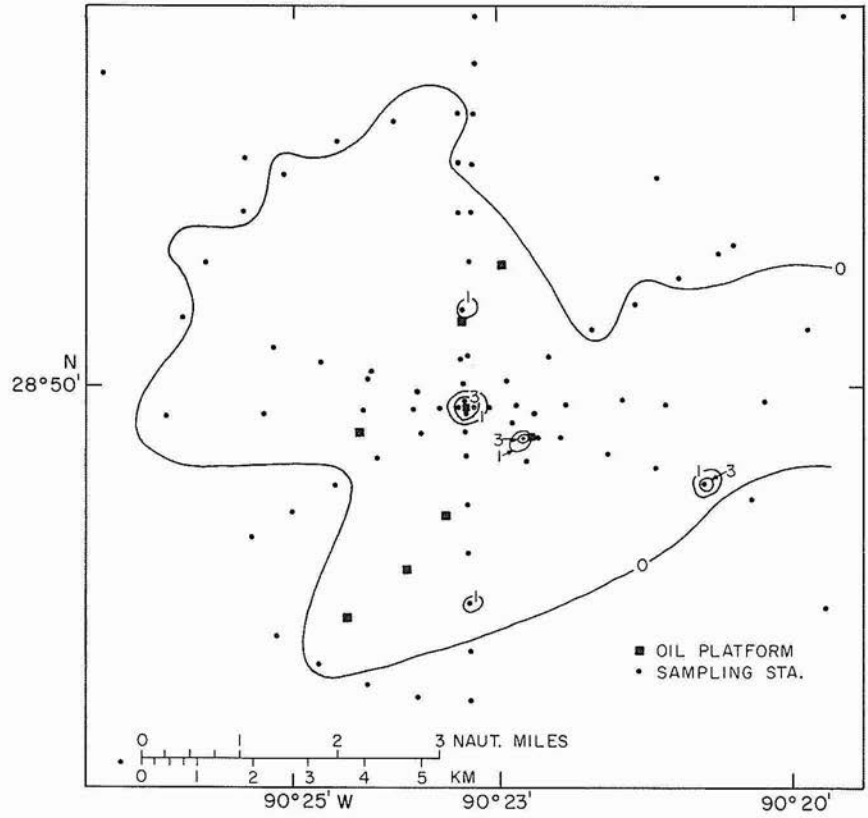

FIG. 5. PERCENTAGE OF COARSE SAND (0.5-1.0 mm).

The percentage of total sands (figure 6) shows distribution patterns similar to those shown by the general sediment types (figure 4). Eight-tenths of a kilometer north of 54A the values for percentage of total sands were generally less than 40%, 0.8 kilometers to the south the values are generally greater than 80%.

The very coarse sand fraction and the coarse sand fraction showed very low values, generally less than 1%, throughout the cores, and with the exception of those samples taken next to the platform consisted of shell hash and organic matter. Those samples taken next to 54A showed higher values (1-8%) for fractions of these sizes.

The values for the medium sand fraction at the surface were generally less than 8% in the area northeast, north, and northwest of Platform 54A. Within 2.4 kilometers to the east and west, and to the southwest, south, and southeast, the values were generally greater than 10%. At the

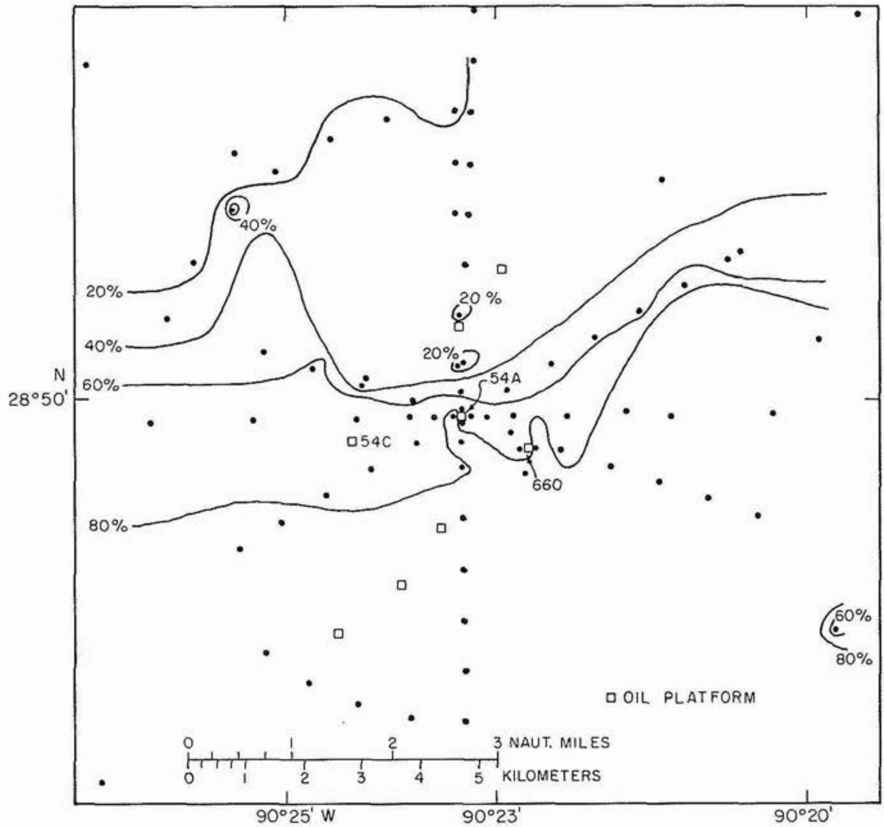

FIG. 6. PERCENTAGE OF TOTAL SANDS.

10 cm depth level the values were generally less than 5%, with the higher values occurring to the south of 54A. A sediment distribution pattern similar to the 10 cm level was found at the 20 cm level. The values at the 20 cm level were generally less than 3%. At all three levels (surface, 10 cm, and 20 cm) the higher values occurred next to the platform.

The values for the fine sand fraction generally increased with increased distance offshore. This was true for all depths. High values were found next to the platform. Very fine sand was found throughout the cores in small amounts, generally less than 10%.

Generally, the percentages of very coarse sand, coarse sand, medium sand, and fine sand all decreased with depth.

The carbonate values were generally less than 10%, with the higher values usually occurring near shore. The carbon values and the granule size fraction values correlate very well. The total organic carbon values were usually low, 4-12%. The sandy area south of 54A had values that were usually less than 3%.

Only one sample had a characteristic petroleum odor. It was collected next to a producing platform.

Silica (SiO_2), the most abundant element measured, ranged from 42% to 85% of total, with an average value of 61%. No surface distribution pattern could be established, but values were generally lower at the bottom of the cores. Al_2O_3 ranged from 3.5% to 18%, with an average of 10.8%. Slightly higher values occurred in those sediments with a higher percentage of mud. The values at the bottom of the cores were generally slightly higher. Iron (Fe) is found in formation water brines and drilling muds, and it accumulates in heavy oils and asphalts. It ranged from 0.9% to 7.5%, with an average value of 2.8%. Lower values occurred in sandy areas and slightly higher values occurred at the bottom of the cores.

TiO_2 ranged from 0.20% to 0.90%, with an average value of 0.60%. Lower values were found in sandy areas and slightly higher values occurred at the bottom of the cores. P_2O_5 values ranged from 0.06% to 0.20% and averaged 0.10%. The values obtained were fairly uniform throughout the study area. MnO values from 0.02% to 0.15% were recorded, and averaged 0.08%.

Barium (Ba) values were generally high throughout the offshore area, with the lower values occurring in the sandy areas. Barium values ranged from 520 to 2100 μg/g, and averaged 741 μg/g. Values at the bottom of the cores were generally lower than those at the top.

Oils are usually poor in chromium and molybdenum. In the study area chromium exhibited a range of 21-155 μg/g, and averaged 60 μg/g. Molybdenum was always less than 30 μg/g. Both chromium and molybdenum had their lowest values in the sandy sediments.

Boron (B) is commonly concentrated in oil field brines. In this study it ranged from 33 to 120 μg/g and averaged 70 μg/g. Cobalt (Co) value ranged from less than 5 to 30 μg/g and averaged 10 μg/g. Both boron and cobalt had their lowest values in sandy sediments, and at the top of the cores. Nickel (Ni) ranged from less than 5 to 75 μg/g, with an average of 38 μg/g.

Copper (Cu) had a range of 3 to 60 μg/g and averaged 20.2 μg/g. Zirconium (Zr) had a range of 110-1200 μg/g and an average of 250 μg/g. Although these three elements varied in their ranges, they all exhibited their lowest values in the sandy sediments. Where copper and vanadium showed higher values at the bottom of the cores, zirconium showed a reverse pattern with the higher values at the top of the cores.

Lanthanum, scandium, and yttrium all had their lower values in the sandy sediments, and at the top of the cores. Their measured values were: lanthanum, 10-80 $\mu g/g$, average 31 $\mu g/g$; scandium, less than 3 to 19 $\mu g/g$, average 8 $\mu g/g$; and yttrium, less than 5 to 60 $\mu g/g$, average 22 $\mu g/g$.

DISCUSSION

Timbalier Bay

A comparison between a 1968-1969 study by the Louisiana Wildlife and Fisheries Commission and the study reported here shows that the sediment distribution pattern of Timbalier Bay and its surrounding area has varied little over this time period. Both studies show the main sediment to be sandy silt, with silty sand and sand in the pass between the barrier islands of Timbalier and East Timbalier. The major difference between the two studies was the change in the shape and size of East Timbalier Island (figures 2 and 3). The present study shows the island to be much larger than in the former. In addition, some smaller islands in the bay no longer exist. Since this type of environment is highly dynamic, the differences are presumed to be due to natural causes, such as the reworking of bottom sediments and erosion by wave and current action. The values found for the silt, sand, and granule size fractions vary little between the two studies. Those small differences which are observed are probably due to redistribution of sediments by wave action, currents, boat propeller wash, shrimping activities, dredging, and drilling and well rework activities.

It should be noted that neither this study nor that completed by the Louisiana Wildlife and Fisheries Commission provides a true natural baseline for the parameters measured in the Timbalier Bay region, because oil and gas wells have been drilled in the bay since 1938, with the heaviest drilling activity having taken place in the mid-1950s and early 1960s (Morgan 1973).

Drill cuttings are those materials brought to the surface during the drilling of a well. In this report, cuttings are defined as those sand and shale particles coarser than a very fine sand (125 microns). This size limitation is based on a 1938 study by the U.S. Army Corps of Engineers (1939), which stated that no material coarser than a very fine sand was being transported as suspended sediment by the Mississippi River, and on the opinion of Dr. J. P. Morgan (personal communication), who believes that this has been the case for the past 5,000 years. Therefore, it has been assumed that anything coarser than a very fine sand has derived from drilling operations that have brought the deeper, coarser sediments to the surface.

The only additional source of sands in the Timbalier Bay region is the old deltaic lobes of the Mississippi River. When the relative amount of sands available from these old deltaic lobes and from drill cuttings are compared, and the composition of the sediment types coarser than a very fine sand examined, it is evident that the effect of oil drilling operations on the size distribution of the sediments in Timbalier Bay is insignificant.

The reworking of the bottom sediments by wave and tidal action near the pass between the barrier islands has resulted in the fine size particles and light materials being winnowed out. This explains, to some degree, the observed distribution patterns of the carbonate and organic carbons. It is assumed that the marshes bordering the bay have provided essentially all of the organic carbon found in the bay.

The sands are predominantly quartzose. This explains the observation that silica was the most abundant element of those measured.

The values for chromium and iron were expected to be higher than those values reported from non-drilling areas because they are two of the principal components of ferrochrome lignosulfonate, a component of drilling muds. The values for these two elements, as well as those for most of the other elements measured, however, fall within or close to the limits and averages reported in the literature for these elements in non-drilling areas. Any enrichment of these elements by drilling operations appears almost nonexistent, and certainly is insignificant.

The sources of barium in the bay are naturally occurring barium and barium contained in barite, one of the major constituents of drilling mud. Although baseline data for the naturally occurring barium in Timbalier Bay could not be determined, the average value of barium in the study area was found to be many times greater than the average value for it in sediments from outside the study area. Those sediments in Timbalier Bay had an average value of 861 $\mu g/g$, while those from outside the study area to the east of the Mississippi River delta had an average value of 57 $\mu g/g$, some 15 times less. The sediments analyzed from these areas outside the Timbalier Bay region were sandy, and sandy sediments in general have lower trace element values than finer sediments. One must not overlook the fact, however, that even when the sandy sediments from outside Timbalier Bay are compared to sandy sediments within the bay, there is still a very large difference, with the concentrations within the bay some ten times greater. When those sediments in Timbalier Bay were compared to silty sediments collected from the Mississippi River delta, the average barium values were still significantly higher. Sediments from the delta area, collected at the mouth of the Mississippi River, had an average value of 762 ppm. Although the difference in these values is not so large as differences for the other values from outside the study area, it must be realized that the possibility of enrichment to the Mississippi River sediments from the large number of nearby platforms and from accidental spillage of drilling mud from barges and work boats on the river is certainly significant, and that no definitive natural (pre-drilling) baseline could be obtained. These high concentrations of barium are therefore attributed to the effect of the barite component of the drilling mud.

With few exceptions, the measured elements demonstrated lower values in the sandy sediments. This is because clay minerals tend to adsorb many elements, and in the sands the finer particles, such as silts and organic matter, have been removed by winnowing wave action. The exceptions to this are SiO_2, P_2O_5, Ni, and La. These elements demonstrated relatively uniform values throughout their range of distribution.

Offshore area adjacent to Timbalier Bay

The great variety of sediment types found around Exxon Platform 54A may be due to the fact that this area is a natural transition zone between a silty area and a sandy one, caused by the addition of drill cuttings to the sediments, or the result of a combination of these conditions.

The types and relative abundance of the clay minerals in the offshore study were expected because the rivers that empty into the Gulf of Mexico in this region carry predominantly montmorillonite clay assemblages, with subordinate illite and little kaolinite.

The silt size fraction (<62.5 - $>4\mu$) in the study area may have originated both from the Mississippi River and from the drilling muds discharged from the platform during drilling. Scruton (1956) reported that in the Mississippi River no suspended sediment in transport contained materials coarser than a very fine sand (62.5-115μ). Moreover, only a very small percentage (2%) of this material actually fell within the very fine sand range. Barite ($BaSO_4$) can be classified as a sandy silt, with about 75% of the barite falling into the silt size fraction, and the sandy fraction being almost entirely a very fine sand. Therefore, it is impossible to separate the barite mud from the naturally occurring sediments by grain size analysis.

The very fine sands suspended in the Mississippi River drilling mud and old submerged deltaic lobes of the Mississippi River are most probably the sources of sand in the study area. Much of the very fine sand and fine sand probably comes from the old Lafourche deltaic lobes of the Mississippi River. This feature, which covered much of the adjacent region, has been winnowed out. Morgan (1955) reported that Tiger, Trinity, and Ship Shoals are all residual deltaic remnants that have subsided below sea level. When sediments from Ship Shoal, which is located just to the west of the study area, were compared to those sediments in the study area south and southwest of 54A, both exhibited similar fine to medium sand ratios. This suggests that the sediments in the area south and southwest of 54A were deltaic in origin. The increase in the mean phi size between the study sediments south of 54A and those sediments next to 54A is most likely due to the addition of larger particles from drilling operations.

Drill cuttings may cover the entire sand range, the size being dependent on the composition of the substrata through which the well is drilled. In the present study area, only drill cuttings can account for sands coarser than a fine sand.

The greatest number of large cuttings (>1 mm) was found at the base of the platform, where they were relatively common. At any distance from the platform the number of large cuttings was quite small. Since the average current velocity in the area is not strong enough to carry these cuttings any distance from the platform, it must be assumed that they were moved by stronger currents that developed during a severe storm or hurricane.

Sediment distribution patterns show both the effects of drill cuttings and a natural transition zone. Introduction of drill cuttings made the bottom sediments coarser. This can be seen by the increase in the mean phi size next to the platform and by the distribution patterns exhibited by the large cuttings and sands, which all had relatively high values next to the platform. The natural transition of sediment types is demonstrated by the distribution patterns of fine and medium sand to the south and west.

Generally, most of the elements measured had higher values near the bottom of the cores. This may be because sediments containing a higher percentage of silt-size particles ($<62.5 - >4\mu$) were present in greater concentrations in the lower sections of the cores. The exceptions to this trend were silica and barium. The higher values for silica were due to the greater amount of quartz sand in the surface sediments. We presumed that barite, a major component of drilling mud, was responsible for the high barium values; however, this hypothesis could not be confirmed because the natural background level for barium in the study area could not be determined because of the previous history of the region. This statement is based on the number and location of oil and gas wells drilled in the region and on the settling time of barite.

SUMMARY

Timbalier Bay Area:

1. The types of sediment found in Timbalier Bay were silt, sandy silt, silty sand, and sand.
2. The sediment type found most commonly throughout the bay was

sandy silt, but near the pass between the barrier islands, sand was dominant.

3. Silt composed the largest percentage of the total weight of the samples.
4. Very fine sand was the predominant sand size found in the study area. It has its origin in the old deltaic lobes of the Mississippi River and from drill cuttings.
5. Barium was the only element measured that showed values significantly higher than those commonly reported in the literature for sediments in non-drilling areas.
6. In most cases the measured elemental values were lower in the sandy areas.
7. Carbonate and organic carbon values tended to increase as distance from the pass between the barrier islands increased, i.e., these values tended to increase shoreward from the barrier islands.

Area Offshore Louisiana Adjacent to Timbalier Bay:

1. The dominant sediment types found in the eastern portion of this area are sandy silt and silt. In the western portion of the study area the sediment types range from silt to sand. In the naturally occurring transition zone the sediments tend to become coarser with an increase in distance from shore.
2. The silt and the sands found in the study area originate from the Mississippi River and from drilling operations. In addition, some of the sands originate from an old submerged deltaic lobe of the Mississippi River.
3. With the exception of those sandy areas to the south and southwest of Exxon Platform 54A, the shallow sub-surface sediment types are sandy silt and silt throughout the study area.
4. Very fine sand is generally the most dominant and widespread of the sands.
5. Very coarse, coarse, and medium sand exhibited highest relative values next to the platform.
6. The most common clay minerals found in the study area are, in decreasing relative abundance, montmorillonite, illite, and kaolinite.
7. Although some large drill cuttings were found 6.4 km from the nearest platform, most of these cuttings were within 4.8 km of the platform. The highest concentrations occurred adjacent to the platform.
8. The major identified influence of oil and gas drilling on the texture of the sediments in the study area has been to make the sediments within 4.8 km of the platform slightly coarser, with the greatest

effect taking place immediately adjacent to the platform. Only one petroleum-base conglomerate and only one sample that smelled strongly of petroleum were found.

9. The carbonate and organic carbon values were generally low. The carbonate values exhibited a high positive correlation with the distribution of the granule size fraction.
10. With the exception of silica, all the measured elements had lower values in the sandy sediments.
11. The higher values for most of the measured elements occurred at the bottom of the cores.

CONCLUSIONS

Although the drilling of oil and gas wells in the two areas studied has added millions of cubic feet of cuttings and mud to the sediments in this region, the net change in the composition of the sediments caused by this addition is insignificant, except immediately adjacent to the drilling sites, where enrichment by drill cuttings has produced coarser than normal sediments. The amount and type of sediments from the Mississippi River, and from old Mississippi River deltaic lobes, are similar to the sedimentary materials added by drilling, although many times greater in volume and significance.

With the exception of barium and silica, the measured elemental values found for the sediments are within or near those naturally occurring ranges reported in the literature for those elements. It is, therefore, assumed that the high concentration of barium in the sediment was due to artificial enrichment by drilling mud. The high silica values are explained by the high concentrations of quartz in the sands of the area, a natural phenomenon.

The results of this study indicate that no significant sedimentary alterations have occurred in Timbalier Bay or in the adjacent offshore area as a result of drilling activities. The results also show that, with the single exception of increased barium concentrations, no significant elemental concentrations of those elements measured have occurred as a result of drilling operations in this region.

REFERENCES CITED

Carver, R. E. 1971. Procedures in Sedimentary Petrology. New York: John Wiley.

Coleman, J. M. 1966. Recent Coast Sedimentation: Central Louisiana Coast. Louisiana State University Coastal Studies Institute, Technical Report No. 29.

Felix, D. W. 1969. An inexpensive recording settling tube for analysis of sands. Journal of Sedimentary Petrology **39**:777-780.

Folk, R. 1968. Petrology of Sedimentary Rocks. Geological Publications of The University of Texas, Austin, Texas.

Friedman, G. M. 1961. Distinction between dune, beach, and river sands from their textured characteristics. Journal of Sedimentary Petrology **31**:514-529.

Gibbs, R. J., M. D. Matthews, and D. A. Link. 1971. The relationship between sphere size and settling velocity. Journal of Sedimentary Petrology **41**:7-18.

Griffin, G. M. 1971. Interpretation of x-ray diffraction data. *In* R. E. Carver, ed., Procedures in Sedimentary Petrology, a Symposium. New York: John Wiley, pp. 541-569.

Krumbein, W. C. 1939. Tidal lagoon sediments on the Mississippi delta. *In* P. Trask, ed., Recent Marine Sediments. Tulsa, Oklahoma: American Association of Petroleum Geologists, pp. 178-194.

Louisiana Wildlife and Fisheries Commission. 1971. Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana. Phase II, Hydrology and Phase III, Sedimentology. New Orleans, La.

Morgan, J. P. 1955. A geographical and geological study of the Louisiana coast with emphasis upon establishment of the historic shoreline. Coastal Studies Institute, Contribution No. 55-3.

———. 1973. Memorandum—cutting deposition in Timbalier Bay, Louisiana. Prepared for Offshore Ecology Investigation of the Gulf Universities Research Consortium.

Schlee, J. 1966. A modified Woods Hole rapid sediment analyzer. Journal of Sedimentary Petrology **36**:403-413.

Scruton, P. C. 1956. Oceanography of Mississippi delta sedimentary environments. American Association of Petroleum Geologists Bulletin **40**(12):2864-2952.

U.S. Army Corps of Engineers. 1939. Study of materials in transport passes of the Mississippi River. Technical Memo. 158-1. U.S. Corps of Engineers, New Orleans and Waterways Experiment Station, Vicksburg, Miss.

Ziegler, J. M., G. G. Whitney, and C. R. Hayes. 1960. Woods Hole rapid sediment analyzer. Journal of Sedimentary Petrology **30**:490-495.