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THE SEDIMENTS OF THE WESTERN GULF OF MEXICO

PART I — THE CONTINENTAL TERRACE OF THE WESTERN GULF OF MEXICO: ITS SURFACE SEDIMENTS, ORIGIN AND DEVELOPMENT

BY HENRY C. STETSON

Contribution No. 646 from the Woods Hole Oceanographic Institution

PART II — CHEMICAL STUDIES OF SEDIMENTS OF THE WESTERN GULF OF MEXICO

BY PARKER D. TRASK

Contribution No. 647 from the Woods Hole Oceanographic Institution

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BY HENRY C. STETSON

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INTRODUCTION

During the winter of 1947 the research vessel *Atlantis* worked in the western half of the Gulf of Mexico. This cruise was financed jointly by grants from the Penrose Bequest of the Geological Society of America and by the Woods Hole Oceanographic Institution. The primary purpose of the cruise was to determine the texture and organic content of the surface and near-surface sediments with their contained foraminiferal fauna, from the shelf, the slope, and the Sigsbee Deep. The Foraminifera and their distribution have been described by Phleger and Parker (1951), and Trask's report on the chemistry of the sediments appears as Part II of this report. Surface samples and cores up to eleven feet were obtained from 551 stations as indicated on the track chart (Fig. 1). A number of plankton tows and hydrographic stations were made and bathythermo-

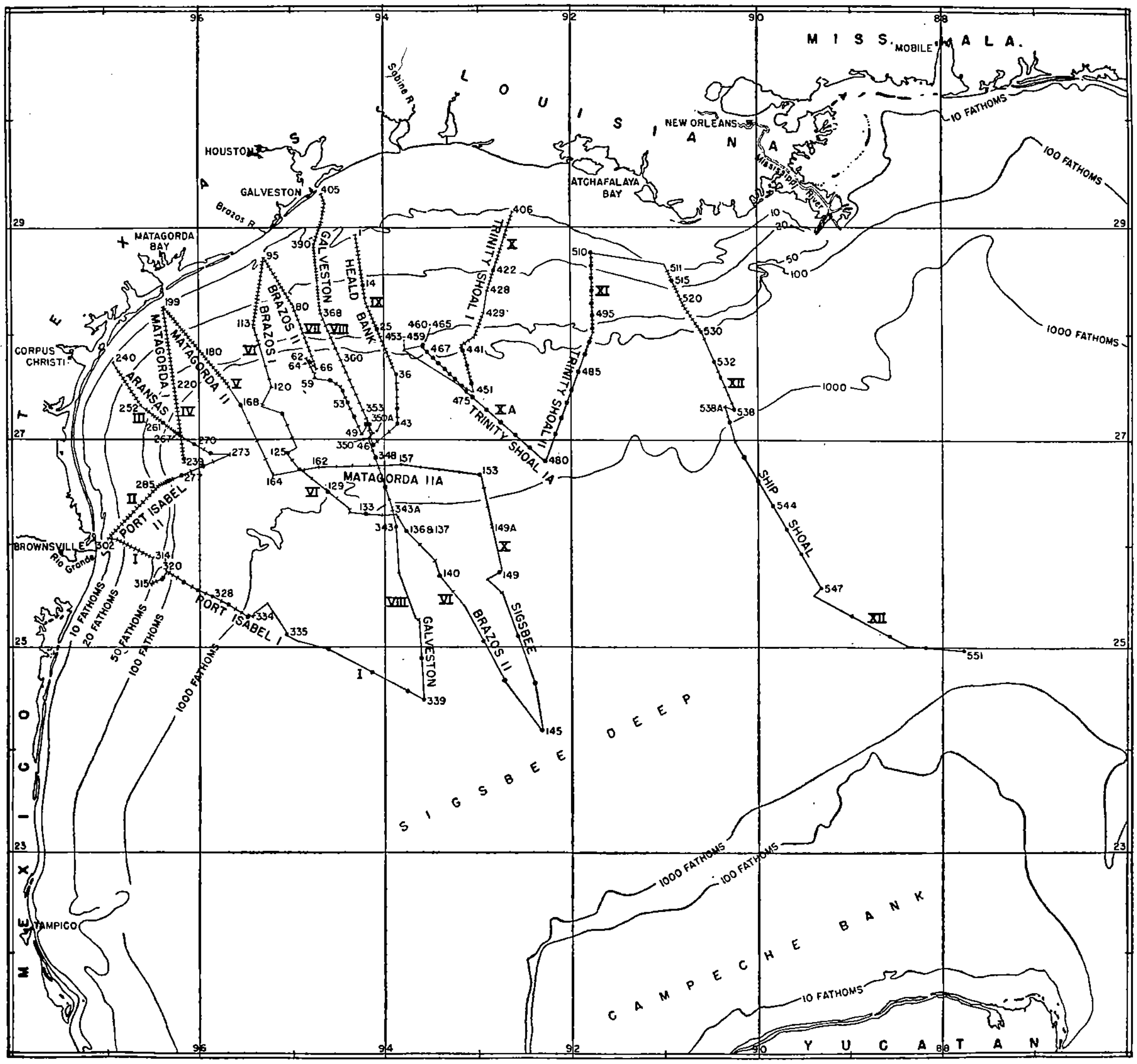

Fig. 1. Gulf of Mexico, western part: Stations occupied during Atlantis cruise, 1947. Sponsored by Woods Hole Oceanographic Institution and The Geological Society of America. Dashes — short cores and circles — long cores.

graph readings were taken to the depth of 100 meters every five miles. Rock dredging was carried out on two of the coral capped hills or "bioherms" which are numerous in the vicinity of the 80 fathom curve.

In all, twelve traverses were run across the shelf, some of which continued down the slope, and five extended into deep water. On the shelf the samples were spaced two miles apart; five mile intervals were used on the slope and either ten or twenty-five mile intervals in deep water. They are named according to the local geography at their inshore ends so that they may be easily located when referred to in the text.

The traverses were not started at the beach because at the time this cruise was planned several Gulf Coast geologists had already done some work on the shallow water foraminiferal faunas and more was contemplated. In general, they begin or end in the vicinity of the ten fathom curve.

All positions were determined by celestial navigation and dead reckoning because in the winter of 1947 no Loran stations were maintained in the western Gulf. The soundings in the tables and fathograms are uncorrected for pressure, temperature and salinity. For an overall picture of the detailed topography of the area the reader should refer to the charts constructed by Gealy (in press) from the smooth sheets of the U. S. Coast and Geodetic Survey, supplemented by fathograms taken by *Atlantis* and the U. S. Navy Hydrographic Office. An attempt was made to place the sediment traverses on these charts with indifferent success due to the fact that the sextant is not accurate in comparison with the various surveying methods used by the Coast and Geodetic Survey. However, each of the fathograms graphed above the sedimentary data, is taken from the original trace and represents the actual bottom over which *Atlantis* was sailing. Those portions of the graph taken while the ship was on station have been deleted. The positions of the stations and traverses relative to each other are sufficiently accurate for a sedimentary survey even though their actual position on the surface of the globe is known to be somewhat in error. Occasional irregularities in the courses either represent periods when *Atlantis* was hove to during bad weather or set off her course by unknown currents. Some of these have been straightened in drawing the sedimentary profiles but the actual positions of the stations as tabulated have not been altered.

The cores were taken with a free fall gravity tube which has been previously described (Hvorslev and Stetson, 1946). This tube carries a two inch plastic liner which retains the column of sediment. The surface samples were collected with a smaller adaptation of the same sampler designed by F. B Phleger, which takes an inch and one-half core from six to twelve inches long. The advantage of this smaller tube for surface sampling over the usual grab or scoop is considerable. Not only is the sample protected by the liner from washing on the way up, but the layering is undisturbed so that the actual surface may be obtained with no mixing of deeper materials. Furthermore, because of their short length, the cores can at all times be kept vertical so that the flocculent, fluid layer of material which is in direct contact with the water is not poured off. The rock dredge has also been described previously (Stetson, 1936). This project was originally discussed and planned in collaboration with Parker D. Trask and Fred B Phleger, and the latter carried out the initial work at sea with the assistance of Carlyle R. Hayes. The writer is also much indebted to Betty Lee Gealy since the many critical discussions which took place during the construction of her contour maps of the west Gulf continental slope (in press) have materially aided the writing of this report. My thanks are also due to Constance F. Klebba and Sally M. MacAuslan for the laboratory analyses of the sediments and for plotting and drafting the graphs, and to Jean Stilwell for assistance in the final preparation of the manuscript.

LABORATORY PROCEDURE AND PRESENTATION OF DATA

In order to make a mechanical analysis of a marine sediment, it is usually necessary to remove the salts to prevent flocculation and obtain a complete dispersion of the particles. Various methods have been devised but the one employed here uses porcelain filters and a vacuum pump. A peptizing agent, usually sodium oxalate, is added. The procedure has been described in detail (Stetson, 1936). The mechanical analysis was carried out by the combined sieve and pipette method (Krumbein, 1932) and the data plotted as cumulative curves on four-cycle, semi-logarithmic graph paper. They were treated statistically using the median, coefficient of sorting and skewness following the method described by Trask (1932), and when descriptive terms are used they refer to the grade sizes of the Wentworth scale. The statistical constants have all been graphed in Figs. 2–16, and give a picture of the distribution and zoning of the sediments in a seaward direction. The names correspond with those of the traverses in Fig. 1. In each case the bottom profile, plotted from the fathograms, appears at the top. The middle graph, the median diameter or mid point of the size distribution, is plotted in microns to a logarithmic scale; and the curve for the sorting is at the bottom. Triangles for stations on the sorting curve indicate that the third quartile was estimated, because the material was so fine that more than 25 per cent of the sample remained in suspension after 100 hours. An analysis cannot be carried beyond that time interval as Brownian movement seriously affects the settling velocities of the very fine particles of which such a suspension would consist. Such curves, however, were extrapolated only for a short distance. The data for each station, distance from shore, median, and sorting lie along the same ordinate, and the depth of water may be obtained from the scale at the left of the bottom profile. Thus the zoning of the sediments and any patterns of distribution are at once apparent. It is obvious that the higher the curve for the median climbs the coarser is the texture, and the higher the curve for So climbs the poorer is the sorting.

Perfect sorting would have a value of 1, but of course, this is never found under natural conditions. For purposes of comparison it might be noted from the analysis of hundreds of samples by the author that beach sands, which are among the best sorted of marine sediments, sometimes attain a value of 1.25, while a value of 1.45 is good for sands from the neritic zone. Some sediments from these zones occasionally have higher values. A curve for skewness or for its logarithm, which Trask prefers to use, is not given although the values for this constant are included in the Tables. At the present time skewness is difficult to interpret and its relationship to the other statistical constants not too clear, at least as far as sediments are concerned. Because it is easily derived from the same cumulative curve as the other constants, it is included here with the hope that when sufficient data have been tabulated its geological significance may be more apparent.

In the description of the traverses which follows, the complete data for any station may be obtained from Tables 1 to 15, and the graphs, Figures 2 to 16, present the overall picture of sedimentary distribution. The ordinates and abscissae are necessarily omitted for publication.

SEDIMENTARY DATA BY TRAVERSES

Port Isabel I

This traverse, 331 miles long, starts in 12 fathoms, 8 miles from shore, crosses the continental shelf and slope, and ends in the Sigsbee Deep at 1940 fathoms. The curve for the median diameters indicates that the sediment covering the surface of the shelf is very patchy, sands alternating with silts and clays and with extreme values ranging from 200 to 2.5 microns.

Just before the break in slope is reached the sediment becomes much finer and the curve for the median drops from 127 microns at 32 fathoms and 4.9 microns at 36 fathoms to 0.95 microns in 200 fathoms. From this point seaward, down the

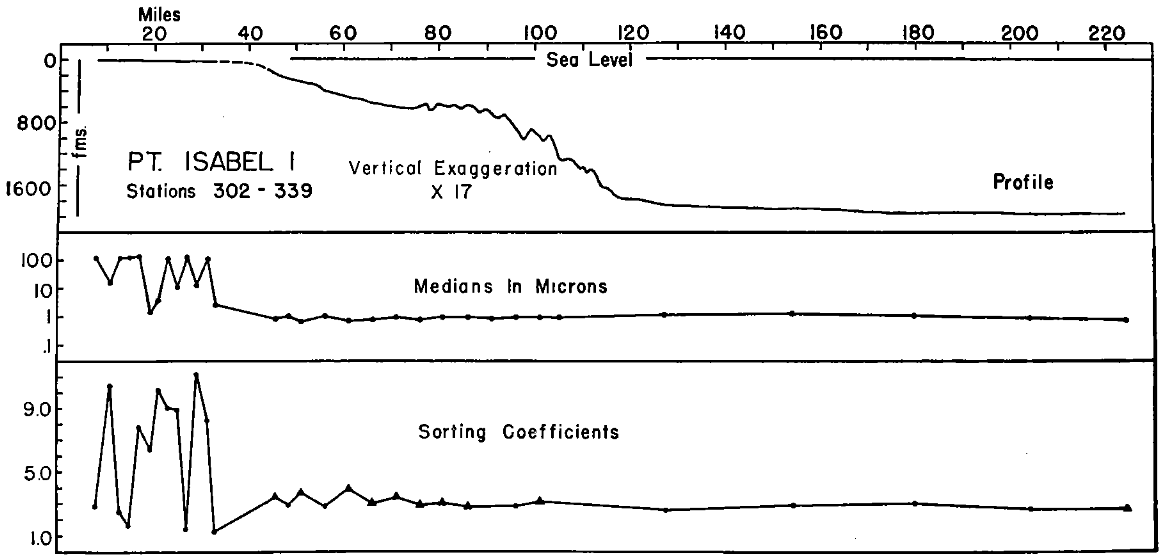

FIG. 2. Port Isabel I Traverse: Topography and distribution of sediments.

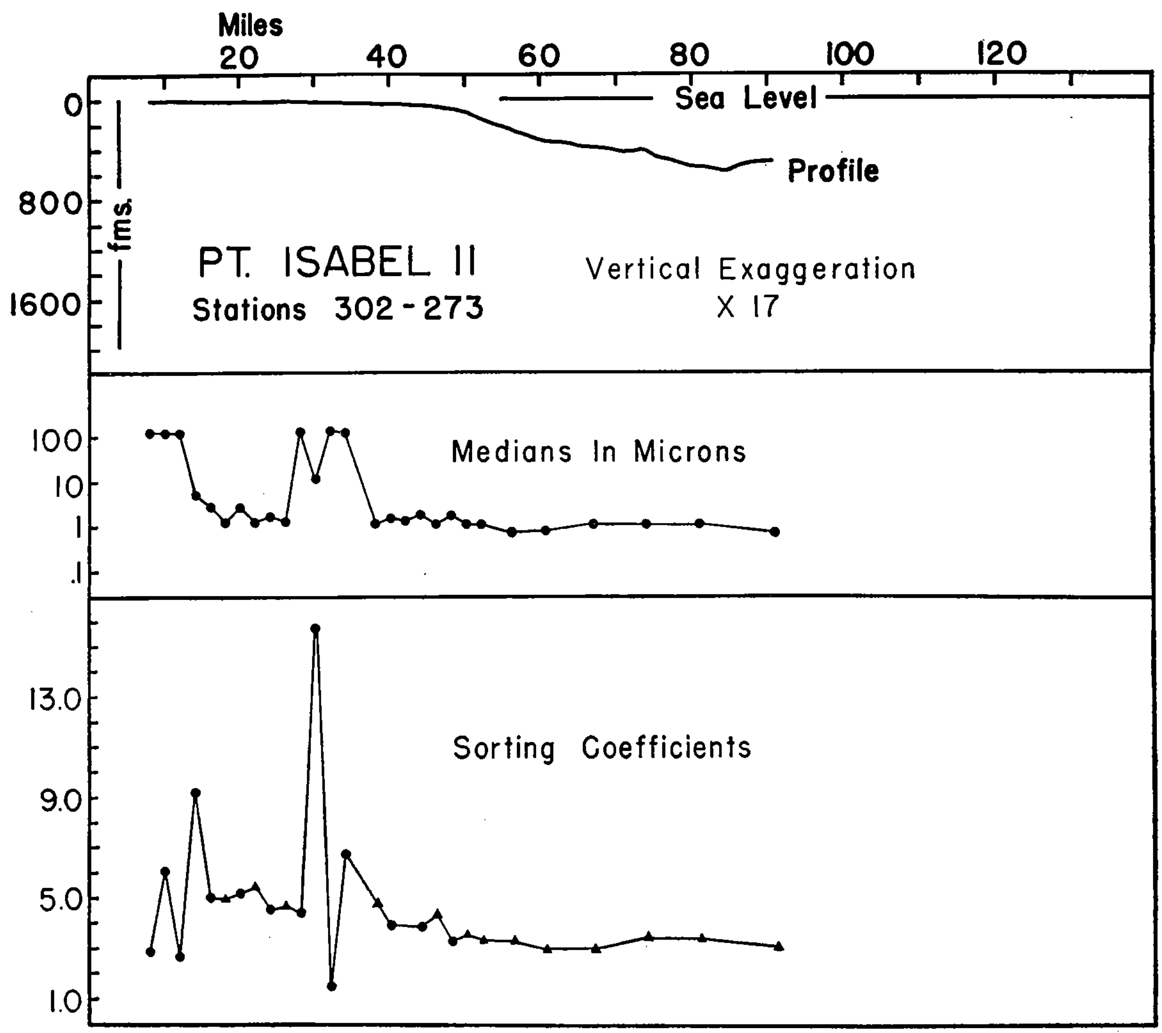

FIG. 3. Port Isabel II Traverse: Topography and distribution of sediments.

continental slope and out into the Sigsbee Deep to nearly 2000 fathoms, the surface sediments remain remarkably uniform and very fine grained, with values in the clay sizes. This uniform trend is maintained regardless of the depth of water or the topography. The sediment which covers the irregular slope and that lying on the flat floor of the Sigsbee Deep is practically identical in texture.

Over the shelf sorting also fluctuates, reaching the extreme values of 10.45 and 11.18 and indicating that the sedimentary particles are distributed through so large a range of grade sizes that the deposit can scarcely be said to be sorted at all. As a rule, these are silts and clays and are interspersed with coarser sediments, including the sands, with excellent sorting coefficients reaching 1.36 and 1.60 in some cases. Below the break in slope, seaward of station 328 in 260 fathoms, sorting values steadily remain near 3 even though the sediment is a clay. These deep water clays are very different from their neighbors of the shallow waters of the shelf. Like the median, sorting is unaffected by topography.

The term break-in-slope as used in the descriptions of the traverses is a relative one, and indicates the general position of the change in angle between flat shelf and steeper slope. Often this change is very gradual. A discussion of this feature, common to all continental margins, appears in another section.

Port Isabel II

This short traverse resembles the inner parts of Port Isabel I. It starts in 12 fathoms, 7.3 miles from shore, and only extends seaward a little over 90 miles, to 536 fathoms, crossing the shelf diagonally in a northeasterly direction. The median diameters for the shelf sediments fluctuate between 165 and 1.5 microns. Just before the break in slope the curve drops to nearly a micron and remains in the clay grades for the rest of the line.

The curve for the sorting coefficient behaves in a similar manner. Over the shelf it fluctuates between good and poor values, ranging from 1.49 to 15.7 on successive samples. This last value at station 291 should probably be regarded as an accident of sampling. In general, the coarser samples tend to be the better sorted. On the slope, where the sediment is uniform clay, sorting values also remain fairly constant at about 3 to 3.5. Topography, apparently, has no influence on sorting.

Aransas

This short traverse begins 11 miles from shore in 12 fathoms of water, crosses the shelf and part of the continental slope in a southeasterly direction, and joins the seaward end of Port Isabel II at station 273, for a total length of 85 miles.

The graph for the median fluctuates somewhat over the shelf, although not as markedly as on the three previous traverses, and indicates a patchy bottom of silt and clay. Just before the break in slope the median curve flattens out, with values ranging around a micron, indicating a clay or a fine clay in the colloid range for the bottom part of the slope.

The sorting is fair to poor over the shelf with values ranging as high as 7.23. The graph is very irregular and on this traverse there seems to be little relationship between grain size and sorting until the break in slope is passed. From this point to the end of the line the graph levels off with values of about 3.

Matagorda I

This is another short line, 90 miles in length. It traverses the shelf at a sharp diagonal in a southerly direction, crosses Aransas and ends in 360 fathoms.

Although it is close to Aransas, values for the shelf medians average higher, and they are likewise very irregular, indicating a patchy bottom with some very fine sand, considerable silt, and a little clay.

The graph for the sorting of these sediments also fluctuates, with some good values below 2 for the sands which puts them in the beach range, and some high values for the silts and clays. In general, the coarser textures have the better sortings.

As usual, just before the break in slope both graphs level off, the one for the median indicating a fine clay with values just over a micron, while the sorting values for the most part range around 3.

Matagorda II

Starting in 8 fathoms, 2 miles from shore, this line crosses the shelf and slope at right angles, and ends in 790 fathoms for a total distance of 117 miles.

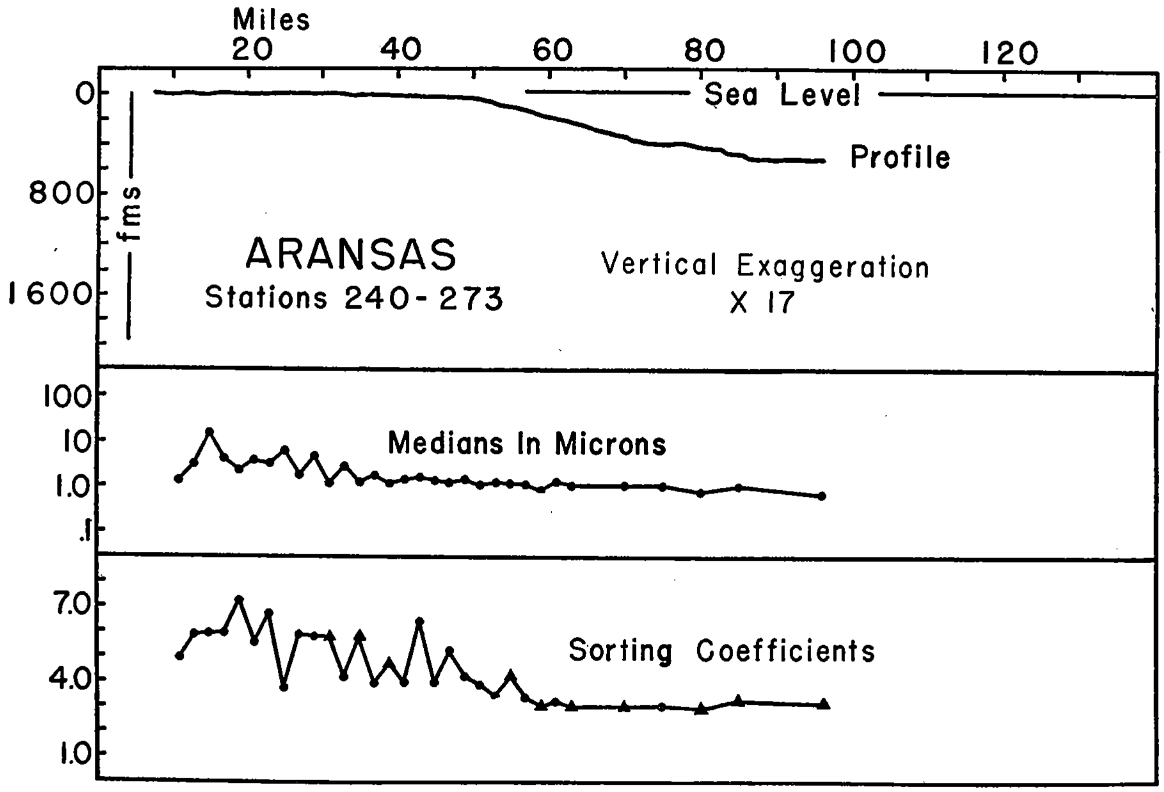

FIG. 4. Aransas Traverse: Topography and distribution of sediments.

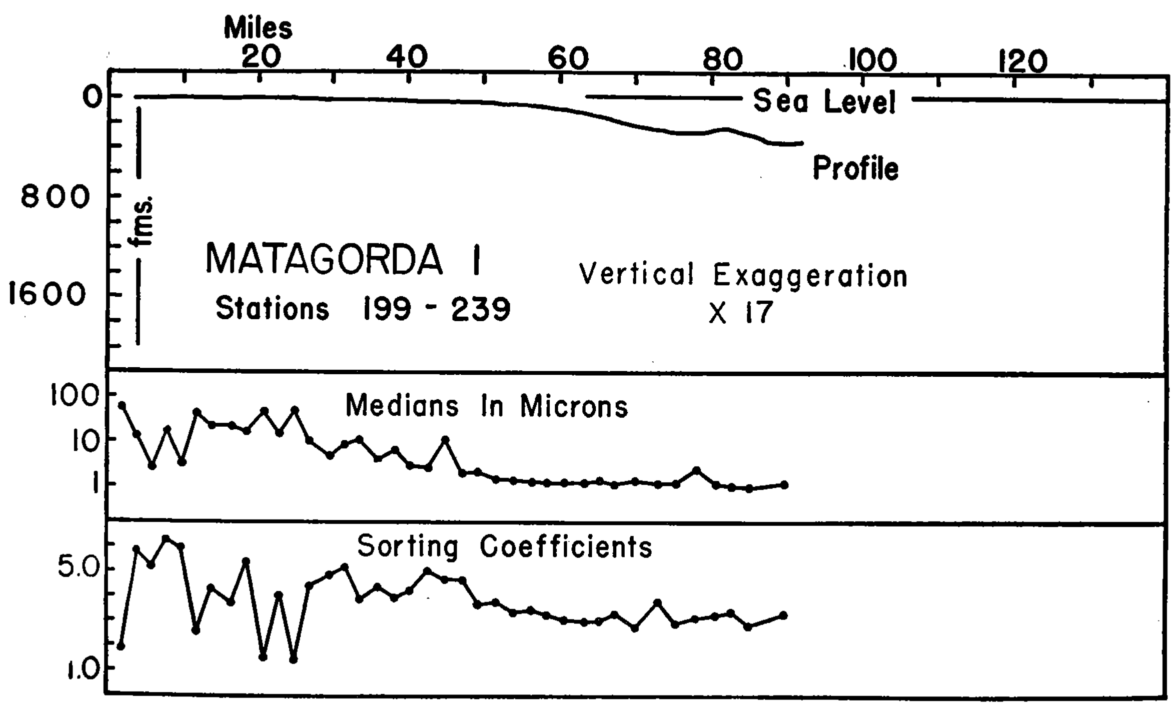

FIG. 5. Matagorda I Traverse: Topography and distribution of sediments.

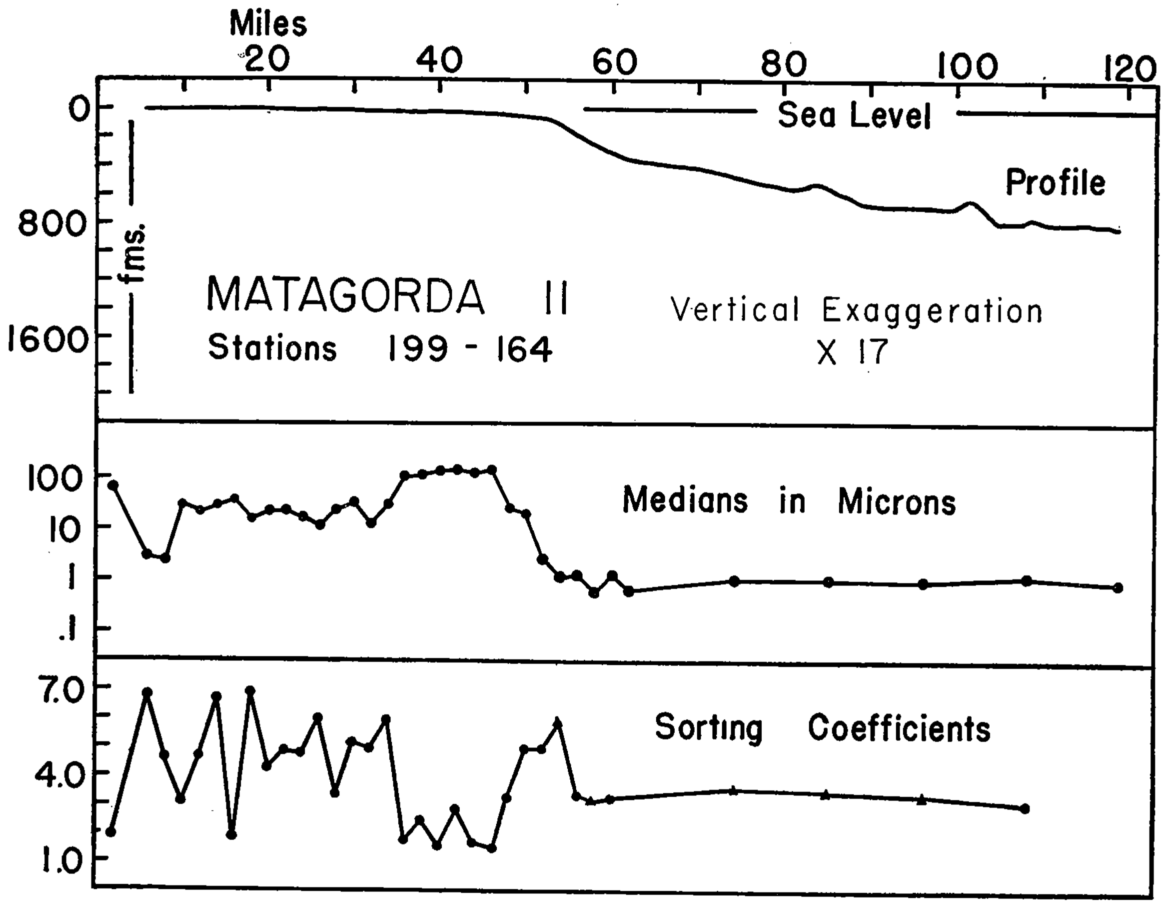

FIG. 6. Matagorda II Traverse: Topography and distribution of sediments.

Median values are fluctuating over the shelf but are generally somewhat higher than on the previous traverses, and for the first time fine sand in some quantity appears. This area, some 26 miles across, is found just before the break in slope. Past this point median values drop rapidly, and at station 169 the curve levels off with values close to a micron.

The graph for the sorting follows the same general trend: rapid changes over the shelf with extreme values of 6.86 and 1.47, leveling off near 3 beyond station 172 in 193 fathoms of water. As usual, the coarser samples tend to have the best sorting.

BRAZOS I

Weather conditions and unknown currents affected the ship's course when running this traverse, which starts in 13 fathoms, 14 miles from shore, and is arbitrarily ended at station 131 in 920 fathoms for a total of 161 miles. Over the shelf the graph for the median is irregular but remains within the silt and fine sand grades, ranging from 157 to 13 microns. The coarser samples are the better sorted. The values drop rapidly before the break in slope and at a short distance below the graph levels off at about a micron indicating the usual fine clay that is found on the deeper portions.

The sorting curve is very irregular over the shelf, but levels off at station 120 with a value ranging around 3 for the clay sizes.

BRAZOS II

This is one of the longer traverses and reaches the Sigsbee Deep. As it happens to cross a portion of the continental slope where the terrain is very rough, consisting of steep ridges and deep, closed basins, it serves as an excellent example of the fact that topography has no apparent in-

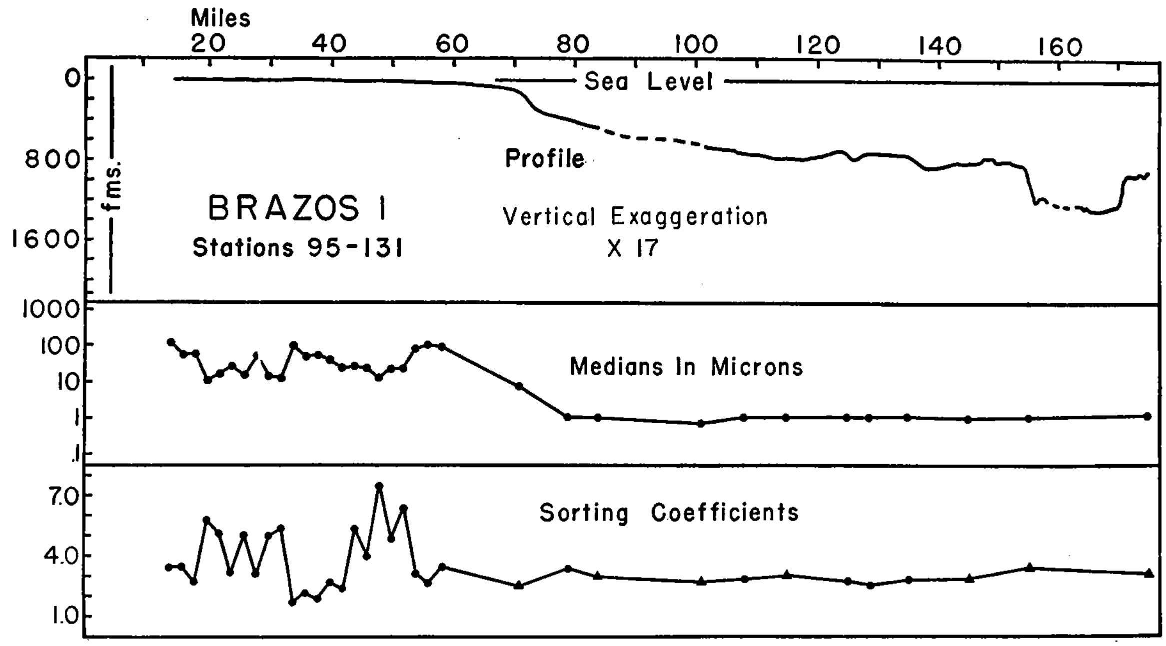

FIG. 7. Brazos I Traverse: Topography and distribution of sediments.

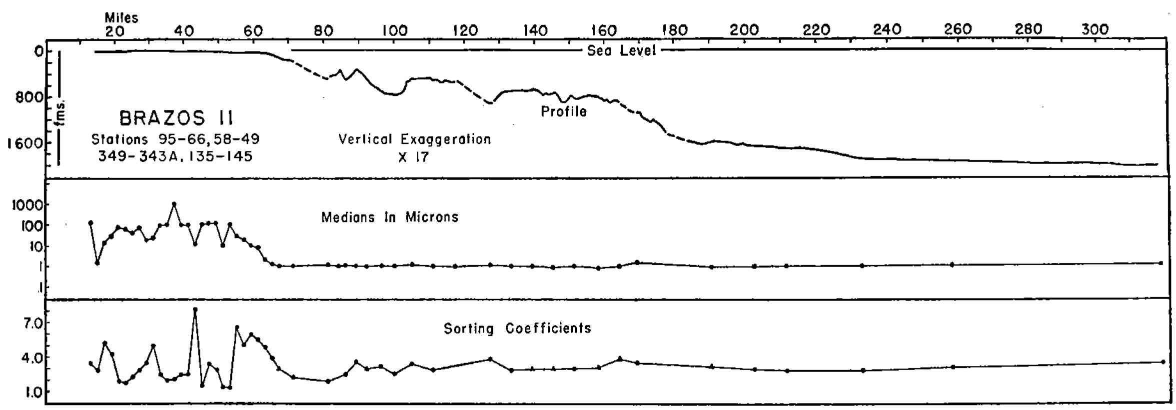

FIG. 8. Brazos II Traverse: Topography and distribution of sediments.

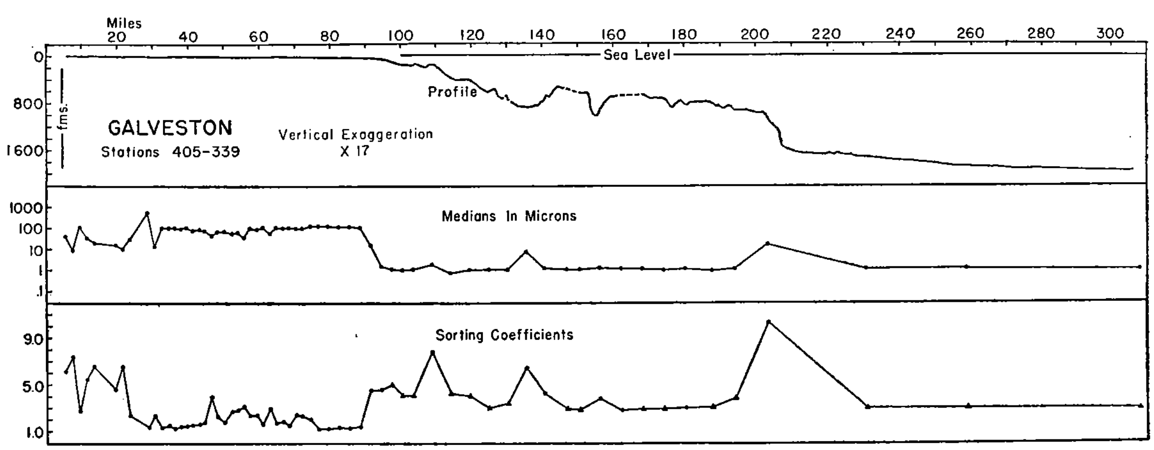

FIG. 9. Galveston Traverse: Topography and distribution of sediments.

fluence on grade size. It starts 13 miles from shore in 13 fathoms and continues to station 145, in 1985 fathoms, 318 miles distant.

There are the usual fluctuating values for the medians over the shelf. The majority of the stations show a fine sand, but silty areas are interspersed, and there is one sample of clay in 13 fathoms, and one of very coarse sand in 17 fathoms. Before the break in slope the sediment immediately becomes finer; the graph for the median indicates a clay and levels off at values close to 1 micron to its termination in the Sigsbee Deep.

Sorting values over the shelf are highly variable, but with the coarser textures tending to be better sorted except in the case of station 94 where clay was found. A value here of 3.19 is comparable to the good sorting found in the deep water clays. At the break in slope the sorting graph drops rapidly but remains somewhat variable until station 138 is reached, in 1550 fathoms, approaching the Sigsbee Deep. From this station to the end of the line values range around 3.

Galveston

Starting at the sea buoy marking the entrance to Galveston Bay in 9 fathoms of water, this traverse crosses Brazos II just below the 1000 fathom curve, and connects with the seaward end of Port Isabel I in the Sigsbee Deep, in 1950 fathoms, for a total of 307 miles. Like Brazos II it crosses a very irregular terrain, but unlike the other lines which reach deep water, the graphs for the median and sorting do not completely flatten out below the break in slope, but remain somewhat irregular until the Sigsbee Deep is reached.

Sand, mostly very fine, covers all the shelf for a distance of about 88 miles, except for 7 samples on the inner portions which are silts. Below the break is found the usual clay bottom with medians of about 1 micron. On three stations, 357, 352 and 343, however, there is a coarsening in texture which is also reflected in very poor sorting values. This will be referred to again in the description of the sedimentary distribution.

The graph for sorting is somewhat irregular throughout its length, except for the three stations in the clay of the Sigsbee Deep. On the inner portions of the line, as far as station 392, the sands are better sorted than the silts. Crossing the zone of sandy bottom, referred to above, the sorting of several samples is good to excellent with several values below 1.51, which are comparable to beach sands. Below the break in slope the sorting becomes poorer than in this sandy zone, although the values are comparable to those of the other clays found on the slope and in deep water. Three very poor sortings occur on the slope at stations 357, 352 and 343 which produce marked jumps in the graph, one of them reaching 10.25. These probably should not be considered sampling errors, and as mentioned above, will be discussed later.

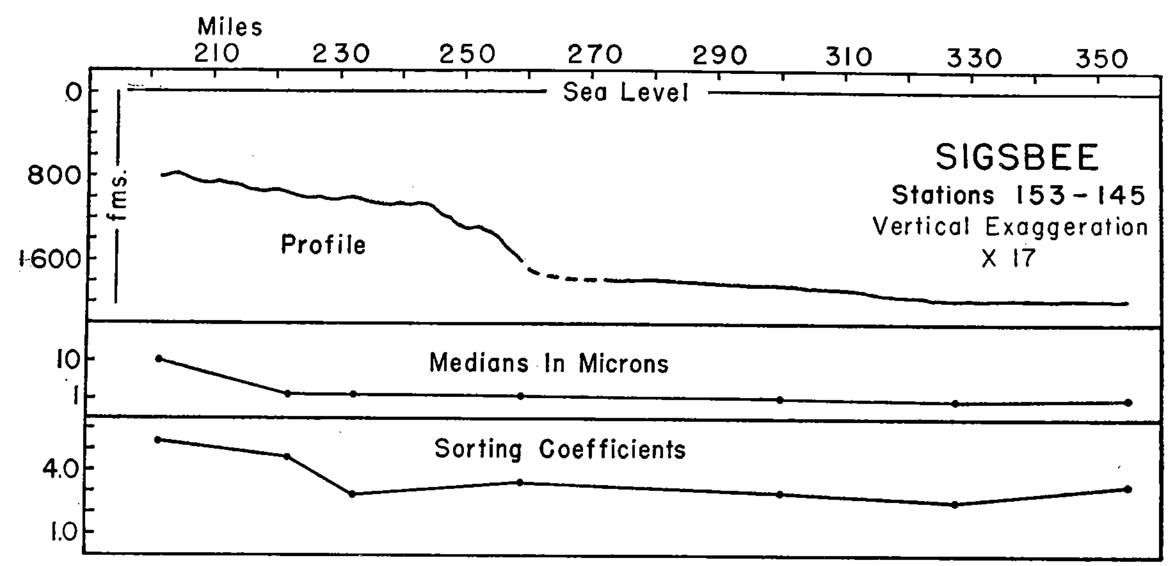

Fig. 10. Sigsbee Traverse: Topography and distribution of sediments.

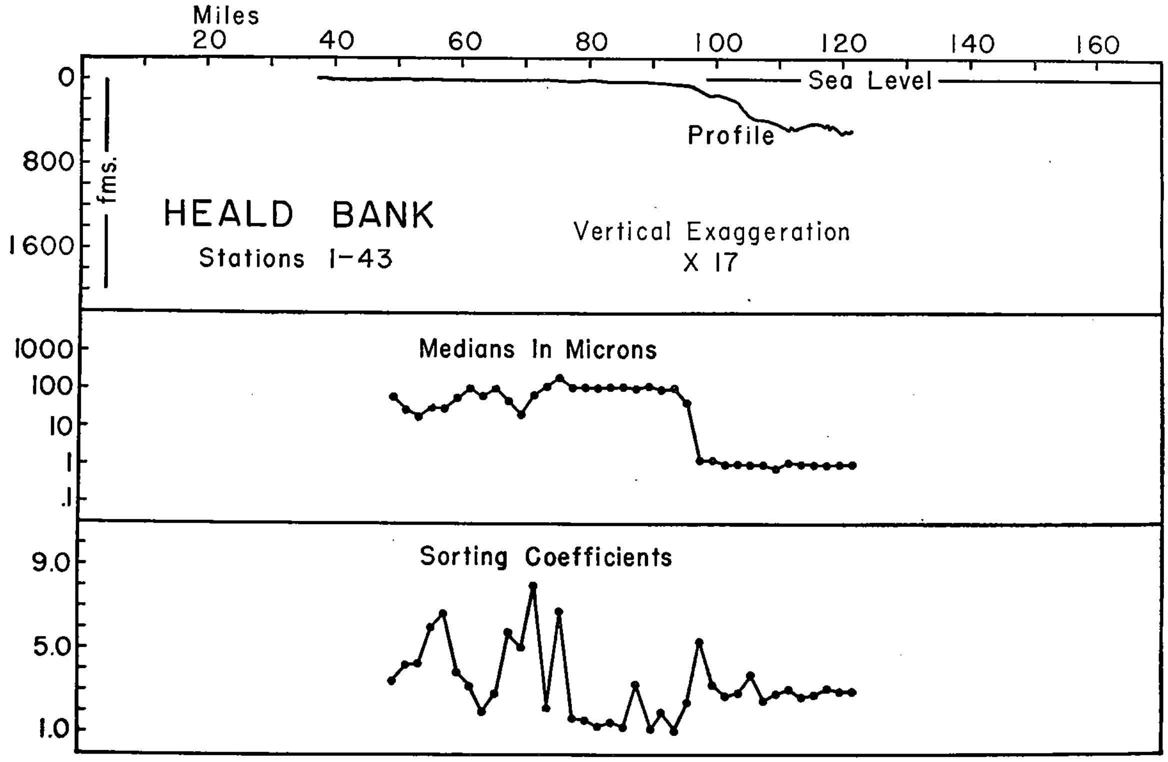

FIG. 11. Heald Bank Traverse: Topography and distribution of sediments.

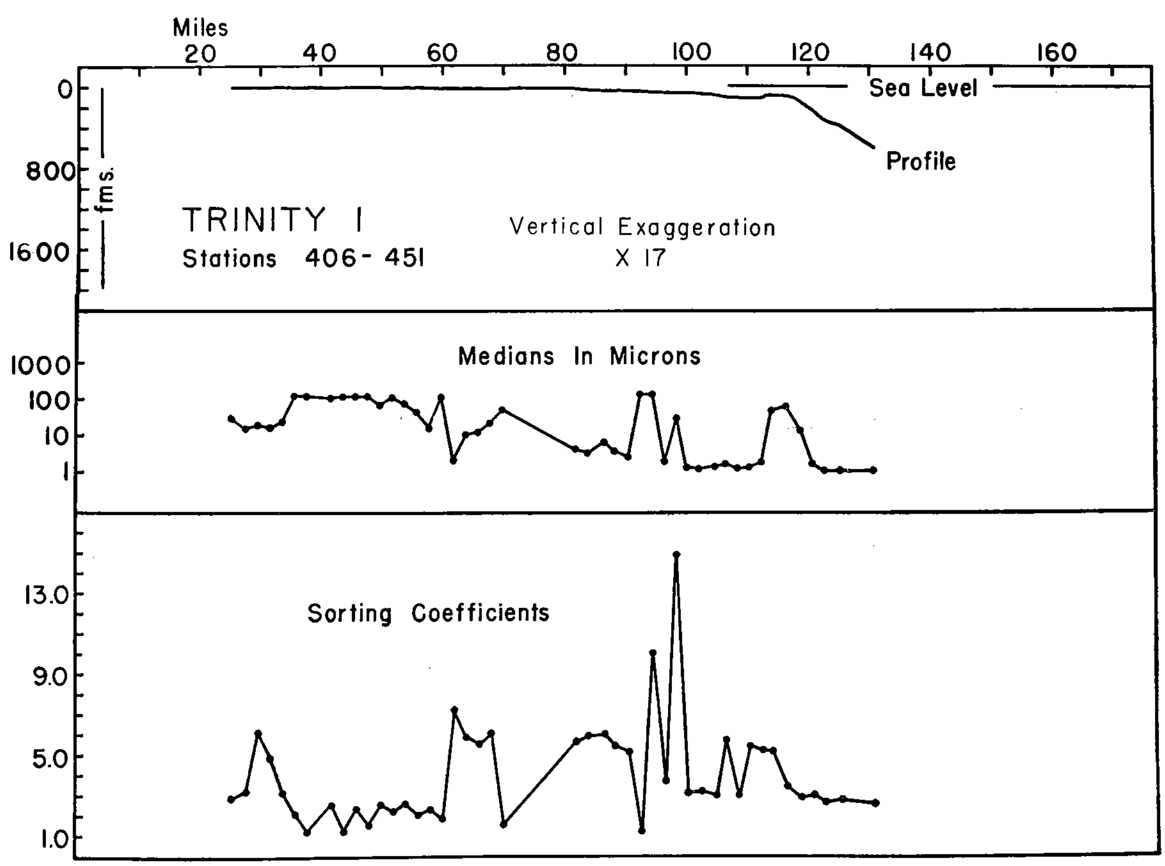

FIG. 12. Trinity Shoal I Traverse: Topography and distribution of sediments.

Sigsbee

Only nine stations make up this traverse of 151 miles, but it is one of the three which enter the central parts of the Sigsbee Deep. It starts on the slope in 820 fathoms and connects with the seaward end of Brazos II, and as might be expected from its position, there is a close resemblance. There is little variation in the median curve and sorting; every sample is a fine, well sorted clay except the first which is a poorly sorted silt.

Heald Bank

Starting in 11 fathoms, 49 miles from shore at the buoy 12 miles southwest of the shoal, this short traverse closely resembles those portions of the Galveston line which lie parallel to it. It only reaches part way down the slope, ending in 630 fathoms.

The shoreward portions are somewhat patchy: mostly silt with very fine sand. However, just before the break in slope there is a sandy area 22 miles across in which the medians usually range around 100 microns. This is probably the lateral continuation of the more extensive sandy zone found on the Galveston line. The upper part of the slope is covered with the usual fine clay.

The graph for the sorting is very irregular over the central and outer parts of the shelf. The usual relationship between coarser texture and good sorting doesn't always hold on this line, as some of the sands have high values. However, the same remarkably low values for off-shore sediments occur in some of the sands on the outer part of the shelf as were found in the Galveston line. Below the break in slope, the sorting of the clay bottom ranges around 3, the usual value for this type of sediment in the Gulf.

Trinity Shoal I

Beginning 25 miles from shore, in 11 fathoms of water, this short line ends in 500 fathoms just beyond the break in slope, running for a total of 106 miles. It crosses the shelf contours at a slight diagonal in a southeasterly direction.

Silt occurs on five stations on the inner end of the line followed by a sandy zone, 21 miles wide, which has the same median diameter of about 100 microns as the shelf sands found on the Heald Bank and Galveston lines. Proceeding seaward the graph for the median indicates a patchy bottom of sands alternating with clays and silts, and with a zone of clay, about 12 miles wide, on the outer part of the shelf just before the break in slope. Although clay has appeared on the shelf before, this is the first time that any appreciable area has been crossed. This clay zone extends eastward and becomes much wider on the two traverses lying nearer to the Mississippi Delta. Seaward of this clay zone the bottom changes to a sand at the break in slope and becomes the usual fine clay on the short section of the slope proper, which this line crosses.

Sorting is also irregular. The sandy zone, mentioned above, is well sorted, and this is generally true of the other sandy patches except just before the break in slope. The silty areas, however, have poor sorting, but the graph drops to the usual value of about 3 for the clay of the slope.

Trinity Shoal II

Starting 43 miles from shore in 14 fathoms, this traverse reaches 1020 fathoms near the bottom of the continental slope where it joins the Trinity Shoal Ia traverse. The total length is 116 miles.

On the shelf, silt is found at four stations on the inner part of the traverse. Clays with borderline silts first appear in 22 fathoms and continue for 38 miles to the break in slope. There the sediment changes to a silt before the uniform clays of the slope proper are reached. This is a repetition of the general sedimentary distribution found on the Trinity Shoal I traverse except that here the zone of clay is much wider, and the graph for the median only rises into the silt grades at the break in slope instead of indicating sand.

Over the shelf the sorting of these silts and clays varies from sample to sample with no discernable trend towards better sorting in either group. One of the silts at the break in slope, with a value of 12.12, is scarcely sorted at all. On the slope, sorting improves and the clays which cover it have, with one exception, the usual values of about 3.

Trinity Shoal Ia

Starting in 51 fathoms on the outer part of the shelf, this traverse cuts the slope diagonally in a southeasterly direction and ends in 1020 fathoms. It is 97 miles long. The break in slope is somewhat indefinite as it falls off in a series of

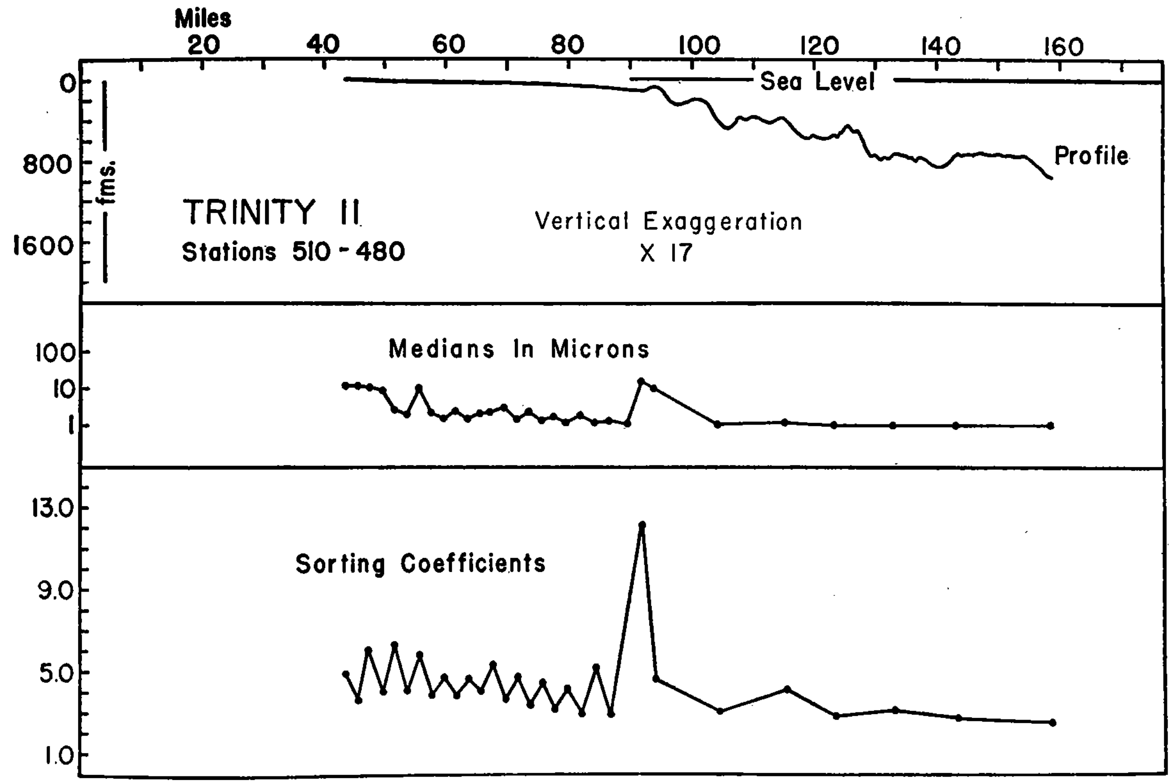

FIG. 13. Trinity Shoal II Traverse: Topography and distribution of sediments.

terraces, but the sedimentary distribution gives us a clue to its position as it is somewhat similar to Trinity Shoal I. The shelf sample is a sand which is succeeded by a narrow clay zone about 9 miles wide. This band is in turn followed by sand, with a median of 100 microns, which changes to silt before the uniform clays of the slope, with the usual medians ranging around a micron, are reached.

Sorting is somewhat haphazard except for the clays of the slope which are always close to the value of 3. One clay sample from the shelf has the very poor value of 9.61, while another lying inshore from it has a sorting comparable to that of the slope clays. The few sands and silts are also well sorted.

Matagorda IIa

This is the only traverse which runs in an east-west direction, and, consequently, is more or less parallel to the strike of the slope. Depths vary as the ridges and valleys which cut this surface are crossed.

Texture, however, remains uniform as is indicated by the level graph for the median which shows a well sorted clay ranging about a micron, except for one poorly sorted silt sample at the easterly end.

The same clay is found at the stations which lie on either side of the Galveston and Brazos I crossings as appears on those two lines.

Ship Shoal

The most easterly of the traverses starts in 12 fathoms and continues for about 256 miles in a southeasterly direction, changing to due east for the last two stations. It ends in 1875 fathoms off the northeasterly extension of the Campeche Banks.

The surface water over the shelf at the time *Atlantis* made this line was a dirty green from the suspended load of the Mississippi, and the clear, blue water of the Gulf was not picked up until the ship had nearly reached the 100 fathom curve. The graph for the median reflects this extra load of fine grained sediment and the bottom deposits of the outer portions of the shelf are silts becoming clays approaching the break in slope.

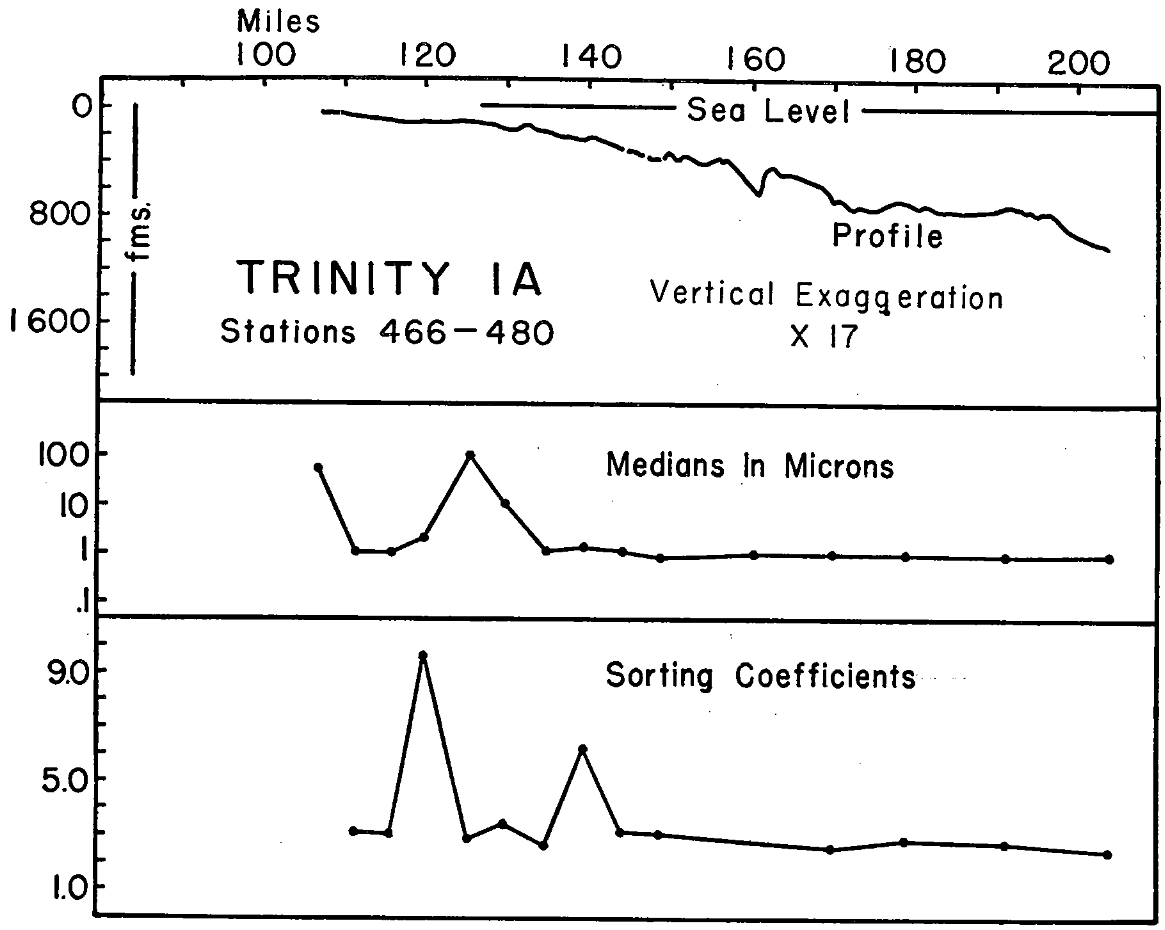

FIG. 14. Trinity Shoal IA Traverse: Topography and distribution of sediments.

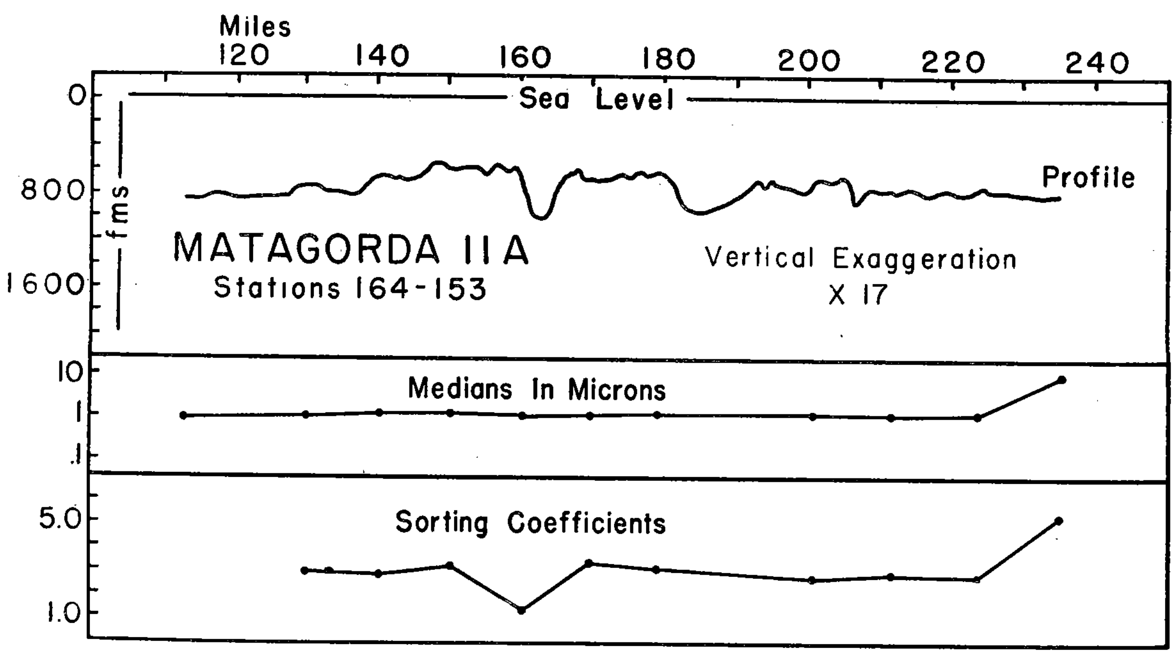

FIG. 15. Matagorda IIA Traverse: Topography and distribution of sediments.

On the slope proper the sediment is also a clay, generally somewhat finer grained, with the median near a micron, while at the bottom of the slope and in the easterly extension of the Sigsbee Deep the sediment is slightly coarser, though still in the clay and borderline silt range.

The sorting fluctuates over the shelf, and values for the silt grades are usually high except for the first two stations. It improves in the clay grades, with the coarser clays always showing the lowest values. Over the slope sorting is also good, but becomes poor for the clays of the Sigsbee Deep, the single exception found in any of the deep water clays of the western Gulf.

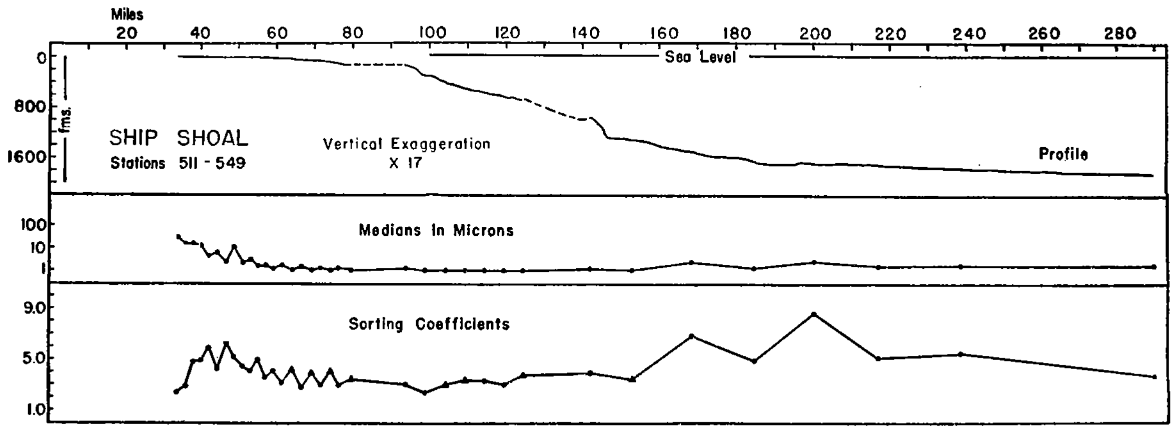

FIG. 16. Ship Shoal Traverse: Topography and distribution of sediments.

DISTRIBUTION OF THE SEDIMENTS

ZONATION

From the foregoing description it is apparent that a marked zonation of the surface sediments is present in the western Gulf. The present state of our knowledge of the distribution of marine sediments indicates that this is the exception rather than the rule. Both Shepard (1948, p. 106) and the writer have worked over thousands of charts from all over the world, when constructing bottom sediment charts for the U. S. Navy during the war, and have thereby gained a comprehensive picture of the distribution of the bottom deposits of the continental margins. Regular gradation in texture from coarse to fine in an offshore direction is not often found, and furthermore, off many coasts, notably eastern Asia and some of the larger East Indian Islands, the finer grained deposits lie nearer the beach with the coarser material offshore. In most areas the bottom deposits are patchy, with the sediment occurring in lenses of varying size and shape which grade laterally into each other. It is true, of course, that few submarine areas have been sampled with as closely spaced a net of stations as has been made in the western Gulf of Mexico. These samples, taken in traverses, will bring out sedimentary relationships not readily apparent in the case of the spot samples which were taken in the course of hydrographic surveys. Nevertheless, sufficient data are available from the navigation charts, incomplete though they may be, to present a generalized, overall picture of the broad outlines of sedimentary distributions for most parts of the continental shelves and slopes of the world (Shepard 1948, Ch. 6), supplemented by the few regions known in greater detail. It is interesting to note that during the war Pratje of the Deutches Seewarte working with similar data turned out bottom sediment charts for the German Navy in his *Ubootshandbuchs* published in 1943, which give independent confirmation to the effectiveness of working from charts alone.

The bottom of the North Sea has been described in detail by Borley (1923) as a background for some fisheries investigations. Chart 14 of his report gives a very good idea of the extreme patchiness of the sedimentary texture in this area. It is true that in addition to deposition since the Wisconsin, the sediments are glacial and mixed continental and marine sediments that were already lying on this part of the European shelf before the sea began its latest advance and attained its present level. The material has been reworked by modern waves and bottom currents but no regular gradations or zonations have been established. This situation, repeated in other parts of the world, may in part account for the apparently hit or miss arrangement of shelf sediments which is the general rule today. They are the product of several environments only partially reworked by the present seas in the relatively short time since the level we find today has been established. This point will be considered further under the discussion of continental shelves.

The sediments of the continental shelves surrounding France have been charted in detail by Thoulet in his 1912 edition of his lithologic charts of the coasts of that country. These have been partially reproduced in the Atlas de France (1933–1939). The sediments of the Channel are very patchy as might be expected. Over the Bay of Biscay shelf there appears to be some zonation but there is no outward gradation from the shore. The narrow Mediterranean shelf is also patchy although the deeper outer portions do have a soft mud bottom which is continuous with the muds of the central basin.

The portion of the northwestern Gulf considered here is a semicircular basin and the sampling traverses roughly approximate the radii of a circle centering on the Sigsbee Deep, except for Matagorda IIA which is parallel to the slope. A study of their graphs indicates very clearly that the same types of sediments, with minor variations, are successively crossed on each one, and that, therefore, the sediments in this area are deposited in a concentric pattern. All traverses normal to the shelf and slope cross a zone of patchy bottom with alternating sands, silts and clays as the case may be. On some, the clay and most of the silt may be nearly eliminated, and on others sand may be scarce, yet the sedimentary distribution remains lensy and the sorting very irregular. Unfortunately, all the traverses begin ten miles or more from shore but from what information we have from other sources, we can delineate a narrow sandy strip shoreward of the innermost zone described here. The writer had occasion during the war to construct a bottom sediment chart (1126-BS) of the western Gulf for the U. S. Navy Hydrographic Office from bottom samples furnished by the U. S. Coast and Geodetic Survey, as well as from the bottom notations on their charts. Sedimentary data were also furnished by R. Dana Russell from his own field work. On this chart, reproduced by Carsey (1950), this belt of sand is shown as discontinuous, stopping at about the longitude of Trinity Shoal and beginning again as a much narrower zone at the Sabine River and continuing westward along the Texas coast. It is probable, however, that this sandy strip is really continuous along the whole Texas-Louisiana coast. Storm (1945) also comments on sandy zones in the offing of Corpus Christi Bay.

Seaward of the patchy bottom of sands, silts and clays, lies a uniform blanket of clay with median diameters near a micron, which covers the whole of the continental slope as well as the bottom of the Sigsbee Deep. Matagorda IIA running parallel to the slope between 600 and 800 fathoms lies entirely within this area of fine sediment. It does, however, cross one deep valley which has no effect on texture. Such a large area of the same type of sediment covering hill tops and ridges as well as lying in the valleys, with little change in the median or sorting values, is very usual. Kuenen (1943) speaks of the very uniform conditions of sedimentation in the Dutch East Indies, possibly indicating unchanging environment extending back into the Pleistocene, and which could, in part, be due to the even climate of the tropics. A steady and uniform supply of sediment would thus be assured unmarked by changes of texture and unconformities which would result from climatic change. Yet the climate of the hinterland supplying the present Gulf with very extensive deposits of uniform clay is far from even. It should be pointed out that in the not very distant geologic past varied lithologic sequences appear immediately below this surface layer, which is rarely more than five or six inches thick. The cores have not been completely analyzed but major textural changes were noted when the cores were logged. An explanation for this depositional change is not readily apparent.

Texture and Sorting Related to Topography

From their bottom sampling off southern California, Trask (1931) and Shepard (1941) have pointed out that submarine ridges, divides, sills, plateaus, and seamounts are the sites of coarse deposits which may be the result of initial deposition, but probably represent lag concentrates of a former environment from which the finer material has been washed. These are the areas over which the currents of various types usually sweep the strongest. The troughs and valleys, on the other hand, serve as traps for the finer sediments because here bottom currents have low velocities. The writer has found the same sedimentary distribution in the Gulf of Maine where the hills and uplands, basins and valleys are a continuation of the dissected New England mainland, now submerged, with an overlay of glacial debris. Murray (1947), using echo soundings from the U. S. Coast and Geodetic surveys in the western Gulf of Maine, has also noted the same thing, and has presented figures giving the depth of soft fill in the valleys overlying the hard material of their floors. This was possible because the supersonic beam from the fathometer penetrated this soft material almost as though it were water and gave a double echo. In some cases he found the valley fill amounted to as much as 90 feet. The inference is that this fine clay has been deposited during and since the present rise of sea level. On the cruise of the *Snellius* in the Dutch East Indies, Kuenen (1943) found that the sediments lying on the sills and ridges of that area were coarse deposits and that the silts and clays were in the deep, quiet water of the basins.

Such is not the case in the Gulf of Mexico. The contour charts of the slope (Gealy, in press) show the many closed basins, ridges and valleys indicating great local relief. However, the graphs (Figs 2–16) for the statistical constants for the traverses, which in each case lie below the topographic profile graphed from the fathograms, clearly show that topography has no influence upon texture or sorting. Over the flat shelf the medians fluctuate widely and sorting follows suit. On the other hand, going down the slope, no matter how rough the bottom topography, these graphs remain monotonously level, and the coring tube cuts the same uniform surface layer station after station on the ridges, in the basins, and in the bottom of the Sigsbee Deep.

Texture and Sorting Related to Depth

There is some general relationship between texture and depth in that the coarser sediments are found on the shallow shelf landward of what might be called the "break in slope" or more recently "shelf-break" (Dietz and Menard, 1951). Seaward of this boundary between continental shelf and slope which is often indefinite in the Gulf, the sediment becomes uniformly fine-grained, as noted above, regardless of the depth of water. Sorting which may be good or very poor in the shallow water of the shelf, becomes good as the water deepens, but beyond the shelf-break increasing depth has no apparent effect upon it one way or the other. Examination of the sediments from the areas previously mentioned outside the Gulf show that deep water sediments are usually more poorly sorted. The western Gulf of Mexico is unique in the relationship which both the texture and sorting of its sediments exhibit towards bottom topography and depth.

Sills and seamounts, of course, are relatively shallower than the basins. Nevertheless, the tops of many lie at several hundreds of fathoms, and it is probable that topography is still the important factor in the control of texture even at considerable depth. Any submarine obstruction would tend to cause increased velocity of the currents flowing over it whatever the depth. A case in point is Sylvania Seamount (Dietz and Menard, 1951, fig. 6) on which bottom photographs have been taken in 750 fathoms showing a current rippled globigerina ooze that probably has the texture of a sandy mud, typical of most of the organic sediments of this type.

The Bioherms

Between about the 50 and the 200 fathom curves off the Texas and Louisiana coasts are many steep-sided plateau-like hills which have been referred to as salt domes by various writers (Shepard 1948; Weaver 1950). Superficially, they look like bioherms, but whatever their origin, at present they are topographic highs (Gealy, in press, and U.S.C. & G.S. chart 1116) rising above the muddy plain of the continental shelf, upon which the spores and the larval forms of many lime secreting organisms can attach themselves and grow. The flat shoulders lie between 20 and 30 fathoms, but the peaks may rise to within 9 or 10 fathoms of the surface. Two, situated at

N. Lat. 27°53′ W. Long. 93°49′, and N. Lat. 27°54′ W. Long. 93°35′, were investigated in some detail and a profile of the latter, drawn from the fathogram, is shown in Fig. 17. In the case of these two it was found that the clays and silts of the shelf lap up on their flanks for some distance, edge; on 462 and 465 cores were obtained which are largely terrigenous with an admixture of calcareous fragments. The statistical constants are as follows: 462, median—.0027 and sorting—4.71; and 465, median—.21 and sorting—1.5. No gradual transition between the two types of sedi-

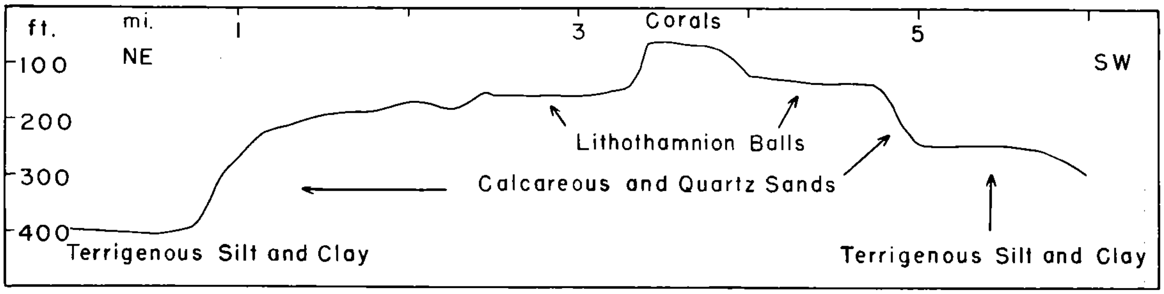

FIG. 17. "Bioherm": N. Lat. 27° 54′, W. Long. 93° 35′; stations 460–465; vertical exaggeration X 20.

eventually being replaced by an increasing proportion of calcareous debris. The shoulders of these two plateaus, beginning in about 26 fathoms and 23 fathoms respectively, are covered with balls of lithothamnion with the diameters ranging from 16 to 5.7 cms and weighing from 1364 to 67 grams. When dredged, they were alive on all sides. The shallow peak of the one shown in Fig. 17 is covered with coral, specimens of which were broken off by the rock dredge. None was obtained from the first hill, possibly because the coral grows in small reefs which were missed by the dredge. Specifically, the stations occupied yielded the following material. On the first hill, stations 453 to 459, fragments of lithothamnion were obtained at 455 and a large haul of complete specimens was made at 456.

Sample 454 was largely shell fragments with a median of 0.6 mm. and a sorting of 4.61 and 458 was similar with a median of 0.31 and a sorting of 2.46. All the rest showed hard bottom with no sample. From the second hill, on station 461, the dredge obtained lithothamnion balls and the following corals, which were broken off in good sized fragments. They were identified by Dr. Elisabeth Deichmann and are all common West Indian forms as follows: *Montastrea annularis* Ellis and Solander, *Minicina gyrosa* Milne Edwards and Haim, *Diphloria stringosa* Dana, *Poriles astreoides* Lamarck, *Modracis mirabilis* D. and M. Stations 462–465, were made on the flanks in 45 to 69 fathoms. On 463 and 464 the coring tube struck hard bottom which dented the cutting

ments was shown by the samples due to the difficulties of maneuvering the ship and getting the stations at exactly the right place in this small area because there was a fresh breeze blowing. It is probable that a gradation exists, but the data given here show an abrupt change from one type to another. Shrock (personal communication; and Cumings and Shrock 1928, Fig. 37) have pointed out the superficial similarity between these hills and the Silurian bioherms of Indiana, where shales surrounding the bioherms interfringe with limestones derived from the calcareous debris shed from the central reef. Whether or not the Texas examples really are old reefs of this type that have grown upwards and kept pace with rising sea level, or are salt domes with a thin cap of calcareous organisms shedding debris down the flanks is a problem only seismic data can solve. It is extremely unlikely that they are erosion remnants which once stood on an emergent Coastal Plain.

The lithothamnion balls (Fig. 18) raise an interesting point with regard to the depth of wave action. Their shape and the fact that the algae at the surface were all living, indicate that the balls are turned over frequently. Bottom currents are responsible; but of what type? Oscillatory currents developed by waves would seem to be the obvious answer but the depth of 20 plus fathoms at which they are found is in conflict with the recent figures given by Dietz and Menard (1951) for effective wave scour. It would seem that a current flowing in one direction for any length of time, and strong enough to turn the balls over, would eventually roll them over the edge of the plateau-like hills where they live and develop. Off the island of Bermuda is a flat-topped platform known as Challenger Bank which presumably is a truncated volcanic cone that at present does not reach the surface. The depth of water is 27–31 fathoms. Similar litho-

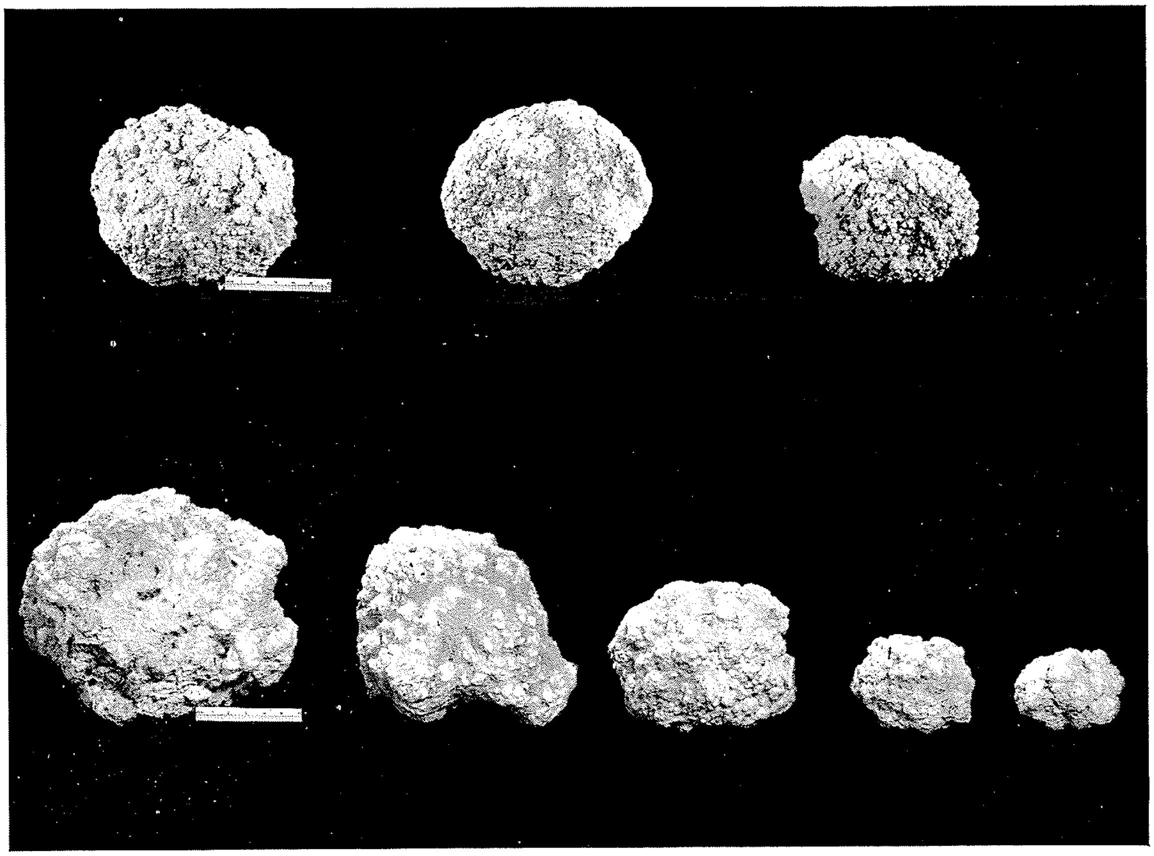

FIG. 18. Lithothamnion Balls: Top row from Challenger Bank off Bermuda, depth 27–31 fathoms; bottom row from "bioherm" plotted in fig. 17. The rule is 6 cms. About ¼ X.

thamnion balls weighing up to 1056 grams and 12 cms in diameter are found here, and H. B. Bigelow (personal communication) says that when he dredged them over 50 years ago the algae were likewise alive on all surfaces. This platform is somewhat deeper than the "bioherms" in the Gulf but here also are currents with sufficient velocity to roll the balls around and prevent the development of flat surfaces. Field evidence of this sort cannot be ignored. Is it possible that internal waves provide the answer? The specimens are in storage in the Museum of Comparative Zoology.

Rounded Quartz Sand

Quartz grains with a very high degree of sphericity and roundness occur in many of the coarse fractions from the samples over the shelf. It is most noticeable in particles ranging from 1–0.5 mm in diameter, and on Krumbein's scale would be rated with a sphericity and a roundness of 9. (Krumbein & Sloss, 1951, p. 81). Not all the grains in any given course fraction are rounded; in fact, some would fall into the lowest categories on the above scale. As is usual, below 0.5 mm roundness and sphericity decrease, and there are few grains of any kind larger than 1 mm. They are found in most of the shelf samples from Port Isabel I to Trinity Shoal I but only occur in an occasional sample on Trinity Shoal II and Ship Shoal. It should be remembered that these two westerly traverses have less sand of any kind in their shelf samples. Most of the rounded grains are also lightly frosted.

Sand with an equal degree of roundness and sphericity, although running somewhat coarser, has been reported from the continental shelf south of New England (Stetson, 1936). Here it was explained as old dune sand which had been through several cycles during the various low water stages of the Pleistocene. Upon the last readvance of the sea the dunes were once again flattened out and their sand is now being mixed with sediment of other types. Nothing approaching this sand in degree of roundness or sphericity is found in any of the modern beaches or shore dunes on Cape Cod or the outlying Islands, although a little is found in some of the older, buried surfaces associated with ventifacts.

It is equally probable that these rounded grains found in the present day sediments of the western Gulf may have had a similar history during the Pleistocene, and may have passed through several abrasional cycles during the lower sea-levels of the Pleistocene. No topographic trace of these ancient dunes remains today on the continental shelf. Like their northern counterparts, the last readvance of the sea would have flattened them out and distributed their sands over the surface of the shelf, later to have become mixed with material transported and deposited under the modern environment.

COMPARISON WITH THE ATLANTIC CONTINENTAL SHELF AND SLOPE

The Atlantic continental shelf has been sampled by the writer (Stetson, 1938) in a series of 10 traverses across it from southern Massachusetts to Florida. Numerous cores have been taken on the slope and in the canyons, and samples of sedimentary rock have been broken from the canyon walls (Stetson, 1940). Stratigraphically, the Atlantic and Gulf Coastal Plains have had the same history, as both are thick accumulations of sediment, interfingering continental and marine, which began to assume their present form by the Lower Cretaceous. Structurally they are similar although the stratigraphic column in the Gulf Coastal Plain is several times thicker than in the Atlantic. In both cases the similarity presumably can be extended to their submerged portions. The different types of sediments, and their distribution in each of these major seas, afford an interesting study of the geologic and oceanographic processes which have resulted in the construction of two continental platforms that have been evolving for approximately the same length of time. A survey of their parallel development, and a detailed comparison of their present day sediments afford an excellent illustration for the sedimentologist of what will happen when the sea is free to deal with large supplies of unconsolidated material for long intervals of time under relatively stable tectonic conditions.

The greatest single sedimentary difference between the two areas is that the surface of the present platform in the Atlantic is dominantly sandy, while that in the Gulf is dominantly muddy. In this respect the Atlantic shelf is unique, as there is no known area of comparable size where the sediments are almost entirely sandy. The only one approaching it in size is off Argentina. The situation in the Gulf is more usual, as many of the shelves of the world have large muddy areas. In both cases the continental slope is covered with fine grained sediment.

Specifically, the only fine grained area of any size on the surface of the Atlantic shelf is found south of New England (Stetson, 1938). Although occasional notations on the Coast and Geodetic charts give a muddy bottom elsewhere, these must be only small patches as none of the ten traverses, except as noted above, picked up any appreciable amount of fine material. This proved to be the case on the shelf off the Carolina Capes where some detailed sampling has recently been carried out by the Woods Hole Oceanographic Institution (unpublished manuscript). Everything else is sand and gravel, either dominantly quartz or dominantly shell fragments and oölites. Wherever a well sorted sandy or gravelly bottom is found, no matter what the depth, a current with a velocity competent to rework the bottom material and to remove silt and clay sizes must be present. There must also be a balance between the amount of sediment supplied and the ability of the sea in any given area to distribute and transport it. This factor in its turn would have an effect on texture, and in the ratios between velocity and supply we have what are probably the main differences between the factors controlling the sedimentary environment in the Atlantic and in the western Gulf.

Judging by what little oceanographic data we have, it is probable that the bottom currents over the Atlantic shelf have higher velocities than in the western Gulf. Atlantic storm waves and swells, because of a longer fetch, have longer periods and are capable of moving silt and clay particles at greater depths than the shorter period waves of the western Gulf. At present there is some question as to the effectiveness and depth of wave erosion (Dietz and Menard, 1951), but it is a factor which must enter in to some extent. The tidal range on the open Gulf coast is small compared with the Atlantic (roughly 1.5 ft. at Galveston as compared with 4–5 ft. at Delaware Breakwater), and there must be a consequent reduction in the velocities of the tidal currents which are of considerable importance in transporting and distributing sediment in shallow waters. Lastly, the swift Gulf Stream impinges against the Atlantic continental slope from Florida to Cape Hatteras. This tends to sweep all sediment from the continental slope, from the deeper lying Blake Plateau, and undoubtedly tends to coarsen the grade sizes at the break in slope and for an indeterminate distance shoreward of this point. It has been demonstrated that the Gulf Stream flow is very turbulent and that great eddies are thrown off from time to time in both a shoreward and a seaward direction (C. O'D. Iselin, personal communication). These factors must enter the sedimentary picture but their effect has not been evaluated.

Conditions of supply are also very different in the two areas. There is no question that today the western Gulf is receiving vastly more sediment than is the western North Atlantic. All the drainage from the central United States from the Appalachians to the Rockies empties into the Gulf and the sedimentary load which these rivers carry is heavy. Consequently, the Gulf currents, of whatever origin, are called upon to transport and distribute enormous amounts of material as compared to those of the Atlantic, which are probably more competent to begin with. Practically no sediment due to runoff reaches this ocean north of the entrance of Chesapeake Bay. The large rivers of New England are practically clear, and what little sediment does reach salt water is effectively trapped by the deep basin of the Gulf of Maine and by Long Island Sound. The Hudson is also a clear stream and the Delaware relatively so with a bay at its mouth to serve as a catch basin. Chesapeake Bay receives a large run-off and the rivers entering it from the Susquehanna to the James are muddy. The bay itself and its arms act as a partial sediment trap as is shown by the widespread silt and clay bottoms throughout the area. Considerable fine-grained sediment does escape, however, as is demonstrated by the color of the outflowing tide between Cape Charles and Cape Henry. Nevertheless, as the scoured bottom between these two capes is largely sandy and the continental shelf seaward has a sandy surface to the shelf-break, the silts and clays are now being by-passed to the continental slope. The rivers of the south Atlantic states, except Florida, such as the Santee and the Savannah, to name but two, are notably muddy. Muddy bottoms, however, are restricted to the shallow waters of the sounds and channels between the Sea Islands of South Carolina and Georgia. The open shelf is sandy, and except for the occasional patches noted previously, the inner slope off this section of the Blake Plateau coast is either a hard bottom or has a little calcareous sand. The extensive Blake Plateau itself likewise has the same type of bottom. This means that whatever mud is delivered direct to the Atlantic along this stretch of coast is by-passed to the slope, outside the plateau, which pitches to the bottom of the Atlantic basin.

The sedimentary data afforded by the traverses across the Atlantic continental shelf from New Jersey southward, clearly indicate that the main sources of the sediment which appears on the surface of the present day shelf are the submerged formations of the Coastal Plain which the sea is now reworking (Stetson, 1938). In the first place, the land mass is protected by a long succession of barrier beaches themselves derived from the continual reworking of the Coastal Plain formations, and secondly, the offshore sediments present evidence of reworked material. The uniform sandiness encountered almost everywhere on the bottom can only be explained in this way, as no sand is being supplied directly from run-off. In addition, on all traverses south of Cape Hatteras, oölites and shell fragments, water-worn and deeply stained, make up the larger proportion of the material on the outer parts of the shelf. Obviously, these can only have come from the older marine deposits. How many times this process has been repeated since this material was first laid down, it is impossible to say, but it is probable that the present day sediments have gone through many cycles as the strand line has oscillated back and forth. Sedimentary conditions as we find them here are governed by conditions of supply, and at the present time the surface of the Atlantic shelf can be considered an erosional area with the sea actively engaged in reworking and redistributing sediments that were deposited in an earlier era. What may be regarded as "permanent" deposition of terrigeneous material is only taking place on the continental slope and in the Atlantic basin.

The sedimentary data derived from the Gulf traverses present a very different environmental picture from that found in the Atlantic. The Gulf is evidently an area of deposition, and sediment is being supplied to the sea faster than it can be removed to deep water. The result of the over-supply of silts and clays is a blanket of this fine grained material laid down over the surface of the shelf and the hills and valleys of the slope. The fines have been removed partially or entirely from certain of the shelf areas leaving behind slightly coarser deposits, but elsewhere deposition is dominant over erosion. The material is piling up faster than the sea can transport it from the shelf or sweep it from the ridges and plateaus of the slope into the basins and valleys. Perhaps this is not so surprising when one considers the rivers, in addition to the Mississippi, which are delivering their loads to the western Gulf. To name only the major ones there are, from east to west, the Atchafalaya, Sabine, Trinity, Brazos, Colorado, Guadaloupe, San Antonio, Nueces, and the Rio Grande. The bays through which many of them enter are already mud-choked except for the dredged ship channels, which in themselves form canals of direct discharge.

The contrast between the Atlantic and the Gulf may well point the difference between sedimentary deposits resulting from the reworking of sediments, both continental and marine, that have already been through several cycles, and those resulting from the initial deposition of material where the supply is abundant. In the first instance, patchy distribution might be expected to result, and in the second the sedimentary cover might be more homogeneous. It should be noted that environmental conditions which we are considering in the western Gulf can only be of very recent date, and it is emphasized once more that only the top few inches of sediment are under discussion. Specifically, only the top inch was used in the analyses. Examination of the cores reveals a very varied lithology a short distance below the surface, as has been noted previously. The rapid changes shown in the closely spaced cores from the area in the western Gulf which was surveyed by *Atlantis* in detail (Gealy, in press) can be taken as typical of the whole region in this respect.

The sorting of the Gulf silts and clays is unusually good for deep water sediments of this type, and indeed, for any fine-grained marine sediments regardless of environment. The Atlantic slope and deep water deposits are poorly sorted, and in all cases the coarser material of the shelf always has the better sorting values. This relationship seems to be the rule between coarse and fine sediments in other marine areas with which the writer is familiar from personal experience and through the literature. The reverse condition is often true in the Gulf and the relatively coarser shelf material may be more poorly sorted than the deep water clays of the slope and Sigsbee Deep. Possibly the explanation for the good sorting displayed by what are now marine silts and clays lies in the fact that they have already had a long transportational history as riverborne sediments. So much of this river sediment is being delivered directly to the western Gulf that at the present time the sea transports and deposits this type of material almost exclusively, uncontaminated by other types of sediment. The Galveston and Ship Shoal traverses do show occasional high sorting values in the fine sizes. Ruling out the accidents of sampling, these might be accounted for by local slumping which must occur on this slope in places. (Gealy, in press; Phleger, 1951.)

GEOMORPHOLOGY AND EVOLUTION OF CONTINENTAL TERRACES

Introduction

We have been considering specifically the topmost layer of sediments of a continental terrace of huge proportions that began to take shape in the Cretaceous, and which has continued to grow ever since. It is still growing today in thickness and in length. The west Gulf Coastal Plain, its emergent landward portion, is too well known to warrant further discussion here, and the reader is referred to the excellent descriptions by Storm (1945), Lowman (1948), Carsey (1950), and King (1951). However, certain aspects of present day sedimentation, and certain features of the existing topography which have come to light during the present study are pertinent to the problem of the origin and evolution of continental terraces, and will bear further consideration.

The fate of the Paleozoic continental terraces, both in the Atlantic and in the Gulf, is a major geologic mystery. In the Atlantic and the Gulf today we have their counterparts, but they are not building on the remains of the older ones, for in both cases the terraces rest on basement granite. Kuenen (1950) has compared the much larger probable size of the Atlantic Paleozoic terrace with the present one in connection with the problem of subsiding borderlands. Obviously terrace development and the phenomenon of marginal sinking, which has apparently been going on throughout geologic time, are closely intertwined.

Break-in-Slope or Shelf-Break

The change in the angle of slope between the flattish top of the continental terrace and the steeper seaward face is of importance when considering terrace formation, as it is either a morphological feature related to present sea level or else is the result of factors but recently operative. It is much more sharply defined in some instances than in others, but the change in gradient to a greater or lesser degree is a characteristic common to submerged continental margins throughout the world.

Recently Dietz and Menard (1951) have re-examined the shelf-break, as they call it, using the new topographic evidence furnished by fathograms. They have discarded the theory of shelf origin wherein the shelf-break represents the angle between topset and foreset beds of a delta-like deposit, and also the idea that the continental platform represents a surface of abrasion cut at some depth and related to "wave base." They argue that the old concept of wave base is no longer valid because modern oceanography has shown that "marine currents capable of stirring sediment exist far below wave base — hence there is no base" (ibid. p. 2002). The velocity of currents generated by oscillatory waves decrease rapidly with depth until a zone of no motion is reached depending on wave length and height. But there is no abrupt reduction in the velocity of currents produced by oscillatory waves, which Dietz and Menard regard as essential to form the shelf-break. "An abrupt change in velocity occurs only where waves of oscillation are transformed into waves of translation or, in other words, where breakers form" (ibid. p. 2003). A summary of wave observations limits the breaker zone to a maximum depth of 25–27 feet and, therefore, under the above argument, this is the controlling depth for the construction of the shelf-break, past and present, which is interpreted by them "as the outer edge of a wave-cut terrace abraded by wave action related to a sea-level lowered to within a few fathoms of the break" (ibid. p. 2011). Present day shelf-breaks the world over are related to the lowered sea-levels of the Pleistocene.

The weak point in this argument is the dearth of wave-cut terraces with marginal shelf-break related to present sea level which should be forming today. They are apparently not produced off coasts composed of easily eroded sedimentary rock as no mention is made of a shelf-break in 25–27 feet of water off the California coast. Neither are they produced on bottoms composed of completely unconsolidated material. From New Jersey to Florida numerous topographic profiles extending seaward from the beaches have been drawn by the Army Engineers and published in their House Document reports on beach erosion. No terrace is evident at the supposedly correct depth of water; yet a well marked shelf-break exists along the whole length of the Atlantic continental margin. No terrace and shelf-break exists on the Gulf of Maine side of the Cape Cod moraine, in spite of the steeper seaward slope of the offshore bottom, nor, apparently, did one form in the Pleistocene at the time when the one fronting the Atlantic was supposed to have formed.

They present evidence that, under certain conditions, an abundance of sediment will bury a wave-cut notch and its resultant terrace. But it should also be pointed out that a well developed wave-cut terrace is rather a special case, and that the ones cited as the best illustrations are all cut in sedimentary rocks of just the right degree of induration. They are not found on all coastlines; yet the shelf-break is world wide. The hard igneous and metamorphic rocks of the Maine coastline, for instance, have not been notched at all. When dealing with unconsolidated material it is doubtful if a wave-cut bench can form at this or any other sea level. If a wave-cut terrace and shelf-break could be formed in the past from this very same material, it is difficult to understand why one is not forming today. This raises a doubt that the violent wave action of the breaker zone is the real explanation. Apparently the only features of the foreshore that owe their origin to breakers are the longshore bars and longshore troughs (Shepard, 1950). They are a well marked, though shifting, feature of a foreshore which is composed of unconsolidated material, and they in no way resemble terraces, not even in miniature.

Shelf-Break in the Western Gulf

An examination of the fathograms which cross the shelf in the western Gulf indicate that the break in slope is not particularly sharp, and when the vertical exaggeration is eliminated, it looks very little like the outer edge of a wave-cut terrace. It should be noted that the shelf-break, or lack of it, can be seen much more clearly on the full scale graphs of the fathograms than in the reduced figures of the tracings which are published here. Before making the graphs those sections of the tape had to be eliminated which were recorded while the ship was on station. For this reason sections of the original tape are not reproduced as the ship drifted off her course somewhat while the station was being occupied.

There are six traverses on which the shelf-break can be located with any exactness on the original plots; and all of them show a gentle convex surface. On the Port Isabel I Traverse the angle between shelf and slope changes between 70–75 fathoms, and on nearby Aransas at about 70. Matagorda II shows one of the clearest which likewise occurs at about 70 fathoms. On Brazos II the change in slope is very gradual and takes place over a distance of about 2 1/10 miles and through a depth of about 50 to 65 fathoms. Galveston shows a fair break in about 65 fathoms, and Heald shows it well at about 60 although there is a very slight change in grade before that depth. The others give little information on the depth of the shelf-break. On Port Isabel I the ship drifted across the break diagonally while hove to during a blow. Matagorda I also crosses it on a diagonal. Brazos I shows a slight break in the grade at about 85 fathoms, and a marked one at about 140 fathoms which may be structural. Trinity I has a slight break at about 80 fathoms, with the bottom shoaling before falling off to the next break which is defined at about 105 fathoms, following a second small dip which only shows on the fathogram itself. This topography of this line is probably structural in the main. There is no real shelf-break on Trinity II because at this point a hill is situated on the outer edge of the shelf which may be the shoulder of a bioherm similar to the two described above. On the fathogram several small peaks appear, with the shoalest at 65 fathoms. Ship Shoal shows a gentle break at about 105 fathoms. The ship was then hove to during a blow at station 531 and drifted 21 miles to station 532. From this station seawards the slope has increased but the ship's course over the intervening distance is too uncertain to plot an accurate profile.

There appears to be little similarity between these shelf breaks as we find them and the margin of a wave-cut terrace, although it could, of course, be argued that the contours have softened since they were cut during the lower stands of the Pleistocene seas. It seems much more probable they are developing by the sum total effect of the currents, however generated, that are constantly shifting sediments offshore. The change in the angle of slope is very gradual over a considerable horizontal distance, in some cases many miles. In the case of the Atlantic there is a change in the type of sediment but in the Gulf there is not. It does not seem essential to have an abrupt reduction in the velocity of the transporting current to produce such a feature. It in no way resembles the sharp line of demarcation that separates the topset from the foreset beds of a delta. We know that in many areas, as in the Gulf, that the shelf-break area is one of deposition and it seems reasonable to suppose that the gradual change in the slope is what would result from the gradual building forward of the terrace front. The constructional processes which built this terrace are discussed below.

None of these west Gulf profiles show the sharp shelf-breaks which Dietz and Menard (1951, Pl. I) figure, and it is doubtful if they are comparable in origin. All of the latter lie off tectonically active sections of coast, and the strong possibility exists that faulting may have taken place. Shepard (1948, p. 193) is inclined to attach considerable importance to the fault scarp origin of continental slopes, and it is very probable that in many cases the shelf-break as a topographic feature is not produced by bottom currents however generated. To cite an example in the eastern Gulf by way of contrast, there can be scarcely any doubt that the steep west Florida continental slope is a huge fault scarp (Jordan, 1951).

Bed Rock and Hard Bottom on the Continental Shelves

Shepard (1948, Chs. 6, 7, 8) has repeatedly stressed the presence of bed rock and gravel or stony bottoms on continental shelves the world over as evidence of erosion or at least non-deposition. From there he goes on to build up a case for a wave-cut continental shelf, and rules out the idea that it is constructed by sedimentary processes. Other geologists have followed his lead and at present the older concept of a sedimentary terrace is, for the time being, largely in the discard. Apparently, no one considers the type of rocks involved in this blanket statement regarding shelf origin; whether they are igneous or sedimentary. Shepard (personal communication, 1952) lists all outcrops and possible outcrops of igneous rock known to him from the walls of submarine canyons. "Carmel Canyon has granite on both sides. Dume Canyon has basalt or some dark colored intrusion on one side. Monterey Canyon has granite on at least one side." Nazaré Canyon off the Portuguese coast winds past some islands made of igneous rock and he infers that these may comprise part of the canyon walls. From the 17 California canyons listed (Shepard, 1941) as yielding rock on numerous dredging tows, two of the canyons above are listed as producing granite; all the rest had walls of sedimentary rock of various types and degrees of induration. He also reports much sedimentary rock dredged from the banks and sea-mounts which make up the shelf off southern California. The writer (Stetson, 1949) has dredged many bed rock samples from the canyons on Georges Bank, all sedimentary, and sedimentary rock talus from Norfolk Canyon. No igneous outcrops were found. Ewing (1950) has shown that the sediments, unconsolidated and semi-consolidated, attain a thickness of about 16,000 feet half way across the continental shelf off Maryland and about 14,000 feet off New York. At the continental margin, the sediments are upwards of 5,000 feet thick south of New England and upwards of 12,000 feet off the Chesapeake. How such a structure can be regarded as non-depositional is difficult to see. Even off California where bare rock does outcrop it is almost always sedimentary. In certain areas on some shelves erosion is at the moment taking place. Indeed, such is the case on the east coast shelf from Cape Hatteras to New Jersey (Stetson, 1938, p. 31–32). However, because the surface of the continental shelf is, in places, temporarily being planed off it does not follow that the whole feature was produced as an abrasion platform or that the shelf-break is always the outer edge of a wave cut terrace.

The Norwegian continental shelf has been charted in detail by Olaf Holtedahl (1940) and recently Hans Holtedahl (1950) has made a study of the topography and sediments of a section of the slope west of Møre. His findings coincide with Shepard's faulting hypothesis of slope origin. The slope here descends in a series of steps, and the steep slopes between represent fault scarps. Furthermore, dredging indicates that the bed rock of the steep upper slope is largely granitic. Obviously, there is no parallel between the present-day conditions that are found here and those of the east and Gulf coasts of the United States. It should be pointed out that the Norwegian hinterland provides a limited drainage area and that the native rock is hard. Heavy marginal deposition, therefore, is not to be expected. Moreover the shelf has been heavily glaciated which has added to the topographic irregularity which was probably initiated by subaerial erosion (Nansen, 1904).

No rocky bottom or even stones or gravel are found on any of the traverses in the western Gulf, the living reefs excepted. Considerable fine material is being carried over the shelf to the slope and the Sigsbee Deep but much remains behind. The entire environment is one of deposition, and even the limited erosion that is taking place on the shallow southern Atlantic shelf apparently does not occur here. The load delivered to the Gulf is greater than the sea can completely transport seaward. Compare this with the situation off southern California described by Shepard (1941) where fine-grained material is bypassed over the shallow banks and deposited in the deep basins, resulting in extensive areas of rocky and stony bottom.

The Delta Analogy

It is well known that the change in slope between the topset and the foreset beds of deltas is produced by the rapid decrease in the velocity of a sediment-laden stream entering a standing body of water. Because of the topographic similarity the continental terrace is frequently compared to a delta and an analogy drawn between the topset and foreset beds and the surface of the continental shelf and slope. Herein lies a fallacy which should be noted before carrying the delta analogy too far. The classic deltaic pattern does not develop except in relatively small, quiet bodies of standing water. In the sea, wave action with its attendant longshore currents plus whatever the tides can contribute to the longshore component, prevent such a depositional arrangement of the beds. This rules out the marine environment except in cases where a large river debouches into an estuary. The Fraser River entering Georgia Strait is a good example (Johnston, 1921), and has apparently constructed its delta more or less after the classic pattern. Even the Mississippi has not been able to build this type into the waters of the Gulf of Mexico (Russell and Russell, 1939). Although this is the only large delta on an open coast whose structure is known in detail, it is probable that others such as the Nile, the Rhone, or the Ganges have been built up after more or less the same pattern. Furthermore, there is nothing in the well known structure and stratigraphy of either the Atlantic or Gulf Coastal Plain formations to suggest a typical deltaic arrangement of topset, foreset, and bottomset beds, or that the continental terrace in either ocean ever grew in such a manner. The shelf-break, therefore, cannot be considered analogous to the change in gradient between topset and foreset beds.

Offlap and Onlap: The Case for Sedimentation

Recently Dietz (1952) has proposed a new sequence of events in the genesis of a continental terrace which will evoke considerable discussion. The reader is referred to the original paper for details, but roughly the idea is as follows. The sialic continental block stands high above the heavier simatic block of the ocean basin. The primordial ocean beats against the steep sialic slope notching it, cutting a continental shelf and later prograding a small terrace which is augmented by what are termed "hinter surf" beds: littoral, lagoonal, deltaic and tidal flat deposits. At the same time fine-grained material is kept in suspension and carried seaward by oceanic currents of various types to settle out in a sort of mud-drift at the base of the sialic slope and forming a very thick apron over the sima. This is the location of the heaviest accumulation, and these clays and silts furnish most of the material for constructing the mature continental terrace. As sedimentation continues in both areas, the small terrace and the now very extensive apron meet. The original sialic slope is now completely covered and the geomorphic form of the continental terrace as revealed by fathograms, has been attained. Various isostatic adjustments accompany this process, and for these and other supplementary details the original paper should be consulted. The shelf-break is always the outer margin of the shallow, wave-cut terrace rigidly controlled by the position of the surf zone.

Without mentioning it by name the mechanism which Dietz is using to construct the upper half of his continental terrace is the well-known sedimentary process of offlap and onlap. The present writer (Stetson, 1949) proposed that the continental terrace in prototype was constructed by transgressive and regressive overlap, resulting in a huge longitudinal series of overlapping sedimentary lenses. The development of the East Coast continental shelf was cited as an example, and what is known of its stratigraphic history was traced from samples of formations in place, obtained principally from the Georges Bank canyons. The delta theory was rejected and has been further discounted here. The main points of difference between this concept and that proposed by Dietz is that following this argument, the main bulk of the continental terrace is prograded from the shoreline with the building material partly transported as bed load. The fine-grained deposits lying on the ocean floor and banking up against the continental margin are secondary and necessarily much thinner. The end result, or at least the resultant physiographic form, is the same in each case. Under both theories the whole terrace is sedimentary in origin, but the method of formation differs. Neither considers that the delta analogy any longer holds. Since at least the Lower Cretaceous the Gulf Coast geosyncline has been growing both in thickness and in width. At times in the past larger areas of this sedimentary structure were out of water than are exposed today, followed by periods of relatively greater submergence. It comprises what is probably the most active depositional area about which we have detailed stratigraphic and topographic knowledge, and it is still growing. Furthermore, the same processes, both subaerial and submarine, that have controlled its growth and structure are in full operation today. Here then, is a continental shelf in the process of formation. The present in this case is certainly a key to the past: the past, that is, as far back as Mesozoic times. With the Gulf Coast terrace in mind, let us reconstruct a primordial terrace largely by transgressive and regressive overlap.

The angle of slope of the seaward margin of the original sialic continent is of course unknown, and may even have been as gentle as that of the basement underlying the present Atlantic Coastal Plain (Spangler, 1950). In any event, the ocean waves of that period would have been no more successful in attacking a granitic terrain than are those of the modern ocean. The metamorphic and granitic rocks of the coast of Maine have scarcely been touched since the sea assumed its present level after the Wisconsin. What little coastal abrasion does appear, is largely the result of frost action along joints followed by removal of the debris by wave action. We are so accustomed to spectacular examples of wave cutting along the coastline that we are apt to forget that cliffs resulting from marine erosion are all produced in sedimentary rocks. Where cliffs of igneous and metamorphic rock do appear as on the coast of Maine and elsewhere, a structural or glacial origin must be sought. The "knife edge" of the surf zone has little effect on rocks of this type. The picture of undercutting in the course of which "parts of the continental block tumble down into the surf zone where they are comminuted by vigorous wave action" (Dietz, 1952) certainly does not fit. It is difficult to imagine a hard, resistant granitic shoreline being cliffed and planed by wave action alone, or being able to supply even a fraction of the debris required for the prograding of a terrace comparable to the proportions of the one considered here.

On the other hand, a fresh, granitic terrain would disintegrate and decompose rapidly under the attack of subaerial forces. Here then is the most productive source of detritus for prograding the terrace from the strandline, and also of the fine-grained material for the deep-water apron, whatever its thickness. Streams would be the means of moving this material to the coastline; wave attack and tidal currents would be confined to distributing it and putting the fine-grained material within reach of other types of currents for further transportation offshore, much as they do today over the continental shelves off both the Atlantic and Gulf Coastal Plains. Transgressive and regressive overlap have done the rest and the net result has been the construction of a huge terrace composed of overlapping lenses of sediment of all textures and types superimposed on a basement of igneous and metamorphic rocks. There is abundant evidence from Gulf and Atlantic Coastal Plain stratigraphy that this is exactly what has happened. The sea has advanced and retreated many times, and each shift of the strand line has produced either erosion, deposition, or equilibrium conditions on the surface of the shelf, with an overlapping of coarser deposits of finer or the reverse (Malkin and Jung, 1941; Malkin and Echols, 1948). Deposition on the slope was continuous throughout all these oscillations of the strand as well as during periods of stillstand; and the face of the slope progressed steadily seaward into deeper water. Consequently, the terrace has grown in thickness with many depositional breaks; and it has grown continuously in width. For example, the depth of the monocline near the Texas-Louisiana coast has been estimated at more than 40,000 feet (Lowman, 1949; Nettleton, 1952) and apparently is still thickening in a seaward direction, but the maximum width is measured by the 600 odd miles lying between Cairo, Illinois, the high water mark of the Upper Cretaceous seas, and the present continental slope.

The topography of this continental slope is at present unique as far as our knowledge goes, although adequate soundings may reveal a similar morphology in other oceans. The succession of ridges and basins, some of them closed, on the upper parts of the slope, and the deep channels cutting downwards across the bottom sections are difficult of explanation until the general structure of this terrace is taken into account (Gealy, in press). A series of sediments, such as these, some of them unstable, cannot help but fail considering the great thicknesses which have been deposited. Shearing under stress, both at depth and surficially, must have occurred repeatedly; slumps and mud flows must also have taken place. Lastly, we have the surface effects, both erosional and depositional which the somewhat enigmatic suspension currents may have produced. No one knows how much of a role to assign to them, but if ever there was a locale favorable for their maximum operation it is the western Gulf slope. Gealy (op. cit.) has analysed the problem fully and has drawn two detailed contour charts, and it is not proposed to discuss the problem further here, except to point out that the topography which has been developed is probably a composite picture produced by the various ways that different types of sediments behave under stress.

The mechanism which caused these constant fluctuations is beyond the sedimentary scope of this paper. Simple overloading of the earth's crust is only part of the picture. Tectonic forces operating in the deeper layers of the earth must play a major part in these repeated oscillations, plus the fluctuations of the Pleistocene. It is obvious that deposition could not have caused the original subsidence. The first beds must have been laid down on a basement that was already subsiding. Subsequent deposition may have overloaded the crust and materially aided downwarping, but it cannot be the primary cause; nor can it explain the reversals. Stephenson (1926, p. 462) in discussing some time ago the stratigraphy of the Atlantic and Gulf Coastal Plains gives an excellent, overall description which cannot be improved upon. "The different kinds of materials do not form separate, uniform sheets extending throughout the entire length of the Atlantic and Gulf Coastal Plain, for the sediments laid down at any given time differed from place to place and the conditions of sedimentation constantly shifted from time to time. Briefly stated, this means that no two columnar sections, unless closely adjacent to each other, are identical in lithologic succession."

Major Faulting Associated with the Continental Slope

The case presented here for the origin of the ancestral continental terrace implies that originally the slope is simply the forward moving face of a continuously growing bank of detritus. Let us proceed a step further in terrace phylogeny. The association of what are apparently fault scarps of considerable magnitude with the seaward face of this and other terraces must be considered in conjunction with the purely sedimentary hypothesis presented above. To cite only three instances: there is an extensive scarp bounding the continental platform off the west coast of Florida (Jordan, 1951) which the author followed southward on a cruise in 1951 nearly as far as Key West. There is another in the western Gulf which is responsible for at least the bottom part of the slope bounding the Sigsbee Deep on the north side (Gealy, in press). The continental slope off California is in many places controlled by fault scarps; some of them very extensive (Shepard et al, 1941). This fact does not necessarily invalidate the theory presented here that the prototypal continental terrace must always be a sedimentary or depositional structure. The cases cited above perhaps represent another step in terrace development. If an active fault marks the boundary between the sialic continental blocks and the basement blocks of the sea floor any attempt of the sea to construct a sedimentary platform over this junction might result in repeated faults in the sedimentary cover also. In other words, once the sedimentary terrace has been graded seaward to this zone, further outbuilding is truncated. Very possibly the western and eastern Gulf Coast terraces which started their growth in the Mesozoic, have now reached this position, but it is doubtful if there is any marginal fault in the Atlantic marking the slope from Hatteras to Georges Bank.

Any discussion of the origin of continental terraces leads inevitably to a fundamental question which cannot be answered. What has happened to the terraces which were constructed during the Palaeozoic or even earlier? Umbgrove (1947, p. 117–120) and Kuenen (1950) have already commented on this enigma; and it is part of the baffling problem of subsiding borderlands. We cannot even explain satisfactorily the gentle sloping basement of igneous rock upon which the Atlantic and Gulf Coastal Plains are built. The reasons for the variety of forms which continental terraces the world over exhibit today are but parts of this much larger problem. Not only is it completely unsolved, but as Kuenen (1950, p. 50) points out the entire concept adds further difficulties, because the sinking of such vast marginal continental blocks as appear to have occurred seems to run counter to established ideas "on isostacy, the permanence of the oceans . . . and the geophysical differences between the continental and oceanic sections of the earth's crust."

CONCLUSIONS

As our knowledge of the topography and sediments of the continental shelves and slopes grows through the use of the new oceanographic techniques it is becoming evident that many different stages of development are present. For example, there is no topographic or lithologic resemblance between the continental platforms off Norway and California on the one hand, and those off Texas and the eastern coast of the United States north of Cape Hatteras on the other. Yet no one would question that these areas represent submerged portions of the continents. Apparently there is no single explanation of "terrace" formation that is universally applicable because the problem is not static. Terraces go through a series of evolutionary changes in the course of their geologic history, and some have had a more complex geologic history than others. The Atlantic and Gulf terraces are here regarded as being in the primary stage, although they are relatively old. They have been little modified by diastrophism, and the processes of erosion and sedimentation under constantly transgressing and regressing seas, as well as under littoral, lagoonal and continental conditions, are still operative. It is fortunate that these have retained their primitive features because little idea of constructional processes can be gained from an examination of other terraces of which we have any detailed knowledge.

The zonation of the sediments over shelf and slope in the western Gulf and in the central Sigsbee Deep which has been given here, pictures a sedimentary environment governed by the oceanographic and geologic conditions which are operative today, and represents but a brief interval in a long geologic history. The sediments are still for the most part unconsolidated or semiconsolidated, and although lithology has varied frequently, the constructional pattern has remained the same. The topography of the western Gulf slope is the result of the behavior of unstable sediments under stress. Deep-seated sheer planes have had surface expression in ridges and basins, and the whole has probably been modified by slumping, mud flows and density currents (Gealy, in press). The science of soil mechanics, which is being rapidly expanded by engineers, is in a position to be of great help in the fields of geomorphology, stratigraphy and sedimentation.

Such, then, is considered to be the sequence of events in the evolution of one specific case. The Atlantic continental terrace north of Cape Hatteras has had a similar sedimentary history, but the slope presents a totally different geomorphic aspect. In the western Gulf although extensive faulting has played a part, diastrophism has not as yet profoundly altered this submerged continental margin as it has so many others. This may be the next step in its evolutionary pattern. Analogies must be drawn with care when considering theories of origin and development; blanket explanations are no longer valid in this day of rapidly expanding oceanographic techniques, and each case can only be judged on the basis of adequate field data.

TABLES

Table 1 — Port Isabel I Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
302	N. Lat. 26° 05′ W. Long. 97° 00′	12	.224	.165	.028	2.83	−.6383
303	N. Lat. 26° 04′ W. Long. 96° 57′	15	.153	.028	.0014	10.45	−.5622
304	N. Lat. 26° 03.5′ W. Long. 96° 54.5′	15	.209	.167	.034	2.48	−.5935
305	N. Lat. 26° 02.5′ W. Long. 96° 52′	17	.223	.171	.087	1.60	−.1778
306	N. Lat. 26° 01.5′ W. Long. 96° 49.5′	20	1.55	.2	.0255	7.80	−.0052
307	N. Lat. 26° 00.5′ W. Long. 96° 47′	21	.0178	.0025	.00044	6.38	.0980
308	N. Lat. 25° 59.5′ W. Long. 96° 45′	22	.118	.0063	.00114	10.18	.5302
309	N. Lat. 25° 58.5′ W. Long. 96° 42.5′	22	.182	.135	.00223	9.03	−1.6527
310	N. Lat. 25° 57.5′ W. Long. 96° 40′	24	.17	.0136	.00212	8.96	.2900
311	N. Lat. 25° 56.6′ W. Long. 96° 38′	25	.252	.183	.137	1.36	.0128
312	N. Lat. 25° 55.5′ W. Long. 96° 35.5′	29	.17	.018	.00136	11.18	.1331
313	N. Lat. 25° 54.5′ W. Long. 96° 33.5′	32	.171	.127	.0025	8.28	−1.5768
314	N. Lat. 25° 53.5′ W. Long. 96° 31′	36	.034	.00495	.0009	6.15	.0969
315	N. Lat. 25° 29′ W. Long. 96° 32.5′	50	.0078	.0014	.00022	5.95	−.0580
316	N. Lat. 25° 40′ W. Long. 96° 30.5′	55					
317	N. Lat. 25° 40.5′ W. Long. 96° 36′	66	.0085	.00156	.00037	4.80	.1116
318	N. Lat. 25° 41.5′ W. Long. 96° 25.5′	85					
319	N. Lat. 25° 43.5′ W. Long. 96° 24.5′	81	.0036	.0009	.00024	3.87	.0278
320	N. Lat. 25° 46′ W. Long. 96° 23′	112	.00541	.00155	.000494	3.31	.0492
321	N. Lat. 25° 44.5′ W. Long. 96° 20.5′	200	.003	.00095	.000258	3.41	−.0665
322	N. Lat. 25° 43′ W. Long. 96° 18′	260	.0035	.00112	.000399	2.96	.0461
323	N. Lat. 25° 42′ W. Long. 96° 16′	290	.00315	.00086	.00023	3.70	−.0088
324	N. Lat. 25° 39′ W. Long. 96° 11.5′	410	.0038	.00134	.00046	2.87	−.0114
325	N. Lat. 25° 36.5′ W. Long. 96° 06.5′	490	.0027	.00088	.000174	3.94	−.2168
326	N. Lat. 25° 35′ W. Long. 96° 02′	570	.00284	.00092	.00031	3.03	.0170
327	N. Lat. 25° 32.5′ W. Long. 95° 57′	605	.0035	.00102	.0003	3.42	.0039
328	N. Lat. 25° 30′ W. Long. 95° 52′	600	.0031	.00094	.000353	2.97	.0934
329	N. Lat. 25° 28.5′ W. Long. 95° 47.5′	600	.00342	.00101	.00036	3.08	.0821
330	N. Lat. 25° 26′ W. Long. 95° 42.5′	610	.00321	.0011	.00039	2.87	.0149
331	N. Lat. 25° 24′ W. Long. 95° 38.5′	700	.00378	.00096			
332	N. Lat. 25° 21.5′ W. Long. 95° 34.5′	890	.0034	.0011	.000398	2.92	.0492
333	N. Lat. 25° 20′ W. Long. 95° 30′	880	.00365	.00103	.000355	3.21	.0835
334	N. Lat. 25° 20′ W. Long. 95° 26′	1270	.00361	.00123	.000495	2.70	.0719
335	N. Lat. 25° 08′ W. Long. 95° 05′	1880	.00597	.00201	.000798	2.74	.0715
336	N. Lat. 25° 00′ W. Long. 94° 38′	1930	.0092	.00243	.00091	3.18	.1514
337	N. Lat. 24° 49′ W. Long. 94° 08.5′	1950	.0067	.0017	.000661	3.18	.1853
338	N. Lat. 24° 39′ W. Long. 93° 45′	1985	.00377	.0012	.00046	2.86	.0810
339	N. Lat. 24° 31′ W. Long. 93° 23.5′	1940	.00296	.00094	.000364	2.85	.0860

Table 2 — Port Isabel II Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
302	N. Lat. 26° 05′ W. Long. 97° 00′	12	.224	.165	.028	2.83	−.6383
301	N. Lat. 26° 06′ W. Long. 96° 58.5′	14	.203	.15	.0056	6.02	−1.2168
300	N. Lat. 26° 07.5′ W. Long. 96° 57′	15	.195	.15	.027	2.69	−.6308
299	N. Lat. 26° 10′ W. Long. 96° 54.5′	18	.061	.0072	.00072	9.20	−.0716
298	N. Lat. 26° 11.5′ W. Long. 96° 52.5′	19	.0223	.00475	.00087	5.06	−.0655
297	N. Lat. 26° 13.5′ W. Long. 96° 50.5′	19	.0098	.00165	.0004	4.95	.1584
296	N. Lat. 26° 15.5′ W. Long. 96° 48.5′	20	.0235	.00454	.00087	5.20	−.0035
295	N. Lat. 26° 17.5′ W. Long. 96° 46′	21	.0109	.00161	.00379	5.46	.2028
294	N. Lat. 26° 19.5′ W. Long. 96° 44.5′	20	.0128	.00274	.00062	4.54	.0245
293	N. Lat. 26° 21′ W. Long. 96° 42.5′	22	.0079	.00152	.00036	4.69	.0899
292	N. Lat. 26° 23′ W. Long. 96° 40′	22	.21	.165	.0108	4.41	−1.0788
291	N. Lat. 26° 25′ W. Long. 96° 38.5′	24	.159	.0115	.00065	15.7	−.1068
290	N. Lat. 26° 26.5′ W. Long. 96° 37.5′	25	.219	.169	.098	1.49	−.1238
289	N. Lat. 26° 28.5′ W. Long. 96° 34.5′	27	.182	.148	.004	6.75	−1.4780
288	N. Lat. 26° 30.5′ W. Long. 96° 33′	32					

Table 2 — Port Isabel II Traverse — *Continued*

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
287	N. Lat. 26° 32′ W. Long. 96° 31′	38	.0069	.00133	.000307	4.74	.0781
286	N. Lat. 26° 34′ W. Long. 96° 29′	42	.0094	.0024	.000602	3.95	—.0079
285	N. Lat. 26° 35.5′ W. Long. 96° 27′	47	.0096	.00195	.00041	4.84	.0141
284	N. Lat. 26° 36.5′ W. Long. 96° 24′	50	.0107	.00305	.000722	3.85	—.0809
283	N. Lat. 26° 37′ W. Long. 96° 23′	58	.0064	.00137	.00034	4.34	.0645
282	N. Lat. 26° 37.5′ W. Long. 96° 22.5′	72	.00945	.00283	.00085	3.33	.0013
281	N. Lat. 26° 38′ W. Long. 96° 20.5′	95	.0041	.0011	.000317	3.60	.0306
280	N. Lat. 26° 38.5′ W. Long. 96° 20′	150	.0034	.001	.000298	3.38	.0056
279	N. Lat. 26° 38.5′ W. Long. 96° 18.5′	185					
278	N. Lat. 26° 29′ W. Long. 96° 07.5′	230	.00274	.00085	.000293	3.06	.0453
277	N. Lat. 26° 41′ W. Long. 96° 12′	320	.0031	.00089	.00028	3.33	.0406
276	N. Lat. 26° 43.5′ W. Long. 96° 05.5′	370	.00321	.00102	.000337	3.09	.0170
275	N. Lat. 26° 46′ W. Long. 95° 58′	403	.00413	.00105	.000326	3.56	.0864
274	N. Lat. 27° 49′ W. Long. 95° 51′	560	.00396	.0011	.000327	3.48	.0294
273	N. Lat. 26° 53′ W. Long. 95° 39.5′	535	.00262	.00084	.00026	3.18	—.0155

Table 3 — Aransas Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
240	N. Lat. 27° 46.3′ W. Long. 96° 56.5′	13					
241	N. Lat. 27° 43.0′ W. Long. 96° 53.5′	12	.0103	.0021	.000425	4.92	—.0044
242	N. Lat. 27° 41′ W. Long. 96° 52′	15	.0292	.00531	.000852	5.86	—.0535
243	N. Lat. 27° 39′ W. Long. 96° 51′	15	.063	.0258	.00178	5.93	—.7729
244	N. Lat. 27° 37′ W. Long. 96° 49.5′	17	.0328	.00648	.00093	5.94	—.1391
245	N. Lat. 27° 35′ W. Long. 96° 48′	20	.0245	.00415	.00047	7.23	—.1798
246	N. Lat. 27° 33′ W. Long. 96° 46′	23	.031	.0061	.00101	5.54	—.0752
247	N. Lat. 27° 31′ W. Long. 96° 45′	26	.031	.0055	.00069	6.71	—.1475
248	N. Lat. 27° 29′ W. Long. 96° 43.5′	26	.0209	.008	.00149	3.74	—.3134
249	N. Lat. 27° 27′ W. Long. 96° 42′	26	.019	.00315	.00055	5.88	.0237
250	N. Lat. 27° 25′ W. Long. 96° 40.5′	28	.0334	.00695	.00099	5.81	—.1643
251	N. Lat. 27° 23′ W. Long. 96° 39′	31	.008	.00155	.00024	5.77	—.0969
252	N. Lat. 27° 21.5′ W. Long. 96° 38′	33	.0178	.0049	.00101	4.20	—.1261
253	N. Lat. 27° 20′ W. Long. 96° 36′	38	.009	.00178	.000385	4.84	.0394
254	N. Lat. 27° 19′ W. Long. 96° 34.5′	40	.0115	.00318	.00074	3.94	—.0747
255	N. Lat. 27° 18′ W. Long. 96° 33.5′	43	.0078	.0016	.000352	4.71	.0302
256	N. Lat. 27° 17′ W. Long. 96° 31.5′	48	.00844	.00236	.00053	3.99	—.0947
257	N. Lat. 27° 16′ W. Long. 96° 30.5′	51	.0176	.0028	.00042	6.47	—.0297
258	N. Lat. 27° 15′ W. Long. 96° 29′	55	.0087	.00211	.000525	4.07	.0107
259	N. Lat. 27° 13.5′ W. Long. 96° 27.5′	60	.0114	.00177	.00041	5.27	.1732
260	N. Lat. 27° 12.5′ W. Long. 96° 26′	67	.0093	.0023	.000525	4.21	—.0348
261	N. Lat. 27° 12′ W. Long. 96° 24.5′	78	.0065	.00149	.00043	3.89	.1004
262	N. Lat. 27° 09.5′ W. Long. 96° 21.5′	105	.00605	.00183	.000499	3.48	—.0458
263	N. Lat. 27° 09′ W. Long. 96° 20′	125	.0067	.00167	.00037	4.25	—.0506
264	N. Lat. 27° 07.5′ W. Long. 96° 18.5′	160	.00475	.00148	.000415	3.38	—.0458
265	N. Lat. 27° 06.5′ W. Long. 96° 17.5′	195	.003	.00092	.00033	3.02	.0682
266	N. Lat. 27° 05.5′ W. Long. 96° 16′	235	.0056	.00188	.00541	3.22	—.0660
267	N. Lat. 27° 04.5′ W. Long. 96° 14.5′	265	.00345	.00115	.00038	3.01	—.0039
268	N. Lat. 27° 03.5′ W. Long. 96° 13′	290					
269	N. Lat. 27° 01.5′ W. Long. 96° 08′	370	.00308	.00102	.00034	3.01	.0212
270	N. Lat. 26° 58.5′ W. Long. 96° 03′	415	.0042	.00113	.000454	3.04	.1735
271	N. Lat. 26° 56′ W. Long. 95° 58′	452	.00278	.00089	.00033	2.91	.0641
272	N. Lat. 26° 53.5′ W. Long. 95° 53′	500	.0031	.001	.000295	3.24	—.0389
273	N. Lat. 26° 53′ W. Long. 95° 39.5′	535	.00262	.00084	.00026	3.18	—.0155

Table 4 — Matagorda I Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
199	N. Lat. 28° 17.5′ W. Long. 96° 23.5′	8	.114	.078	.032	1.88	—.2218
200	N. Lat. 28° 15.5′ W. Long. 96° 23′	10	.072	.0202	.00214	5.80	—.4237
201	N. Lat. 28° 13.5′ W. Long. 96° 23′	12	.02	.00455	.000755	5.15	—.1373
202	N. Lat. 28° 12′ W. Long. 96° 22.5′	13	.0895	.0301	.0023	6.24	—.6440

Table 4 — Matagorda I Traverse — *Continued*

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
203	N. Lat. 28° 09.5′ W. Long. 96° 22.5′	13	.0268	.00555	.000757	5.95	−.1818
204	N. Lat. 28° 07.5′ W. Long. 96° 22′	14	.107	.0662	.016	2.59	−.4089
205	N. Lat. 28° 05.5′ W. Long. 96° 21.5′	15	.092	.042	.00501	4.29	−.5834
206	N. Lat. 28° 03′ W. Long. 96° 21′	17	.078	.039	.00561	3.73	−.5413
207	N. Lat. 28° 01′ W. Long. 96° 21′	17	.056	.0298	.00195	5.36	−.9101
208	N. Lat. 27° 58.5′ W. Long. 96° 20.5′	19	.092	.0692	.0382	1.55	−.1343
209	N. Lat. 27° 57′ W. Long. 96° 20.5′	20	.0706	.027	.00435	4.03	−.3757
210	N. Lat. 27° 55′ W. Long. 96° 20′	21	.092	.072	.0444	1.44	−.1040
211	N. Lat. 27° 52.5′ W. Long. 96° 20′	26	.0364	.0103	.00188	4.40	−.1911
212	N. Lat. 27° 50.5′ W. Long. 96° 19′	28	.028	.0072	.0012	4.83	−.1884
213	N. Lat. 27° 48′ W. Long. 96′ 19′	32	.0371	.0094	.0014	5.15	−.2306
214	N. Lat. 27° 45.5′ W. Long. 96° 18.5′	33	.034	.0127	.00228	3.86	−.3188
215	N. Lat. 27° 43.5′ W. Long. 96° 18′	35	.026	.00638	.00138	4.34	−.0540
216	N. Lat. 27° 41.5′ W. Long. 96° 18′	38	.029	.00822	.00189	3.92	−.0904
217	N. Lat. 27° 39′ W. Long. 96° 17.5′	42	.0186	.00522	.00105	4.22	−.1451
218	N. Lat. 27° 37′ W. Long. 96° 17.5′	46	.0251	.00473	.00098	5.06	.0410
219	N. Lat. 27° 34.5′ W. Long. 96° 17′	49	.0504	.0144	.00229	4.69	−.1278
220	N. Lat. 27° 32.5′ W. Long. 96° 16.5′	54	.0158	.00364	.00074	4.63	−.0540
221	N. Lat. 27° 30′ W. Long. 96° 16′	59	.0152	.00399	.00112	3.69	.0294
222	N. Lat. 27° 28′ W. Long. 96° 15.5′	65	.0097	.00258	.00068	3.78	−.0039
223	N. Lat. 27° 25.5′ W. Long. 96° 15.5′	73	.0076	.0023	.00066	3.39	−.0232
224	N. Lat. 27° 23′ W. Long. 96° 15′	83	.00743	.00201	.000615	3.48	.0561
225	N. Lat. 27° 21′ W. Long. 96° 14.5′	94	.00643	.002	.000598	3.28	−.0173
226	N. Lat. 27° 19′ W. Long. 96° 14.5′	110	.006	.00194	.000625	3.10	−.0117
227	N. Lat. 27° 16.5′ W. Long. 96° 14′	135	.00561	.00195	.00625	3.00	−.0357
228	N. Lat. 27° 14′ W. Long. 96° 13.5′	165	.0067	.00229	.00072	3.05	−.0367
229	N. Lat. 27° 12′ W. Long. 96° 13.5′	196	.0054	.0017	.00049	3.32	−.0381
230	N. Lat. 27° 09.5′ W. Long. 96° 13′	227	.0065	.00247	.00083	2.80	−.0535
231	N. Lat. 27° 07′ W. Long. 96° 12.5′	263	.007	.00178	.00048	3.82	.0257
232	N. Lat. 27° 04.5′ W. Long. 96° 12′	276	.00625	.00208	.00072	2.95	.0170
233	N. Lat. 27° 02.5′ W. Long. 96° 11.5′	290	.0047	.0016	.000465	3.18	−.0685
234	N. Lat. 27° 00′ W. Long. 96° 11.5′	270	.00564	.00183	.00052	3.29	−.0575
235	N. Lat. 26° 58.5 W. Long. 96° 11′	260	.00435	.00138	.000375	3.41	−.0670
236	N. Lat. 26° 56′ W. Long. 96° 11′	290	.00335	.00113	.00041	2.86	.0326
237	N. Lat. 26° 54′ W. Long. 96° 10.5′	350					
238	N. Lat. 26° 52′ W. Long. 96° 10′	360	.0052	.00191	.00045	3.34	−.1925

Table 5 — Matagorda II Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
199	N. Lat. 28° 17.5′ W. Long. 96° 23.5′	8	.114	.078	.032	1.88	−.2218
198	N. Lat. 28° 16′ W. Long. 96° 22′	11	.0645	.0248	.00249	5.09	−.5833
197	N. Lat. 28° 15′ W. Long. 96° 20.5′	12	.0249	.00478	.00054	6.79	−.2306
196	N. Lat. 28° 13′ W. Long. 96° 19′	13	.0178	.00404	.00085	4.58	−.0329
195	N. Lat. 28° 12′ W. Long. 96° 18′	13	.084	.047	.0089	3.07	−.4711
194	N. Lat. 28 10.5′ W. Long. 96° 16.5′	13	.089	.0353	.0041	4.66	−.5287
193	N. Lat. 28° 09′ W. Long. 96° 15′	14	.094	.046	.00215	6.62	−1.0200
192	N. Lat. 28° 07.5′ W. Long. 96° 14′	15	.08	.058	.0244	1.81	−.2358
191	N. Lat. 28° 06′ W. Long. 96° 12.5′	16	.0775	.025	.00165	6.86	−.6904
190	N. Lat. 28° 04′ W. Long. 96° 11′	18	.087	.0363	.0048	4.26	−.4989
189	N. Lat. 28° 03′ W. Long. 96° 10′	19	.076	.038	.00326	4.83	−.7667
188	N. Lat. 28° 01.5′ W. Long. 96° 08.5′	20	.088	.026	.0039	4.75	−.2941
187	N. Lat. 28° 00′ W. Long. 96° 07′	22	.0401	.0123	.00112	5.98	−.5272
186	N. Lat. 27° 58.5′ W. Long. 96° 06′	23	.076	.042	.00682	3.34	−.5317
185	N. Lat. 27° 57′ W. Long. 96° 04.5′	26	.118	.054	.00445	5.15	−.7447
184	N. Lat. 27° 56′ W. Long. 96° 03′	27	.058	.0163	.00237	4.95	−.2857
183	N. Lat. 27° 54′ W. Long. 96° 02′	29	.126	.0495	.0036	5.92	−.7328
182	N. Lat. 27° 52.5′ W. Long. 96° 00.5′	31	.158	.115	.052	1.74	−.2069
181	N. Lat. 27° 51′ W. Long. 95° 59′	31	.15	.105	.0259	2.41	−.4522
180	N. Lat. 27° 49.5′ W. Long. 95° 57′	32	.32	.198	.129	1.58	.0212

Table 5 — Matagorda II Traverse — *Continued*

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
179	N. Lat. 27° 48′ W. Long. 95° 56′	34	1.168	.219	.147	2.82	−.4461
178	N. Lat. 27° 46′ W. Long. 95° 54′	34	.25	.168	.0883	1.68	−.1079
177	N. Lat. 27° 44.5′ W. Long. 95° 52.5′	38	.284	.203	.131	1.47	−.0438
176	N. Lat. 27° 43′ W. Long. 95° 51.5′	45	.147	.0451	.0136	3.29	−.0074
175	N. Lat. 27° 41.5′ W. Long. 95° 50′	50	.096	.0353	.004	4.90	−.5107
174	N. Lat. 27° 40′ W. Long. 95° 48.5′	70	.019	.00455	.00077	4.97	−.1506
173	N. Lat. 27° 38.5′ W. Long. 95° 47′	116	.0113	.0015	.000351	5.68	.2467
172	N. Lat. 27° 37′ W. Long. 95° 45.5′	193	.0065	.00181	.00059	3.32	.0682
171	N. Lat. 27° 35.5′ W. Long. 95° 44.5′	250	.0025	.0008	.000257	3.12	.0013
170	N. Lat. 27° 34′ W. Long. 95° 43′	310	.00617	.00192	.0006	3.21	.0017
169	N. Lat. 27° 32.5′ W. Long. 95° 41.5′	350	.003	.00082			
168	N. Lat. 27° 22′ W. Long. 95° 33′	470	.00435	.00108	.00034	3.58	.1031
167	N. Lat. 27° 12′ W. Long. 95° 28′	550	.00435	.00116	.00037	3.44	.0774
166	N. Lat. 27° 02.5′ W. Long. 95° 23′	685	.0037	.001	.00033	3.35	.0867
165	N. Lat. 26° 52′ W. Long. 95° 17.5′	790	.004	.0017	.000429	3.05	−.2262
164	N. Lat. 26° 42′ W. Long. 95° 12.5′	825	.0028	.00097	.00039	2.68	.0645

Table 6 — Brazos I Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
95	N. Lat. 28° 44′ W. Long. 95° 18′	13	.23	.157	.0194	3.44	−.7423
96	N. Lat. 28° 42.5′ W. Long. 95° 18.5′	12	.137	.077	.0114	3.47	−.5800
97	N. Lat. 28° 40.5′ W. Long. 95° 19′	12	.129	.0785	.0176	2.71	−.4342
98	N. Lat. 28° 38.5′ W. Long. 95° 19′	13	.046	.013	.00138	5.78	−.4248
99	N. Lat. 28° 36′ W. Long. 95° 19.5′	13	.079	.0282	.00301	5.12	−.5243
100	N. Lat. 28° 34′ W. Long. 95° 20′	14	.095	.0485	.0095	3.16	−.3969
101	N. Lat. 28° 32.5′ W. Long. 95° 20′	15	.084	.026	.0033	5.04	−.3872
102	N. Lat. 28° 30.5′ W. Long. 95° 20.5′	16	.106	.073	.0108	3.13	−.6716
103	N. Lat. 28° 28.5′ W. Long. 95° 21′	17	.067	.024	.0027	4.98	−.5031
104	N. Lat. 28° 26.5′ W. Long. 95° 21.5′	18	.046	0.2	.0016	5.37	−.7352
105	N. Lat. 28° 24.5′ W. Long. 95° 21.5′	18	.136	.099	.047	1.70	−.1858
106	N. Lat. 28° 22.5′ W. Long. 95° 21.5′	19	.11	.072	.023	2.19	−.3143
107	N. Lat. 28° 21′ W. Long. 95° 22′	15	.14	.075	.0393	1.89	−.0088
108	N. Lat. 28° 18.5′ W. Long. 95° 22.5′	17	.122	.064	.0168	2.69	−.3002
109	N. Lat. 28° 16′ W. Long. 95° 23′	18	.0844	.0441	.0149	2.38	−.1898
110	N. Lat. 28° 14′ W. Long. 95° 23′	19	.104	.0375	.0036	5.38	−.5751
111	N. Lat. 28° 12′ W. Long. 95° 23.5′	21	.105	.044	.0066	3.99	−.4461
112	N. Lat. 28° 09.5′ W. Long. 95° 24′	25	.079	.019	.00142	7.46	−.5031
113	N. Lat. 28° 07′ W. Long. 95° 24.5′	24	.122	.042	.0052	4.84	−.4449
114	N. Lat. 28° 05′ W. Long. 95° 24.5′	26	.136	.041	.0034	6.33	−.5702
115	N. Lat. 28° 01′ W. Long. 95° 23′	31	.145	.092	.0147	3.14	−.5986
116	N. Lat. 27° 58′ W. Long. 95° 22′	34	.145	.107	.02	2.69	−.5969
117	N. Lat. 27° 56′ W. Long. 95° 20.5′	40	.144	.096	.012	3.46	−.7256
118	N. Lat. 27° 43.5′ W. Long. 95° 17.5′	147	.00295	.00089	.00046	2.53	.2393
119	N. Lat. 27° 36.5′ W. Long. 95° 15′	403	.0047	.00114	.000411	3.38	.1720
120	N. Lat. 27° 32′ W. Long. 95° 14′	525	.0029	.00102	.00033	2.97	−.0362
121	N. Lat. 27° 22.5′ W. Long. 95° 19′	588	.00326	.00117	.000447	2.70	.0273
122	N. Lat. 27° 16′ W. Long. 95° 06′	625	.00262	.000863	.000353	2.72	.0810
123	N. Lat. 27° 09.5′ W. Long. 95° 03′	750	.00365	.00127	.000449	2.85	.0069
124	N. Lat. 27° 03′ W. Long. 95° 00′	775	.00336	.00103	.00037	3.01	.0682
125	N. Lat. 26° 56.5′ W. Long. 94° 57′	725	.0037	.00135	.0005	2.72	.0065
126	N. Lat. 26° 50′ W. Long. 95° 00′	740	.00306	.00113	.00047	2.55	.0864
127	N. Lat. 26° 45.5′ W. Long. 94° 56′	740	.00395	.00141	.0005	2.81	−.0031
128	N. Lat. 26° 39′ W. Long. 94° 48′	845	.00316	.00099	.00039	2.85	.0997
129	N. Lat. 26° 33′ W. Long. 94° 40′	980	.00405	.00125	.00035	3.41	−.0424
130	N. Lat. 26° 27′ W. Long. 94° 31′	1310					
131	N. Lat. 26° 21′ W. Long. 94° 23′	920	.0037	.0015	.00039	3.08	−.1925

Table 7 — Brazos II Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
95	N. Lat. 28° 44′ W. Long. 95° 18′	13	.23	.157	.0194	3.44	−.7423
94	N. Lat. 28° 42′ W. Long. 95° 17′	13	.011	.0027	.00076	3.81	.1038
93	N. Lat. 28° 40.5′ W. Long. 95° 16′	13	.0664	.0232	.00246	5.20	−.5179
92	N. Lat. 28° 39′ W. Long. 95° 14.5′	14	.095	.053	.0053	4.23	−.7471
91	N. Lat. 28° 37′ W. Long. 95° 13′	15	.121	.09	.034	1.89	−.2941
90	L. Lat. 28° 35′ W. Long. 95° 12′	16	.105	.082	.0355	1.72	−.2596
89	N. Lat. 28° 33.5′ W. Long. 95° 11′	16	.101	.066	.0204	2.23	−.3242
88	N. Lat. 28° 31′ W. Long. 95° 09.5′	17	.112	.084	.014	2.83	−.6536
87	N. Lat. 28° 29′ W. Long. 95° 08′	17	.071	.0358	.0058	3.50	−.4935
86	N. Lat. 28° 27′ W. Long. 95° 07′	17	.092	.0445	.0037	4.98	−.7645
85	N. Lat. 28° 25.5′ W. Long. 95° 05.5′	17	.142	.098	.0234	2.46	.5391
84	N. Lat. 28° 23′ W. Long. 95° 04′	17	.160	.109	.043	1.93	−.2366
83	N. Lat. 28° 21.5′ W. Long. 95° 03′	17	2.6	1.35	.62	2.05	−.0531
82	N. Lat. 28° 19.5′ W. Long. 95° 02′	20	.132	.104	.022	2.45	−.5702
81	N. Lat. 28° 17.5′ W. Long. 95° 01′	22	.154	.103	.0256	2.45	−.4306
80	N. Lat. 28° 16.5′ W. Long. 94° 59′	23	.078	.017	.00118	8.13	−.5003
79	N. Lat. 28° 14′ W. Long. 94° 58′	24	.189	.132	.0904	1.45	−.0088
78	N. Lat. 28° 11′ W. Long. 94° 57′	28	1.4	.179	.123	3.38	.7300
77	N. Lat. 28° 08.5′ W. Long. 94° 56′	26	1.168	.19	.143	2.86	.6656
76	N. Lat. 28° 06′ W. Long. 94° 55′	28	.0178	.0142	.01	1.33	−.0535
75	N. Lat. 28° 03.5′ W. Long. 94° 54′	31	.2	.12	.0935	1.46	.1139
74	N. Lat. 28° 01.5′ W. Long. 94° 52′	40	.117	.052	.00274	6.54	−.9259
73	N. Lat. 27° 59′ W. Long. 94° 52′	46	.089	.036	.00354	5.02	−.6198
72	N. Lat. 27° 57′ W. Long. 94° 50.5′	50	.033	.0106	.00102	5.93	−.5229
71	N. Lat. 27° 54.5′ W. Long. 94′ 50′	53	.044	.0092	.00146	5.49	−.1192
70	N. Lat. 27° 52′ W. Long. 94° 48.5′	65	.02	.00405	.00087	4.80	.0253
69	N. Lat. 27° 50′ W. Long. 94° 47′	87	.00864	.00201	.000579	3.86	.0931
68	N. Lat. 27° 47′ W. Long. 94° 46′	125	.0039	.00125	.00045	2.94	.0492
67	N. Lat. 27° 45′ W. Long. 94° 45′	175					
66	N. Lat. 27° 41.5′ W. Long. 94° 44′	218	.003	.00108	.00062	2.2	.2036
58	N. Lat. 27° 35′ W. Long. 94° 35′	483	.0048	.00182	.00139	1.84	.3054
57	N. Lat. 27° 33′ W. Long. 94° 33′	400	.0030	.00123			
56	N. Lat. 27° 31′ W. Long. 94° 31′	475	.0046	.0015	.00076	2.46	.1903
55	N. Lat. 27° 28.5′ W. Long. 94° 29′	380	.005	.00126	.0004	3.54	.1004
54	N. Lat. 27° 26′ W. Long. 94° 27′	533	.0031	.00105	.00038	2.92	.0334
53	N. Lat. 27° 22.5′ W. Long. 94° 24.5′	770	.0043	.00134	.00043	3.16	.0124
52	N. Lat. 27° 19′ W. Long. 94° 22′	750	.00264	.00106	.0042	2.51	−.0061
51	N. Lat. 27° 14′ W. Long. 94° 20′	500	.00654	.00171	.000572	3.38	.1072
50	N. Lat. 27° 09′ W. Long. 94° 17′	500	.0036	.00116	.00044	2.86	.0719
49	N. Lat. 27° 05′ W. Long. 94° 15′	520	.0033	.001			
48	N. Lat. 27° 11′ W. Long. 94° 11′	510	.0052	.00168	.000564	3.03	.0170
349	N. Lat. 26° 56′ W. Long. 94° 08.5′	1020	.0072	.00168	.0005	3.80	.1059
348	N. Lat. 26° 50.5′ W. Long. 94° 06′	710	.00355	.00118	.000445	2.83	−.0555
347	N. Lat. 26° 45′ W. Long. 94° 04′	660	.0033	.00108	.000388	2.92	.0410
346	N. Lat. 26° 39′ W. Long. 94° 02′	730	.00313	.00096	.000367	2.92	.0962
345	N. Lat. 26° 33.5′ W. Long. 94° 00′	830	.0033	.00101	.000375	2.97	.0828
344	N. Lat. 26° 27.5′ W. Long. 93° 58′	810	.00298	.000935	.000312	3.09	.0261
343A	N. Lat. 26° 21′ W. Long. 93° 56′	900	.0034	.00103	.000234	3.81	−.1249
135	N. Lat. 26° 12′ W. Long. 93° 53′	940	.00645	.00226	.000531	3.49	−.1733
136	N. Lat. 26° 09′ W. Long. 93° 47′	1500	.0058	.00168	.00057	3.19	.0682
137	N. Lat. 26° 09′ W. Long. 93° 47′	1540	.00487	.00116	.000419	3.41	.1810
138	N. Lat. 26° 00′ W. Long. 93° 38′	1679	.0036	.00101	.00035	3.21	.0913
139	N. Lat. 25° 52′ W. Long. 93° 28.5′	1725	.00448	.00133	.000488	3.03	.0920
140	N. Lat. 25° 43.5′ W. Long. 93° 26′	1790	.00523	.00172	.00065	2.84	.0603
141	N. Lat. 25° 34′ W. Long. 93° 17′	1850					
142	N. Lat. 25° 27′ W. Long. 93° 10′	1775	.0055	.00181	.00066	2.89	.0449
143	N. Lat. 25° 05′ W. Long. 92° 57′	1930	.00716	.00195	.000703	3.19	.1212
144	N. Lat. 24° 42′ W. Long. 92° 44′	1970					
145	N. Lat. 24° 13′ W. Long. 92° 20′	1985	.0087	.00195	.000725	3.46	.2201

Table 8 — Galveston Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
405	N. Lat. 29° 19′ W. Long. 94° 40′	9	.106	.0645	.0028	6.15	−1.1463
404	N. Lat. 29° 17.5′ W. Long. 94° 39′	9	.068	.0095	.00125	7.38	−.0250
403	N. Lat. 29° 15.5′ W. Long. 94° 38′	9	.261	.142	.034	2.77	−.3565
402	N. Lat. 29° 13.5′ W. Long. 94° 38.5′	11	.15	.0565	.005	5.48	−.6289
401	N. Lat. 29° 12′ W. Long. 94° 39′	11	.106	.0365	.00243	6.60	−.7144
400	N. Lat. 29° 10′ W. Long. 94° 39.5′	11					
399	N. Lat. 29° 08′ W. Long. 94° 40′	11					
398	N. Lat. 29° 06′ W. Long. 94° 40.5′	11	.0465	.0275	.00217	4.63	−.8755
397	N. Lat. 29° 03′ W. Long. 94° 41′	12	.0315	.0102	.00073	6.57	−.6556
396	N. Lat. 29° 02′ W. Long. 94° 41.5′	7	.0923	.0525	.0165	2.37	−.2573
394	N. Lat. 28° 59′ W. Long. 94° 42.5′	9					
393	N. Lat. 28° 57.5′ W. Long. 94° 43′	9	1.03	.75	.522	1.40	−.0195
392	N. Lat. 28° 55.5′ W. Long. 94° 44′	10	.113	.08	.0201	2.37	−.4498
391	N. Lat. 28° 53.5′ W. Long. 94° 45′	11	.129	.099	.0701	1.36	−.0357
390	N. Lat. 28° 51.5′ W. Long. 94° 45.5′	11	.136	.108	.0599	1.51	−.1561
389	N. Lat. 28° 50′ W. Long. 94° 45.5′	12	.134	.108	.079	1.30	−.0424
388	N. Lat. 28° 48′ W. Long. 94° 45′	12	.118	.096	.0598	1.41	−.1163
387	N. Lat. 28° 46′ W. Long. 94° 45′	12	.151	.109	.0667	1.50	−.0716
386	N. Lat. 28° 44.5′ W. Long. 94° 45′	12	.123	.09	.0491	1.58	−.1278
385	N. Lat. 28° 42.5′ W. Long. 94° 44.5′	15	.123	.094	.045	1.65	−.2034
384	N. Lat. 28° 41′ W. Long. 94° 44.5′	16	.113	.088	.036	1.77	−.2798
383	N. Lat. 28° 39.5′ W. Long. 94° 44′	17	.112	.067	.0072	3.94	−.7457
382	N. Lat. 28° 37.5′ W. Long. 94° 44′	13	.123	.0855	.0235	2.29	−.4030
381	N. Lat. 28° 36′ W. Long. 94° 44′	13	.125	.0855	.0374	1.83	−.1945
380	N. Lat. 28° 34′ W. Long. 94° 43.5′	15	.132	.0763	.018	2.71	−.3904
379	N. Lat. 28° 32.5′ W. Long. 94° 43.5′	16	.131	.081	.0161	2.85	−.4921
378	N. Lat. 28° 31′ W. Long. 94° 43′	17	.125	.06	.0126	3.15	−.3595
377	N. Lat. 28° 29.5′ W. Long. 94° 43′	17	.142	.099	.0246	2.40	−.4486
376	N. Lat. 28° 27.5′ W. Long. 94° 42.5′	18	.143	.0945	.0243	2.43	−.4101
375	N. Lat. 28° 26′ W. Long. 94° 42.5′	19	.168	.125	.060	1.67	−.1904
374	N. Lat. 28° 24′ W. Long. 94° 42.5′	19	.127	.077	.0142	2.99	−.5280
373	N. Lat. 28° 22′ W. Long. 94° 42′	22	.157	.114	.0535	1.72	−.1898
372	N. Lat. 28° 20.5′ W. Long. 94° 42′	23	.138	.103	.0385	1.89	−.3010
371	N. Lat. 28° 18.5′ W. Long. 94° 42′	24	.16	.123	.064	1.58	−.1688
370	N. Lat. 28° 16.5′ W. Long. 94° 42′	25	.138	.097	.0235	2.42	−.4634
369	N. Lat. 28° 15′ W. Long. 94° 41.5′	23	.143	.0975	.0255	2.37	−.4157
368	N. Lat. 28° 13′ W. Long. 94° 41.5′	30	.5	.167	.116	2.08	.3181
367	N. Lat. 28° 10.5′ W. Long. 94° 40′	30	.208	.188	.142	1.21	−.0778
366	N. Lat. 28° 08′ W. Long. 94° 38.5′	31	.202	.178	.123	1.28	−.0996
365	N. Lat. 28° 05′ W. Long. 94° 37.5′	35	.2	.15	.106	1.38	−.0255
364	N. Lat. 28° 02.5′ W. Long. 94° 36′	32	.192	.152	.112	1.31	−.0311
363	N. Lat. 27° 59.5′ W. Long. 94° 34.5′	38	.137	.109	.0685	1.41	−.1024
362	N. Lat. 27° 56.5′ W. Long. 94° 33′	48	.076	.0261	.00368	4.55	−.3862
361	N. Lat. 27° 54′ W. Long. 94° 31.5′	57	.0119	.0026	.00056	4.61	−.0061
360	N. Lat. 27° 50.5′ W. Long. 94° 30′	100	.0075	.00141	.000291	5.08	.0414
359	N. Lat. 27° 48′ W. Long. 94° 28.5′	167	.00538	.00115	.000319	4.11	.1133
358	N. Lat. 27° 45′ W. Long. 94° 27′	163	.0058	.00133	.000335	4.16	.0414
357	N. Lat. 27° 40′ W. Long. 94° 25′	168	.032	.0034	.000521	7.84	.1587
356	N. Lat. 27° 35′ W. Long. 94° 22.5′	365	.0045	.00088	.000243	4.30	.1498
355	N. Lat. 27° 30′ W. Long. 94° 20′	420	.00467	.00104	.00028	4.09	.0821
354	N. Lat. 27° 25′ W. Long. 94° 18′	625	.00363	.00109	.00039	3.05	.0755
353	N. Lat. 27° 20′ W. Long. 94° 15.5	725	.0043	.00113	.00037	3.41	.0962
352	N. Lat. 27° 15′ W. Long. 94° 13′	880	.0371	.0086	.000899	6.43	−.3458
351	N. Lat. 27° 10′ W. Long. 94° 10.5′	810	.0075	.00186	.000415	4.25	−.0458
350A	N. Lat. 27° 05′ W. Long. 94° 08′	520	.00298	.00102	.000351	2.92	.0022
350	N. Lat. 27° 01.5′ W. Long. 94° 10′	650	.00317	.00108	.000386	2.87	.0212
349	N. Lat. 26° 56 W. Long. 94° 08.5′	1020	.0072	.00168	.0005	3.80	.1059
348	N. Lat. 26° 50.5′ W. Long. 94° 06′	710	.00355	.00118	.000445	2.83	−.0555

Table 8 — Galveston Traverse — *Continued*

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
347	N. Lat. 26° 45′ W. Long. 94° 04′	660	.0033	.00108	.000388	2.92	.0410
346	N. Lat. 26° 39′ W. Long. 94° 02′	730	.00313	.00096	.000367	2.92	.0962
345	N. Lat. 26° 33.5′ W. Long. 94° 00′	830	.0033	.00101	.000375	2.97	.0828
344	N. Lat. 26° 27.5′ W. Long. 93° 58′	810	.00298	.000935	.000312	3.09	.0261
343A	N. Lat. 26° 21′ W. Long. 93° 56′	900	.0034	.00103	.000234	3.81	−.1249
343	N. Lat. 26° 11′ W. Long. 93° 54′	1050	.125	.025	.00119	10.25	−.6234
342	N. Lat. 25° 45′ W. Long. 93° 52′	1750	.00342	.0011	.000386	2.98	.0374
341	N. Lat. 25° 19′ W. Long. 93° 40′	1900	.00314	.00101	.000368	2.92	.0538
340	N. Lat. 24° 55′ W. Long. 93° 31′	1950					
339	N. Lat. 24° 31′ W. Long. 93° 23.5′	1950	.00296	.00094	.000364	2.85	.0860

Table 9 — Sigsbee Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
153	N. Lat. 26° 42′ W. Long. 92° 59′	820	.0573	.0115	.00197	5.39	−.0691
152	N. Lat. 26° 32′ W. Long. 92° 57′	896					
151	N. Lat. 26° 22′ W. Long. 92° 54′	1000	.0143	.00206	.000671	4.62	.3541
150	N. Lat. 26° 12.5′ W. Long. 92° 52′	1040	.0062	.00212	.00082	2.75	.0535
149	N. Lat. 25° 46′ W. Long. 92° 47.5′	1650	.0056	.00191	.000464	3.48	−.1481
148	N. Lat. 25° 33′ W. Long. 92° 45′	1852					
147	N. Lat. 25° 07′ W. Long. 92° 35′	1879	.00565	.00164	.000625	3.01	.1179
146	N. Lat. 24° 41′ W. Long. 92° 24′	1985	.00337	.00117	.000492	2.62	.0828
145	N. Lat. 24° 13′ W. Long. 92° 20′	1985	.0087	.00195	.000725	3.46	.2201

Table 10 — Heald Bank Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
1	N. Lat. 28° 57′ W. Long. 94° 18.5′	11					
2	N. Lat. 28° 55′ W. Long. 94° 18.3′	12					
3	N. Lat. 28° 52.5′ W. Long. 94° 17.8′	13					
4	N. Lat. 28° 50′ W. Long. 94° 17.5′	13					
5	N. Lat. 28° 48.2′ W. Long. 94° 17′	14					
6	N. Lat. 28° 46.5′ W. Long. 94° 16.7′	14					
7	N. Lat. 28° 44.5′ W. Long. 94° 16.3′	15	.112	.082	.009	3.52	−.8239
8	N. Lat. 28° 42.3′ W. Long. 94° 16′	16	.11	.05	.006	4.28	−.4216
9	N. Lat. 28° 40.3′ W. Long. 94° 15.3′	17	.093	.036	.0049	4.36	−.4559
10	N. Lat. 28° 38.5′ W. Long. 94° 15′	18	.106	.056	.0029	6.05	−.0088
11	N. Lat. 28° 36′ W. Long. 94° 14.7′	18	.12	.054	.0026	6.71	−.9706
12	N. Lat. 28° 34′ W. Long. 94° 14′	21	.128	.082	.008	3.91	−.7212
13	N. Lat. 28° 31.5′ W. Long. 94° 13.8′	21	.14	.102	.013	3.29	−.7696
14	N. Lat. 28° 29.3′ W. Long. 94° 13.5′	22	.145	.084	.072	2.03	.1703
15	N. Lat. 28° 27′ W. Long. 94° 13′	22	.171	.121	.047	1.91	−.2612
16	N. Lat. 28° 24.5′ W. Long. 94° 12.8′	24	.15	.071	.0044	5.84	−.8861
17	N. Lat. 28° 22′ W. Long. 94° 12′	25	.123	.0405	.00465	5.14	−.4584
18	N. Lat. 28° 19′ W. Long. 94° 12′	25	.164	.086	.0025	8.09	−.2967
19	N. Lat. 28° 16.8′ W. Long. 94° 11′	25	.232	.159	.0466	2.23	−.3686
20	N. Lat. 28° 15′ W. Long. 94° 10.3′	26	1.77	.365	.038	6.83	−.1976
21	N. Lat. 28° 13′ W. Long. 94° 09.5′	26	.268	.148	.086	1.77	.0216
22	N. Lat. 28° 11.5′ W. Long. 94° 08.7′	30	.21	.143	.075	1.67	−.1135
23	N. Lat. 28° 09.5′ W. Long. 94° 07.5′	31	.18	.128	.096	1.37	.0224
24	N. Lat. 28° 07.7′ W. Long. 94° 07′	33	.194	.15	.08	1.56	−.1612
25	N. Lat. 28° 06′ W. Long. 94° 06′	33	.203	.161	.113	1.34	−.0531
26	N. Lat. 28° 03′ W. Long. 94° 04.7′	33	.18	.106	.0156	3.39	−.6021
27	N. Lat. 28° 00.7′ W. Long. 94° 03′	37	.231	.172	.148	1.25	.0626
28	N. Lat. 27° 59.5′ W. Long. 94° 03′	43	.137	.098	.032	2.07	−.3410
29	N. Lat. 27° 56.3′ W. Long. 94° 02′	45	.144	.131	.105	1.17	−.0550
30	N. Lat. 27° 54.5′ W. Long. 94° 01′	58	.095	.058	.0155	2.50	−.3768
31	N. Lat. 27° 52′ W. Long. 94° 00′	112	.0124	.00203	.000418	5.45	.1000
32	N. Lat. 27° 49.5′ W. Long. 93° 58.5′	155	.0042	.0011	.00038	3.33	.1206
33	N. Lat. 27° 47.3′ W. Long. 93° 57.7′	178	.0032	.0012	.0004	2.83	−.0506
34	N. Lat. 27° 45′ W. Long. 93° 56.7′	221	.0035	.00113	.00041	2.96	.1239

Table 10 — Heald Bank Traverse — *Continued*

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
35	N. Lat. 27° 42.5′ W. Long. 93° 55.5′	375	.0059	.00119	.00402	3.83	.2240
36	N. Lat. 27° 38′ W. Long. 93° 53′	386	.0027	.00107	.0004	2.60	—.0246
37	N. Lat. 27° 33′ W. Long. 93° 53′	420	.00277	.000925	.000321	2.94	.0166
38	N. Lat. 27° 28′ W. Long. 93° 53′	500	.0041	.0015	.00041	3.16	—.1261
39	N. Lat. 27° 23.5′ W. Long. 93° 53′	480	.00341	.00106	.000441	2.78	.1271
40	N. Lat. 27° 19′ W. Long. 93° 53′	425	.0033	.0011	.0004	2.87	.0374
41	N. Lat. 27° 15′ W. Long. 93° 53′	450	.00351	.001	.00035	3.17	.0892
42	N. Lat. 27° 10.5′ W. Long. 93° 53′	630	.004	.0012	.00044	3.02	.0864
43	N. Lat. 27° 06′ W. Long. 93° 53′	630	.00358	.00112	.00038	3.07	.0349

Table 11 — Trinity Shoal I Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
406	N. Lat. 29° 09′ W. Long. 92° 39′	11	.143	.051	.017	2.90	—.0292
407	N. Lat. 29° 07′ W. Long. 92° 40′	12	.0725	.027	.007	3.22	—.1574
408	N. Lat. 29° 05′ W. Long. 92° 41′	13	.12	.035	.0032	6.12	—.5058
409	N. Lat. 29° 03′ W. Long. 92° 41′	14	.085	.0292	.00354	4.90	—.4522
410	N. Lat. 29° 01′ W. Long. 92° 42′	14	.158	.043	.0156	3.18	.1193
411	N. Lat. 28° 59′ W. Long. 92° 43′	14	.206	.168	.0454	2.13	—.4802
412	N. Lat. 28° 57′ W. Long. 92° 44′	13	.193	.154	.117	1.29	—.0218
413	N. Lat. 28° 55′ W. Long. 92° 45′	13					
414	N. Lat. 28° 53′ W. Long. 92° 46′	13	.194	.122	.029	2.59	—.4225
415	N. Lat. 28° 50′ W. Long. 92° 46′	14	.194	.157	.123	1.26	—.0132
416	N. Lat. 28° 48′ W. Long. 92° 47′	15	.199	.158	.035	2.39	—.5544
417	N. Lat. 28° 47′ W. Long. 92° 48′	15	.199	.152	.082	1.56	—.1512
418	N. Lat. 28° 45′ W. Long. 92° 49′	16	.168	.085	.026	2.54	—.2182
419	N. Lat. 28° 42′ W. Long. 92° 49′	17	.166	.125	.033	2.24	—.4547
420	N. Lat. 28° 40′ W. Long. 92° 50′	19	1.43	.0845	.0212	2.60	—.3726
421	N. Lat. 28° 38′ W. Long. 92° 51′	20	.132	.0675	.0305	2.08	—.0540
422	N. Lat. 28° 37′ W. Long. 92° 51′	20	.115	.0288	.00215	7.32	.4742
423	N. Lat. 28° 35′ W. Long. 92° 52′	19	.223	.148	.064	1.87	—.1858
424	N. Lat. 28° 32′ W. Long. 92° 53′	23	.026	.004	.0005	7.21	—.0904
425	N. Lat. 28° 31′ W. Long. 92° 54′	26	.062	.0103	.0018	5.87	.0216
426	N. Lat. 28° 29′ W. Long. 92° 55′	26	.047	.017	.00153	5.55	—.4123
427	N. Lat. 28° 27′ W. Long. 92° 56′	26	.152	.04	.0041	6.09	—.4101
428	N. Lat. 28° 25′ W. Long. 92° 57′	26	.212	.14	.0838	1.59	—.0429
429	N. Lat. 28° 12′ W. Long. 92° 58′	37	.0318	.0066	.00098	5.69	—.1457
430	N. Lat. 28° 11′ W. Long. 92° 59′	41	.0295	.00567	.000845	5.91	—.1107
431	N. Lat. 28° 09′ W. Long. 93° 00′	43	.035	.0084	.00096	6.03	—.3226
432	N. Lat. 28° 07′ W. Long. 93° 01′	46	.0295	.0062	.00098	5.49	—.1238
433	N. Lat. 28° 05′ W. Long. 93° 02′	49	.0206	.0046	.00077	5.17	—.1249
434	N. Lat. 28° 03′ W. Long. 93° 02′	50	.294	.217	.189	1.25	.0719
435	N. Lat. 28° 01′ W. Long. 93° 03′	56	.614	.218	.006	10.1	—1.1107
436	N. Lat. 27° 59′ W. Long. 93° 04′	62	.013	.00364	.00094	3.72	—.0353
437	N. Lat. 27° 58′ W. Long. 93° 06′	67	.63	.052	.00285	14.88	—.1778
438	N. Lat. 27° 57′ W. Long. 93° 09′	69	.0072	.00201	.00072	3.16	.1075
439	N. Lat. 27° 56′ W. Long. 93° 11′	72	.0064	.00171	.00062	3.21	.1310
440	N. Lat. 27° 53′ W. Long. 93° 12′	85	.0075	.00232	.00082	3.03	.0573
441	N. Lat. 27° 51′ W. Long. 93° 11′	104	.0228	.00285	.0007	5.71	.2929
442	N. Lat. 27° 49′ W. Long. 93° 10′	108	.00665	.00175	.00073	3.02	.2000
443	N. Lat. 27° 47′ W. Long. 93° 10′	109	.0201	.00221	.00067	5.48	.4409
444	N. Lat. 27° 45′ W. Long. 93° 09′	112	.0299	.0033	.00108	5.26	.4728
445	N. Lat. 27° 43′ W. Long. 93° 09′	95	.116	.071	.0043	5.20	—1.0044
446	N. Lat. 27° 41′ W. Long. 93° 08′	115	.178	.081	.0148	3.47	—.3936
447	N. Lat. 27° 39′ W. Long. 93° 07′	145	.11	.0212	.0125	2.97	.4857
448	N. Lat. 27° 37′ W. Long. 93° 07′	235	.0065	.00191	.000683	3.09	.0853
449	N. Lat. 27° 35′ W. Long. 93° 06′	335	.0034	.00124	.00046	2.73	.0069
450	N. Lat. 27° 32′ W. Long. 93° 05′	380	.00374	.00122	.000471	2.82	.0730
451	N. Lat. 27° 27′ W. Long. 93° 04′	500	.0035	.0012	.0005	2.65	.0846

Table 12 — Trinity Shoal II Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
510	N. Lat. 28° 45.3′ W. Long. 91° 48.8′	14	.0293	.0157	.0012	4.94	−.8459
509	N. Lat. 28° 43′ W. Long. 91° 48.7′	14	.0316	.015	.00239	3.64	−.4737
508	N. Lat. 28° 40.8′ W. Long. 91° 48.7′	16	.032	.0112	.000862	6.10	−.6576
507	N. Lat. 28° 38.2′ W. Long. 91° 48.7′	18	.029	.00952	.00174	4.08	−.2549
506	N. Lat. 28° 35.8′ W. Long. 91° 48.6′	20	.0219	.00472	.00054	6.36	.2749
505	N. Lat. 28° 33.7′ W. Long. 91° 48.6′	22	.0161	.00375	.00095	4.12	.0370
504	N. Lat. 28° 31.4′ W. Long. 91° 48.6′	27	.0162	.004	.000478	5.82	−.3152
503	N. Lat. 28° 28.9′ W. Long. 91° 48.5′	31	.0159	.00414	.00105	3.89	−.0114
502	N. Lat. 28° 26.8′ W. Long. 91° 48.5′	32	.0101	.00217	.00448	4.74	−.2076
501	N. Lat. 28° 24.5′ W. Long. 91° 48.5′	36	.016	.00451	.00107	3.87	−.0737
500	N. Lat. 28° 22′ W. Long. 91° 48.4′	35	.0107	.00266	.000485	4.69	−.1343
499	N. Lat. 28° 19.7′ W. Long. 91° 48.4′	36	.015	.0038	.000895	4.09	−.0315
498	N. Lat. 28° 17.2′ W. Long. 91° 48.4′	36	.0203	.00439	.000715	5.33	−.1221
497	N. Lat. 28° 15′ W. Long. 91° 48.3′	37	.017	.00525	.00103	4.06	−.1965
496	N. Lat. 28° 12.7′ W. Long. 91° 48.3′	32	.0123	.0026	.0054	4.78	−.0074
495	N. Lat. 28° 10.2′ W. Long. 91° 48.2′	43	.0135	.00434	.001	3.67	−.1445
494	N. Lat. 28° 08.3′ W. Long. 91° 48.2′	46	.0099	.00243	.000496	4.47	−.0804
493	N. Lat. 28° 05.8′ W. Long. 91° 48.1′	49	.0095	.00305	.00086	3.38	.0565
492	N. Lat. 28° 03.5′ W. Long. 91° 48.1′	55	.00715	.00153	.00041	4.17	.0973
491	N. Lat. 28° 01.2′ W. Long. 91° 48.1′	62	.0101	.00334	.00102	3.15	−.0343
490	N. Lat. 27° 58.6′ W. Long. 91° 49.2′	68	.014	.0019	.000528	5.15	.3062
489	N. Lat. 27° 56′ W. Long. 91° 50.2′	80	.00599	.00212	.0007	2.91	−.0301
488	N. Lat. 27° 53.5′ W. Long. 91° 51.2′	102	.00698	.00148			
487	N. Lat. 27° 51.3′ W. Long. 91° 52′	105	.175	.0262	.00119	12.12	−.4949
486	N. Lat. 27° 49.3′ W. Long. 91° 53′	70	.064	.0105	.00299	4.63	.2393
485	N. Lat. 27° 39.5′ W. Long. 91° 57′	402	.00425	.00132	.000445	3.09	.0362
484	N. Lat. 27° 29.5′ W. Long. 92° 01.5′	385	.0096	.0018	.000558	4.15	.2183
483	N. Lat. 27° 22′ W. Long. 92° 04.2′	548	.00355	.0011	.000425	2.89	.0959
482	N. Lat. 27° 13′ W. Long. 92° 08′	750	.00409	.00118	.000409	3.16	.0795
481	N. Lat. 27° 03.3′ W. Long. 92° 11.6′	770	.00365	.00116	.00047	2.79	.1055
480	N. Lat. 26° 48.1′ W. Long. 92° 16.8′	1020	.00351	.00133	.00053	2.57	.0220

Table 13 — Trinity Shoal Ia Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
466	N. Lat. 27° 53.5′ W. Long. 93° 37′	51	.156	.0763	.0349	2.11	−.0292
467	N. Lat. 27° 50.5′ W. Long. 93° 33′	86	.0052	.00139	.00052	3.16	.1461
468	N. Lat. 27° 47′ W. Long. 93° 29.5′	126	.00428	.00127	.00045	3.09	.0766
469	N. Lat. 27° 44′ W. Long. 93° 26.5′	123	.0248	.004	.00052	9.61	−.0942
470	N. Lat. 27° 40.2′ W. Long. 93° 22′	125	.201	.131	.0235	2.92	−.5607
471	N. Lat. 27° 37.5′ W. Long. 93° 19′	180	.00525	.0013	.000433	3.48	.1278
472	N. Lat. 27° 34′ W. Long. 93° 14.5′	200	.00449	.00158	.00062	2.69	.0488
473	N. Lat. 27° 30.5′ W. Long. 93° 11′	251	.0365	.0024	.00061	6.23	.5866
474	N. Lat. 27° 27.5′ W. Long. 93° 07′	321	.00584	.0016	.00052	3.21	.0748
475	N. Lat. 27° 24.4′ W. Long. 93° 03.5′	390	.00334	.00096			
476	N. Lat. 27° 17.5′ W. Long. 92° 54.8′	600	.0041	.00136	.000416	3.14	−.0353
477	N. Lat. 27° 10.8′ W. Long. 92° 46.3′	690	.00354	.00118	.000495	2.67	.1004
478	N. Lat. 27° 05′ W. Long. 92° 36.8′	690	.0039	.00122	.000438	2.98	.0596
479	N. Lat. 26° 56.6′ W. Long. 92° 28.7′	720	.00367	.0011	.00045	2.86	.1348
480	N. Lat. 26° 48.1′ W. Long. 92° 16.8′	1020	.0046	.0015	.000621	2.72	.1031

Table 14 — Matagorda IIa Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
164	N. Lat. 26° 42′ W. Long. 95° 12.5′	851	.0028	.00097	.00039	2.68	.0645
163	N. Lat. 26° 45′ W. Long. 94° 55′	785	.00336	.00102	.00038	3.00	.0888
162	N. Lat. 26° 47′ W. Long. 94° 43′	680	.0059	.00167	.00725	2.85	.1855
161	N. Lat. 26° 47′ W. Long. 94° 32′	590	.0069	.00199	.00067	3.21	.0671
160	N. Lat. 26° 47′ W. Long. 94° 21′	680	.0054	.00149	.000561	3.11	.1351
159	N. Lat. 26° 47.5′ W. Long. 94° 11′	700	.00582	.0015	.000506	3.39	.1173

Table 14 — Matagorda IIa Traverse — *Continued*

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
158	N. Lat. 26° 48′ W. Long. 94° 00.5′	665	.0078	.00195	.000794	3.13	.2119
157	N. Lat. 26° 48′ W. Long. 93° 50′	880					
156	N. Lat. 26° 46.5′ W. Long. 93° 37′	720	.00545	.00177	.000699	2.79	.0856
155	N. Lat. 26° 45′ W. Long. 93° 24.5′	765	.00555	.00173	.000645	2.94	.0770
154	N. Lat. 26° 43.5′ W. Long. 93° 12′	760	.00642	.00199	.0008	2.83	.1126
153	N. Lat. 26° 42′ W. Long. 92° 59′	820	.0573	.0115	.00197	5.39	−.0691

Table 15 — Ship Shoal Traverse

Statistical Constants

Station	Position	Depth Fathoms	Q1 mm	M mm	Q3 mm	So	Log sk
511	N. Lat. 28° 36.8′ W. Long. 90° 59.7′	12	.084	.048	.0153	2.35	−.2534
512	N. Lat. 28° 34.7′ W. Long. 90° 58.5′	14	.0492	.0243	.0062	2.82	−.2874
513	N. Lat. 28° 33′ W. Long. 90° 57.4′	16	.0758	.025	.0033	4.80	−.3979
514	N. Lat. 28° 31′ W. Long. 90° 56.8′	18	.0695	.018	.0029	4.88	−.2062
515	N. Lat. 28° 29.8′ W. Long. 90° 55.8′	22	.025	.0068	.00075	5.77	−.3915
516	N. Lat. 28° 37.5′ W. Long. 90° 54.9′	22	.0292	.008	.00164	4.22	−.1255
517	N. Lat. 28° 25.4′ W. Long. 90° 53.8′	22	.0266	.00445	.000683	6.25	−.0376
518	N. Lat. 28° 23.9′ W. Long. 90° 52.9′	23	.0418	.0109	.00156	5.18	−.2612
519	N. Lat. 28° 22′ W. Long. 90° 51.8′	25	.0154	.0041	.000788	4.42	−.1415
520	N. Lat. 28° 20′ W. Long. 90° 50.9′	29	.0188	.0053	.00114	4.06	−.1175
521	N. Lat. 28° 18.2′ W. Long. 90° 49.9′	30	.0143	.00279	.00058	4.96	.2175
522	N. Lat. 28° 16.9′ W. Long. 90° 48.9′	35	.0096	.00305	.00075	3.58	−.1107
523	N. Lat. 28° 15′ W. Long. 90° 47.8′	38	.007	.0018	.00042	4.09	−.0429
524	N. Lat. 28° 13′ W. Long. 90° 46.2′	46	.00781	.00319	.00079	3.15	−.2168
525	N. Lat. 28° 11′ W. Long. 90° 44.5′	56	.00622	.0014	.00039	4.17	.0931
526	N. Lat. 28° 08.8′ W. Long. 90° 43′	65	.0067	.0026	.00087	2.78	−.0620
527	N. Lat. 28° 06.5′ W. Long. 90° 41′	73	.0044	.0013	.000284	3.94	−.1314
528	N. Lat. 28° 04.8′ W. Long. 90° 39.7′	82	.00585	.00213	.000655	2.99	−.0737
529	N. Lat. 28 02.5′ W. Long. 90° 38′	102	.00393	.00108	.00037	4.03	−.0962
530	N. Lat. 28° 01′ W. Long. 90° 37′	125	.0063	.00208	.000702	3.00	.0052
531	N. Lat. 27° 57.9′ W. Long. 90° 35.5′	145	.00471	.00121	.00039	3.48	.0986
532	N. Lat. 27° 44.6′ W. Long. 90° 29′	150	.0062	.00205	.000663	3.06	−.0097
533	N. Lat. 27° 39.9′ W. Long. 90° 26.9′	310	.0029	.00103	.0005	2.41	.1361
534	N. Lat. 27° 35.4′ W. Long. 90° 24.5	410	.0035	.0011	.00038	3.07	.0410
535	N. Lat. 27° 30.6′ W. Long. 90° 22.3′	520	.0043	.0011	.000374	3.39	.1239
536	N. Lat. 27° 26.2′ W. Long. 90° 20′	580	.005	.00137	.00044	3.37	.0686
537	N. Lat. 27° 21.5′ W. Long. 90° 17.9′	640	.00465	.00135	.000505	3.03	.1103
538	N. Lat. 27° 16.5′ W. Long. 90° 15.9′	700	.00423	.00121	.000299	3.77	−.0635
539	N. Lat. 27° 13.8′ W. Long. 90° 24.5′	725	.0053	.00119	.0004	3.64	.1755
540	N. Lat. 27° 08.8′ W. Long. 90° 21.5′	800	.00487	.00123	.000404	3.47	.1139
541	N. Lat. 26° 59′ W. Long. 90° 16′	1040	.0064	.00174	.000402	3.99	−.0706
542	N. Lat. 26° 49.9′ W. Long. 90° 09.9′	1360	.00455	.00108	.00039	3.42	.1821
543	N. Lat. 26° 36.3′ W. Long. 90° 00.9′	1550	.028	.0043	.000604	6.81	−.0381
544	N. Lat. 26° 22.5′ W. Long. 89° 51.5′	1650	.00119	.00221	.000495	4.90	.0806
545	N. Lat. 26° 09.2′ W. Long. 89° 42.7′	1700	.051	.00475	.000682	8.65	.1875
546	N. Lat. 25° 54.6′ W. Long. 89° 33′	1725	.015	.00272	.00056	5.18	.0561
547	N. Lat. 25° 36.2 W. Long. 89° 21′	1765	.027	.00336	.00089	5.51	.3284
548	N. Lat. 25° 19.2′ W. Long. 89° 00′	1830					
549	N. Lat. 25° 07.2′ W. Long. 88° 35′	1875	.0115	.00303	.000836	3.71	.0204

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PART II — CHEMICAL STUDIES OF SEDIMENTS OF THE WESTERN GULF OF MEXICO

SECTION I — ORGANIC CONTENT
SECTION II — CHEMICAL COMPOSITION
SECTION III — WATER CONTENT

Report of a study sponsored jointly by the Woods Hole Oceanographic Institution and the Geological Society of America.

BY PARKER D. TRASK

Institute of Engineering Research, Department of Engineering
University of California, Berkeley, California

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SECTION I — ORGANIC CONTENT

INTRODUCTION

In 1947 the Woods Hole Oceanographic Institution organized an expedition to investigate the bottom sediments and oceanography of the northwest Gulf of Mexico. The Geological Society of America contributed to the support of this undertaking with grants in aid from the Penrose fund. The American Association of Petroleum Geologists through its Executive and Research committees officially endorsed the expedition. The main objective was to investigate the environmental conditions of deposition of the sediments in the offshore waters more than 10 fathoms in depth in order to throw light on the oceanography of the northwest part of the Gulf of Mexico and to develop ecological criteria that would benefit geologists in their efforts to determine the conditions of deposition of ancient sediments deposited in the geologic past in adjacent areas.

The work was carried out under the direction of Henry C. Stetson, Fred B Phleger, and Parker D. Trask, all members of the staff of Woods Hole Oceanographic Institution. Stetson concentrated on the physical conditions of deposition, Phleger on the biology, and Trask upon the chemical nature of the sediments, principally the organic content. The results of the investigation are being published in a series of papers. Phleger and Parker (1951) have reported on the biology, chiefly the Foraminifera. Stetson (1953) describes the mechanical composition of the sediments. The results of Trask's investigation are presented in three parts in the present paper: Section I on the organic content, Section II on the chemical composition of the sediments, and Section III on the water content of the surface layers of the deposits. In addition a preliminary summary paper (Trask, Phleger and Stetson, 1947) was published soon after the completion of the expedition.

The field work was carried on in February and March 1947 with the aid of the *Atlantis*, a research oceanographic vessel of Woods Hole Oceanographic Institution. The details of the expedition are described by Phleger (1951, pp. 1–7) and by Stetson (1953). The *Atlantis* collected 551 short cores of sediments 6 to 20 inches in length and 101 long cores 3 feet to 11 feet long from 12 profiles across the continental shelf and out into deep water from the mouth of the Mississippi to the mouth of the Rio Grande. In addition 25 serial stations were occupied for temperature and salinity observations, and plankton tows were made at 27 stations. Temperatures in the upper 450 feet of water were determined with the bathythermograph at intervals of not more than 5 miles. A few bathythermograms were taken to depths of 800 to 900 feet. The result of the oceanographic observations are reported by Phleger (1951, pp. 7–26).

The location of the 12 profiles and the stations from which bottom samples were procured are given in Fig. 1. Names, as indicated on Fig. 1, have been given to the profiles in order to facilitate discussion. On Fig. 1, dots refer to localities from which cores were procured and dashes to short cores. A short core was taken at every locality of a long core. The short cores were obtained with a device designed by Phleger for procuring undisturbed samples of the surface layers of the sediments. The instrument consists of an open steel tube 2 inches in diameter and 2 feet in length fastened at its upper end to a mass of lead weighing 65 pounds. A plastic tube fits inside the steel tube and is removed after the sample is taken. In operating the sampler, the instrument is allowed to sink under its own weight through the water and into the sediment. The longest sample procured is 20 inches in length. The sample is retained because of cohesion of the sediment. Clean sand samples occasionally are lost. Sufficient formalin to preserve the organic matter of the upper two inches of sediment was added to the core immediately after taking the sample. The formalin, as a rule, penetrated to a depth of two inches in the core. The ends of the core were closed with a rubber stopper and taped to conserve moisture. An extra set of 83 short cores were taken from representative places on the continental shelf and the continental slope for the purpose of determining the water content of the sediments. Formalin was not added to these extra samples collected for moisture determination. The location of these water-sample cores is given in Table 10 and Fig. 1.

The long cores were procured with a sampler devised by Hvorslev and Stetson (1946). The

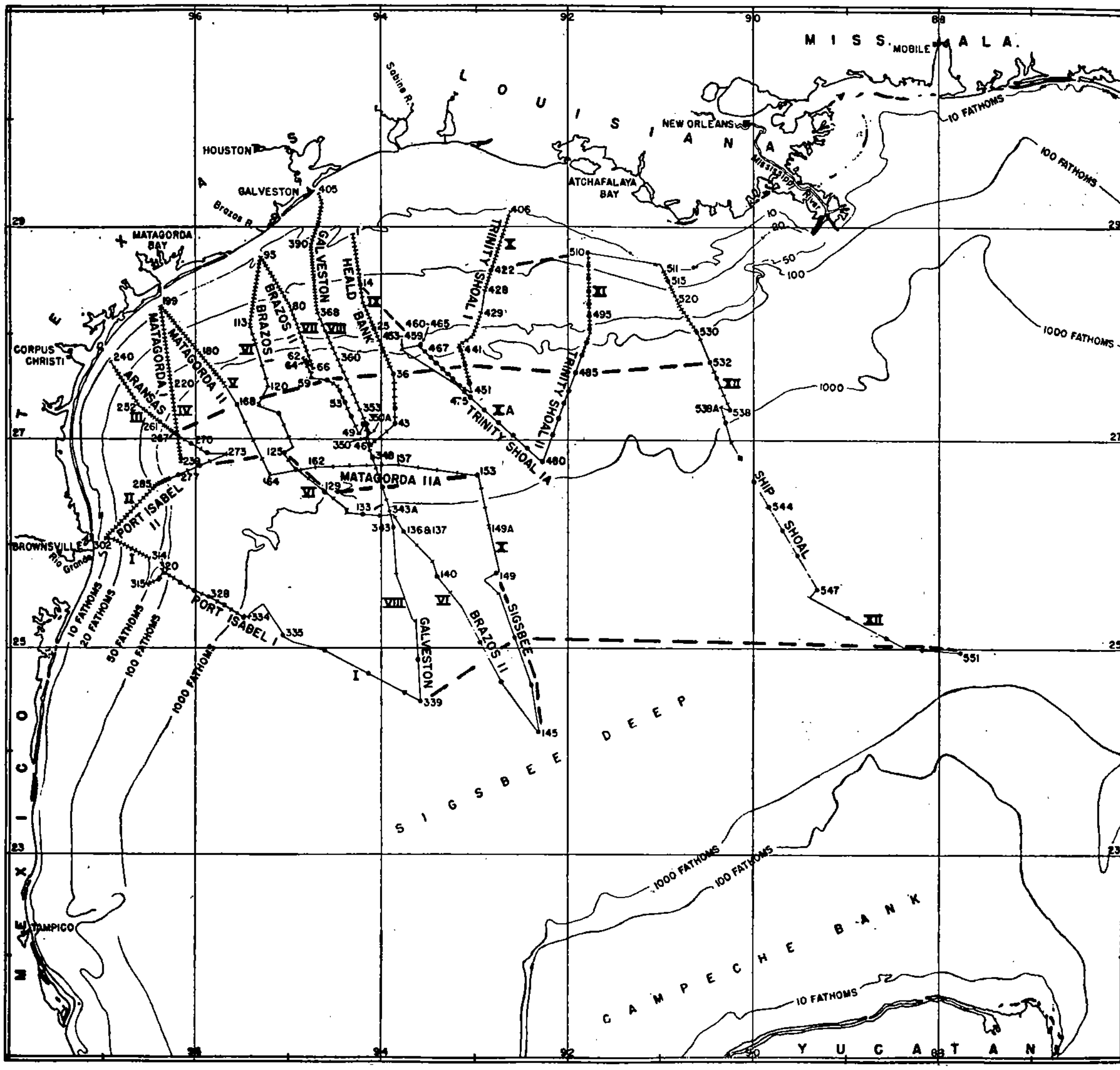


FIG. 1. Location of samples. Solid lines show profiles from which samples were collected. Dashed lines represent profiles presented on figures 11 to 14. Short transverse lines on profile lines indicate location of short (Phleger) cores. Circles give location of long cores. Numbers are core numbers. Names are profile names.

sampling tube of this instrument consists of a steel tube slightly more than 2 inches in diameter loaded at its upper end with one ton of weights. The sampler is operated with the aid of a trigger, the end of which extends 50 feet beyond the end of the sampling tube. The instrument is lowered by winch through the water. When the trigger strikes the bottom a catch is released which lets the sampling tube and lead weight fall freely through the water. Experience has shown that the tube obtains adequate momentum in its fall of 50 feet to penetrate the sediments effectively. Sufficient chain is supplied between the end of the sampler and the end of the cable to provide slack for the free fall. After the sample is taken, the corer is hauled to the surface, the chain preventing kinking of the wire. The collection and processing of the samples is described in detail by Stetson (1953).

The material is collected in a thin brass tube, which is removed from the core barrel when the instrument is brought to the surface. The ends of the brass tube are stoppered and taped. The tubes are stored in a horizontal position and when ready for investigation are sawed in two parts with the aid of a tapered iron tooth which is run up and down along the two sides of the sampling tube until a groove has been scored deeply enough to sever the tube. A thin iron plate is then passed longitudinally through the two slits in the tube in order to divide the core in two parts. The tube is laid open and the two halves are allowed to rest with the open side upward in a wooden tray. The color, texture, and other characteristics of the sample are then noted and the sample photographed before the sediment shrinks because of loss of water. The photograph of the fresh sample helps identify parts of the core that split apart as it dries (Figs. 16 and 17).

ACKNOWLEDGEMENTS

The writer particularly wishes to express his appreciation of the assistance of Henry C. Stetson and Fred B Phleger, his associates in this undertaking. Special acknowledgement is due H. N. Cooper of the Pittsburgh Laboratory of the U. S. Bureau of Mines who kindly determined nitrogen, organic carbon and calcium carbonate in his laboratory. To have the high standards of this laboratory available for the present investigations has proved most valuable. Thanks are also due A. C. Fieldner, chief of the Coal Technology Branch of the Bureau of Mines whose sympathetic attitude helped make possible the analyses of the samples. Acknowledgement is also due Constance F. Klebba for her enthusiastic help in processing the samples and compiling data, and to W. S. Butcher for criticising the manuscript; appreciation also is expressed to others of the staff of Woods Hole Oceanographic Institution, too numerous to mention here, who facilitated the work. Lastly should be mentioned the two directors of the Institution, Columbus Iselin and Admiral E. H. Smith, who have been most helpful.

PROCEDURE OF ANALYSIS

Selection of Samples

The main object of the studies of the organic content is to determine the areal distribution of the organic matter in the surface and subsurface sediments and to ascertain the changes that take place in the quantity and quality of organic matter after it has been desposited. The determination of the quantity and character of organic matter in sediments is difficult, because each chemical constituent of the organic matter also is present in the inorganic substances but in varying quantities. For a discussion of this question see Trask & Patnode (1942) pp. 18–80).

The quantity of organic matter ordinarily is determined most practicably from the organic carbon content. Carbon forms approximately 56 percent of the organic content of marine sediments. Thus the organic content can be estimated by multiplying the carbon content by a factor of 1.8. As a rule the organic content is not more than 10 percent in error when determined in this way. That is, if it is estimated to be 2.0 percent, it probably lies between 1.8 and 2.2 percent of the weight of the sediments. The organic carbon content itself cannot be determined more reliably than this by chemical analysis in sediments containing as much calcium carbonate as do the deposits of the Gulf of Mexico.

Organic Carbon

Organic carbon was determined by the standard method of analysis of the Bureau of Mines, which consists of oxidation of the carbonate in a heated chamber with the aid of lead oxide and collecting the resulting carbon dioxide in askarite. Chlorine was removed with silver sulfate. This process catches all the carbon in the sample,— that due to calcium carbonate as well as that due to organic matter. A separate determination of carbonate carbon is made by adding dilute hydrochloric acid to an aliquot portion of the sediment and measuring the carbon dioxide evolved. Organic carbon represents the difference between total carbon and carbonate carbon. The calcium carbonate content is determined by multiplying by a factor of 2.27 the carbon dioxide liberated by the hydrochloric acid.

Nitrogen

The organic content can also be estimated from nitrogen. Nitrogen constitutes a minor but on the whole reasonably constant part of the organic matter (Trask & Patnode, 1942, pp. 32–40). The average râtio of carbon to nitrogen in surface layers of marine sediments in different parts of the world is 8.5. As shown in Table 1, the average carbon-nitrogen ratio of the surface layers of sediments on the continental shelf and continental slope in the Gulf of Mexico is approximately 8.5. The average for the sediments in the deep water in the Gulf is 9.5, which represents a lower content of nitrogen in the organic matter.

If the ratio of carbon to nitrogen is 8.5 and the ratio of organic matter to carbon is 1.8, the ratio of organic matter to nitrogen is 8.5 x 1.8 or 15.3; for the deep sediments the ratio is 9.5 x 1.8 or 17.1. The average percentage of nitrogen in the organic matter accordingly is roughly 6 to 6.5 percent. Thus, the organic content can be estimated by multiplying the nitrogen content by a figure of 15 for the near shore and hypabyssal sediments, and by 17 for the deep sediments. Because of the variable nitrogen content, estimates for individual samples computed in this way are subject to a certain amount of error, about 10 percent on the average. Averages of groups of samples are more reliable; the error for a mean of 10 samples being approximately 3 percent.

Nitrogen is determined much more reliably and more rapidly than is carbon. Thus, despite its greater variability of distribution in organic matter, it offers a practicable means for estimating organic content. In fact, nitrogen has proved particularly helpful in the present investigation, because the upper 5 to 10 centimeters of each short core were impregnated with formalin to preserve the organic matter in the foraminiferal studies. Formalin contains carbon but is a nitrogen-free compound. Its presence in the sediments prevents the reliable determination of native organic carbon. However, as it contains no nitrogen, reliable estimates of samples impregnated with formalin can be determined from the nitrogen content. Analysis of the nitrogen content of the quantity of formalin added to each sample indicated that it contained less than 1 part in 100,000 (.001 percent) of nitrogen. As the nitrogen analyses are reported only to parts per 100,000 ,the addition of formalin has not introduced any significant error in determining the nitrogen content of the sediments.

Reliability of Analyses

In view of the large number of samples and of the desire not to impose an undue burden upon the Bureau of Mines, which analyzed the samples, the decision was made to make few duplicate determinations. A statistical study of duplicates made in the first part of the program of analysis indicated an average (median) deviation of less than 0.003 percent, which represents an average error of 3.5 percent in determining nitrogen. In most places the variation in organic content between adjacent samples of sediment is materially greater than 3.5 percent. Consequently a better idea of the general distribution of organic matter was obtained by analyzing a large number of samples rather than a smaller number in duplicate. In a general ecological study, such as the present investigation, it is preferable to ascertain the various trends in the vertical and lateral distribution of properties of the organic matter than to make a few determinations with a very high degree of reliability.

PROGRAM OF SAMPLING

The program of sampling involved 745 carbon, 798 calcium carbonate and 1064 nitrogen analyses. One half of the 551 short core samples and 65 of the 101 long cores were analyzed. The upper 5 to 10 centimeters of each of the short cores were removed for biological studies by Phleger. The sediment immediately underlying the material removed by Phleger, occupying the depth interval of 10 to 15 centimeters, was analyzed for nitrogen only; because as mentioned above, the sample may have been contaminated with formalin, which would lead to erroneous determinations of carbon. The bottom five centimeters (two inches) of each short core was analyzed for total carbon, carbonate carbon and nitrogen. In addition to the determinations made on the regular short cores, total carbon, carbonate carbon and nitrogen were determined on many of the duplicate short cores taken for water content. No formalin was added to such samples.

The material selected for analysis was removed from the sample tubes shortly after the tubes were opened. The sediment was dried in an oven at 105° C, ground and sent to the Bureau of Mines for analysis. The material was removed from the sample tubes within four months of the time the samples were collected and the analyses were completed within three additional months.

The material from the long cores, selected for organic analysis, likewise was removed from the coring tube soon after the tube was opened. One-half of each tube was preserved for future reference. One-half of the remainder, that is, one-quarter of the core was saved for foraminiferal investigations, and the other quarter was used for studies such as mechanical analyses, organic content, and chemical composition. In selecting material from long cores, samples were taken from the upper five centimeters of the samples, and at depths of approximately 25, 50, 100, 150, 200, 250, and 300 centimeters, depending upon the length of the sample. Commonly a sample was taken of the bottom five centimeters, particularly if the end of the core was at a depth intermediate between some multiple of 50 centimeters. In addition, material was selected from layers of distinctive lithology, such as sand, silt, or red clay. A few cores were sampled at close intervals in order to trace changes in composition with depth. As a rule, a sample five centimeters in length was removed for each analysis.

RESULTS OF ANALYSES

Basic data on the analyses are given in Table 10, and Figs. 4 to 8 and 11 to 14. The general features are summarized in Table 1. The areal distribution of organic matter and calcium carbonate in the surface layers are shown in Figs. 2 to 8. The variation in properties of the sediments with depth of burial are presented in Figs. 10 to 14, and in tables 2 to 9.

In the study of the sediments from the Gulf of Mexico it is convenient to group them with respect to three depth-of-water zones: I. continental shelf, from 10 to 100 fathoms (approximately 20 to 200 meters); II. continental slope, 100 to 1000 fathoms (200 to 1800 meters), and deep water,

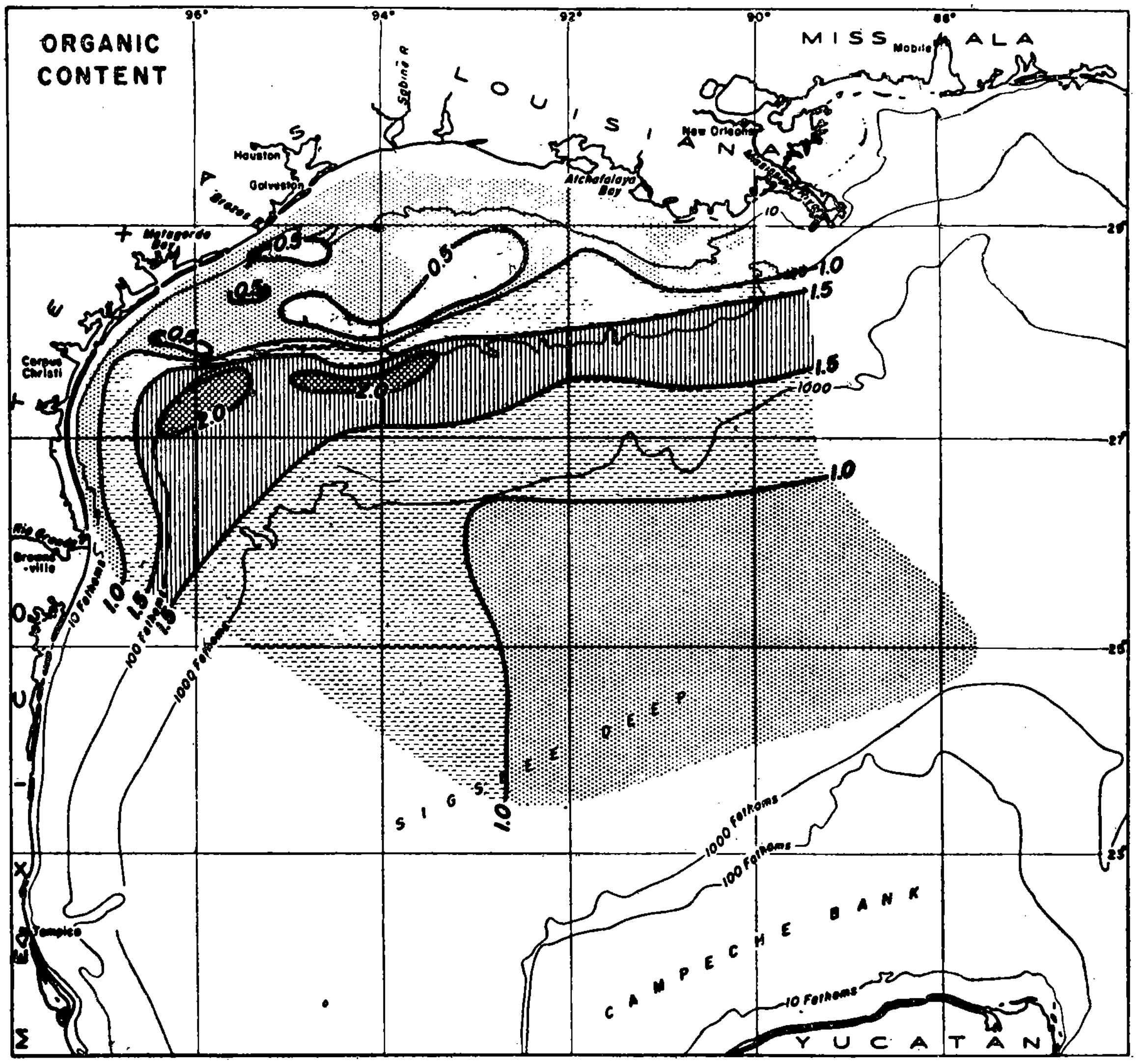


FIG. 2. Organic content of surface sediments. Numbers represent percent of organic matter, estimated as 1.8 times the carbon content.

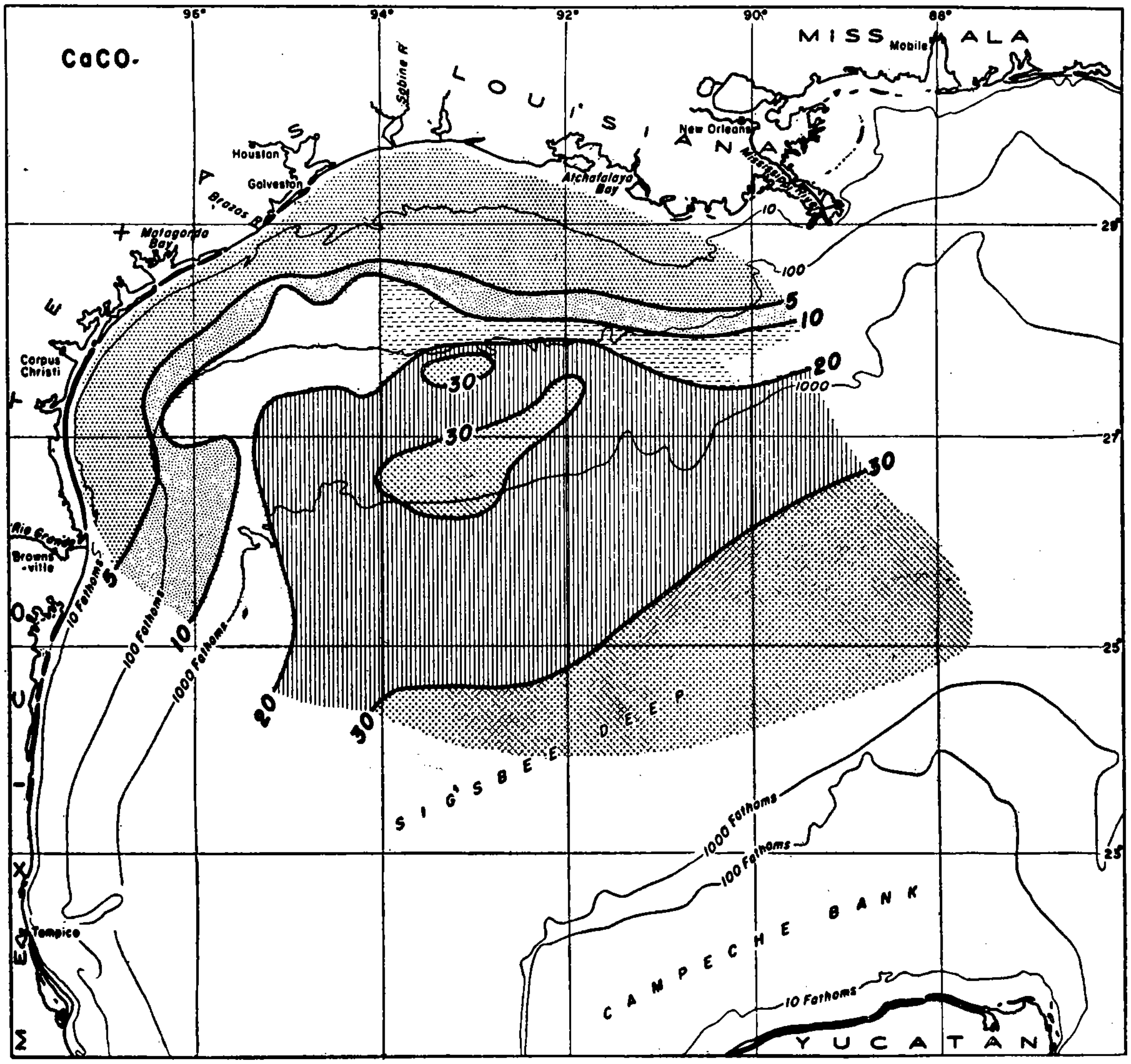


FIG. 3. Calcium carbonate content of surface sediments. Numbers represent percent $CaCO_3$ by weight.

1000 to 2000 fathoms (1800 to 3600 meters). In addition special segregations according to texture or special types of sediment were made. As shown in the profiles of the sea bottom in Figs. 4 to 8, the continental shelf is nearly flat. It ranges in width from 50 to 150 miles and extends out to a depth of approximately 100 fathoms. The bottom then descends rather steeply to a depth of 1000 fathoms, below which it slopes much more gently. Determinations made with fathometer, show that the configuration of the sea bottom is more irregular than indicated on Figs. 4 to 8, which are based upon the depths recorded when the samples were taken. Detailed profiles are shown in the paper by Stetson (1953). In addition a map is being prepared by Betty Lee Gealy under the direction of Stetson which shows in much detail the irregularities on the continental slope. Many of these irregularities are in the form of basins. In view of the lack of adequate control, the relationship of these basins to the cores taken in the present investigation is not known.

AREAL VARIATION OF ORGANIC CONTENT

The areal variation of organic content is shown in Fig. 2. The data in this illustration represent a composite estimate of the organic content based on 1.8 times organic carbon and 16 times the nitrogen content. The figure 16 is taken as a general figure to cover the variation from 15.3 for sediments on the continental shelf to 17 for those in the deep water.

As shown in Fig. 2 the organic content ranges mainly between 0.5 and 2 percent. The quantity is least in the shallow water near shore, where it is 0.5 percent, and greatest in the upper part of the continental slope, where it is 1.5 to 2 percent. The organic content decreases seaward from the crest of the continental slope. It is approximately 1 percent in the abyssal deep. The organic content within any particular depth-of-water zone is reasonably constant, though as discussed below it varies with texture (Fig. 9).

The carbon-nitrogen ratio ranges mainly between 7.5 and 10 in the surface layers. As shown in Table 1 the average for the sediments on the continental shelf and continental slope is 8.5, and is 9.5 in the sediments in deep water.

The calcium carbonate content of the sediments increases progressively seaward from slightly less than 5 percent in water near shore to more than 30 percent in the abyssal deeps (Fig. 3). In a few places on the continental slope the calcium carbonate content is 30 percent, but as a rule it is

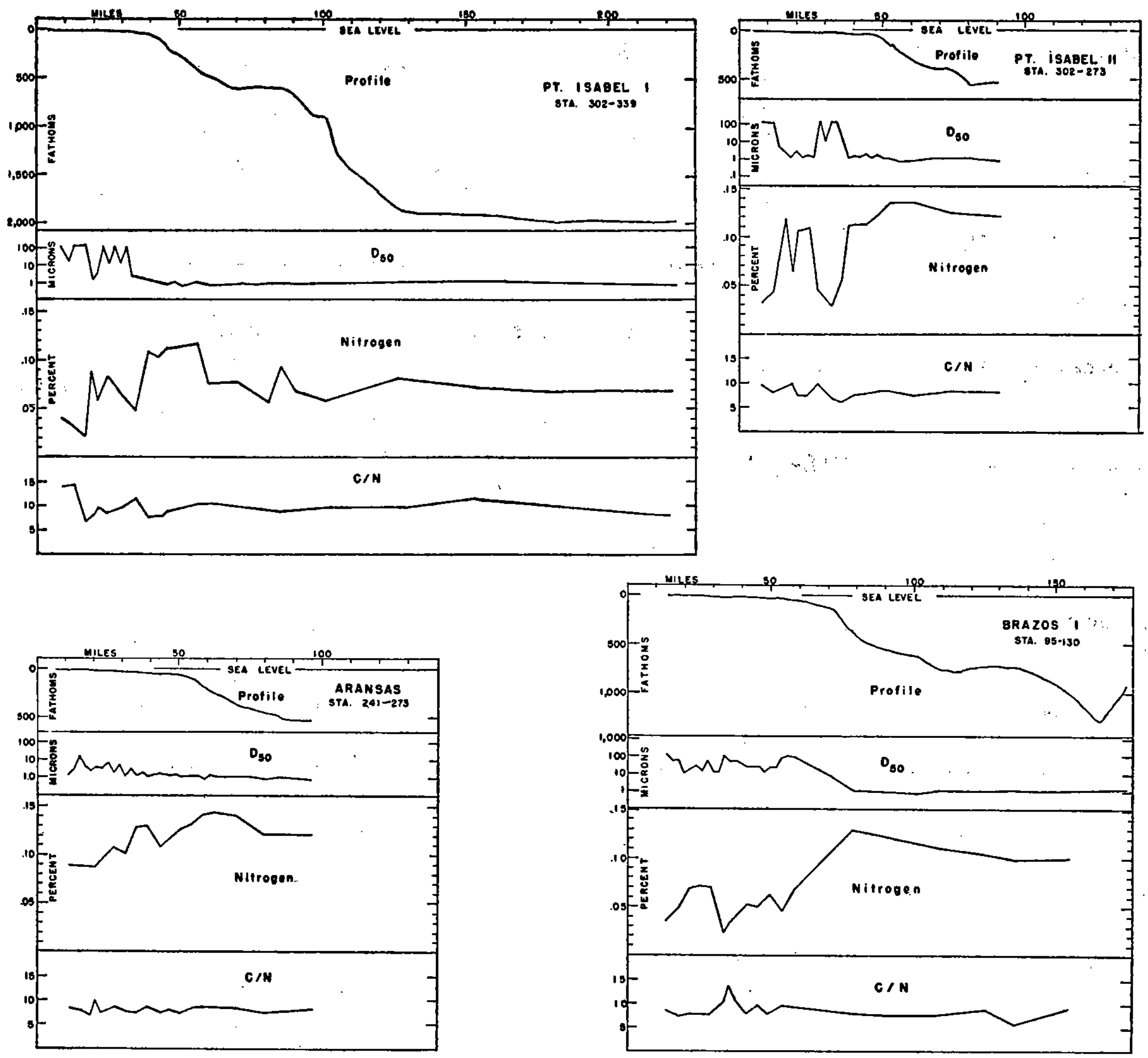


FIG. 4. Basic data on surface sediments along profiles, I.—Port Isabel I and II, Aransas and Brazos I profiles. See fig. 1 for location of profiles. Depth of profiles in fathoms, horizontal distance in miles; D_{50} (median diameter) expressed in microns on logarithmic scale; nitrogen in percent of total weight of sediments, C/N as ratio of carbon to nitrogen content.

around 20 percent. Most of the sediments on the continental shelf contain between 4 and 6 percent. The richest deposits on the shelf are near Heald Bank (longitude 94°) where the content is 6 to 10 percent. The carbonate content, like the organic content, is fairly constant for given depths of water.

Individual Profiles

The organic content of sediments is influenced both by the topography of the environment of deposition and by the texture of the sediments. In order to show the particular relationships of these two factors to organic content in the Gulf of Mexico, a series of charts, Figs. 4 to 8, showing the relationship of organic content to the texture and bottom configuration have been prepared. The data for texture and topography are taken from Stetson (1953). The vertical exaggeration of the profiles is about 30 to 1 and the texture is plotted upon a logarithmic scale for median diameter (D_{50}) of the sediments. The organic content is plotted in two ways: (1) nitrogen content and (2) carbon-nitrogen ratio. The nitrogen content is used because it was determined on more surface samples than was carbon. In these figures nitrogen is presented in hundredths of a percent, that is parts in 10,000, and carbon-nitrogen ratio as units. The profiles in general are arranged from west to east.

Port Isabel I. The Port Isabel I profile (cores 302 to 339) extends for 225 miles southeastward from the mouth of the Rio Grande to the west part of the Sigsbee deep in 2000 fathoms of water. The topography of the intermediate part of the continental slope 75 to 100 miles from shore and in water 700 to 1000 fathoms of depth as shown by the fathometer readings is irregular. A trough 2000 fathoms in depth is indicated about 100 miles from shore near samples 332 and 333. The jog in the section line between samples 314 and 315 shown on Fig. 1 is due to drift between the time of taking successive bottom samples.

The continental shelf is 40 miles wide in this section. The median diameter ranges between 10 and 100 microns on the shelf; one sample (307) has a median of only 2.5 microns. The coefficient of sorting of the sediments varies between 1 and 9. Thus the sediments fluctuate from sand to silt and even to clay. As a rule they are well graded; that is, they are poorly sorted. The organic content as reflected by the nitrogen determinations likewise varies markedly, as a rule inversely with the median diameter. The sands commonly contain .05 percent or less nitrogen and the silts from .05 to .09 percent. The carbon-nitrogen ratio fluctuates considerably but averages about 8.5 percent.

At the outer edge of the continental shelf the grain size decreases abruptly to about 1 micron and continues at essentially this same size for nearly 200 miles to the Sigsbee deep. The sorting consistently ranges around 3.0. The nitrogen content is high and variable over the upper part of the continental slope where the water is less than 1000 fathoms deep; but in deeper water, at distances more than 100 miles from shore the nitrogen content decreases and ranges mainly between .07 and .08 percent. The carbon-nitrogen ratio increases slightly to an average of 9.5.

Port Isabel II. Port Isabel II profile (samples 302 to 273) extends northeastward from the mouth of the Rio Grande across the continental shelf and then down to a depth of 980 meters (540 fathoms). The fathometer readings indicate that the continental shelf is smoother than in the Port Isabel profile to the south. The texture grades seaward from fine sand to clay within a distance of 20 miles on the continental shelf. Near the outward edge of the shelf it coarsens to poorly-sorted sand. The sediments on the continental slope, as in the Port Isabel I profile, are uniformly about 1 micron in median diameter and have a coefficient of sorting of 3.

The organic content varies inversely with the texture,— nitrogen being less than .05 percent in the sands and .07 to 0.12 percent in the silts on the continental shelf and more than 0.10 percent in the clay on the continental slope. The maximum organic content is on the upper part of the continental slope between depths of 150 and 400 fathoms. The carbon-nitrogen ratio ranges mainly between 7 and 10.

Aransas. The Aransas profile (cores 241 to 273) extends from Aransas Pass near Corpus Christi to a depth of 540 fathoms in the central part of the continental slope. The fathometer indicates a relatively smooth bottom. The median diameter near shore in 12 fathoms of water at station 241 is 2 microns, at core 243 three miles seaward it is 25 microns, and then tapers off gradually but irregularly to 1 micron at the edge of the continental shelf. Sorting on the shelf is poor, ranging between 4 and 7.

The organic content increases more or less regularly seaward. Nitrogen ranges from .09 percent near shore to 0.14 percent on the upper part of the continental slope. Near the outer edge of the continental shelf about 30 miles from the landward edge of the profile in water 40 fathoms deep the nitrogen content rises to 0.13 percent, without corresponding decrease in texture. The C/N ratio ranges mainly between 7 and 9, similar to its range in the Port Isabel II profile to the south.

Matagorda I. This profile extends 90 miles southward off Matagorda Bay diagonally across the continental slope to a depth of 360 fathoms on the upper part of the continental slope (Stations 199 to 238, Fig. 5). The bottom is moderately smooth. The texture in general decreases irregularly seaward from fine sand (100 microns or less) near shore to fine clay with median diameter of 1 micron on the upper part of the continental

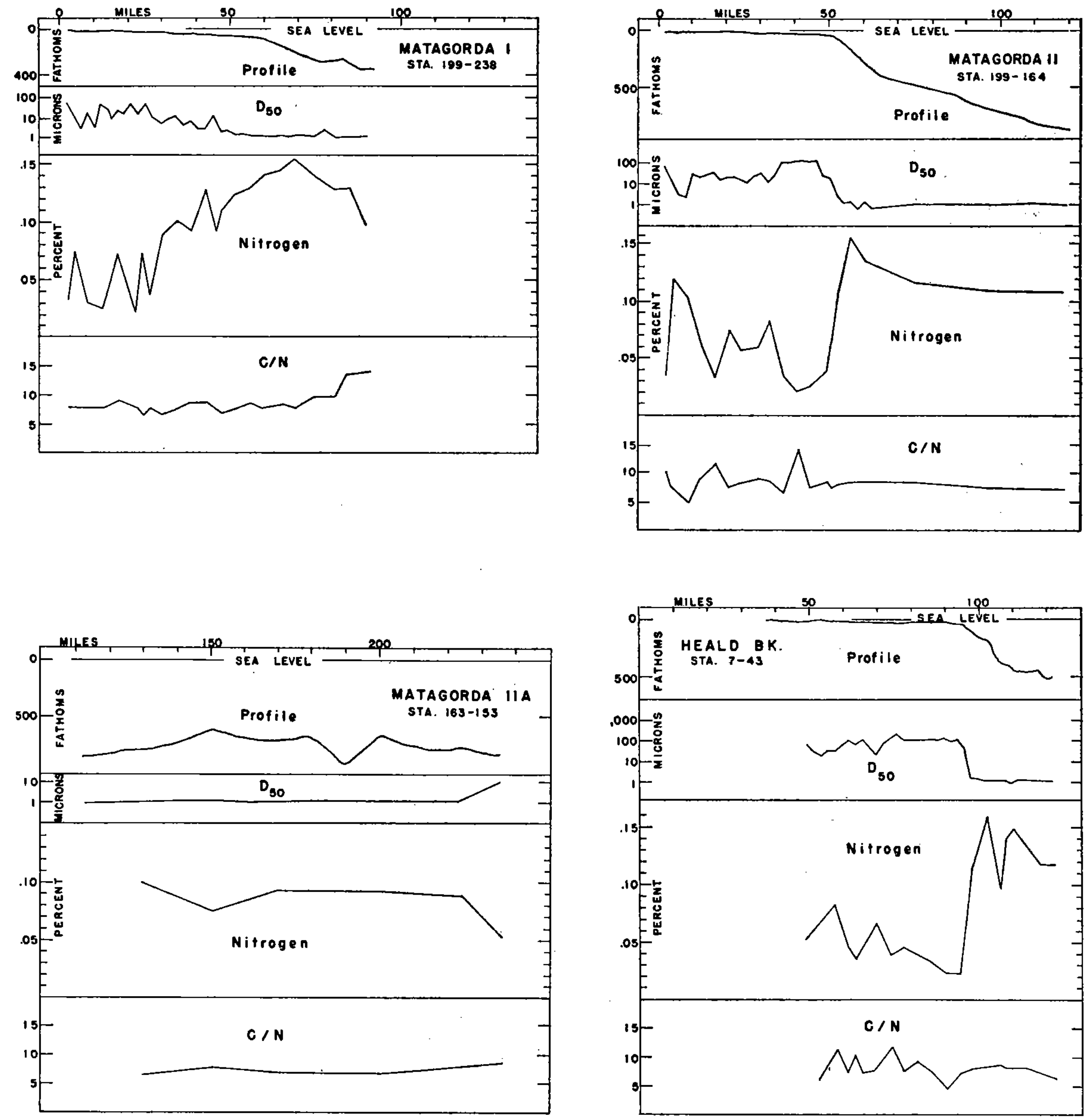


FIG. 5. Basic data on surface sediments along profiles, II. Matagorda I, II-A, and Heald Bank profiles. See fig. 1 for location and fig. 4 for explanation.

slope. The coefficient of sorting ranges between 1.5 and 6.

The nitrogen content is correspondingly irregular but increases in general from about .03 percent in sand near shore to 0.16 percent at sample 230 in 230 fathoms on the upper part of the continental slope. Seaward from this point the organic content drops off rapidly. The C/N ratio ranges mainly between 6 and 9 but increases gradually seaward.

Matagorda II. This profile extends 120 miles southeastward from Matagorda Bay to a depth of 850 fathoms on the lower part of the continental slope (Stations 199 to 164, Fig. 5). The profile is continued in the Matagorda II — A profile which extends eastward 100 miles to Station 153, forming a dog-leg section joined to the Sigsbee profile extending southward for 150 miles across the lower part of the continental slope to Station 145 in the deep part of the Gulf in 2000 fathoms of water.

Brazos II. This profile, 40 miles east of profile Brazos I extends 350 miles southeastward from the mouth of the Brazos River to the middle of the Sigsbee deep (Stations 49–45, 353–343A, 135–145A, Fig. 6). The shelf is 70 miles in width and the slope 100 miles. More than 160 miles of the profile is in the Sigsbee deep. The landward end of the profile is 20 miles from shore where the continental shelf is exceedingly flat. The profile is a composite of several traverses taken by the *Atlantis*

The continental slope is irregular and is cut by numerous troughs, some of which have a relief of 400 fathoms. The sea floor in the Sigsbee deep is relatively smooth and for 100 miles is approximately 2000 fathoms in depth.

The sediments on the continental shelf consist of sand and sandy silt, ranging mainly between 20 and 100 microns in median diameter. One sample, No. 83, is very coarse, having a median of 1350 microns. The coefficient of sorting is variable but in general is less than 5. The sediments seaward from the upper edge of the continental slope, including those on irregular parts of the continental slope, are remarkably uniform in texture, ranging in size mainly between 1 and 2 microns. The samples also are fairly well-sorted, the coefficient of sorting ranging mainly between 3 and 3.5.

The organic content is low and variable on the continental shelf, in general containing less than .04 percent nitrogen. Near the outer edge of the shelf and on the upper part of the continental slope where the texture consists of clay, the organic content is high, nitrogen averaging .15 percent. The organic content seemingly does not vary in response to the irregular topography of the continental slope, as the nitrogen content decreases fairly uniformly down the slope to the landward edge of the Sigsbee deep in 1500 fathoms where nitrogen is .05 percent. The organic content increases slightly toward Station 140 where nitrogen is .09 percent and then decreases to .05 percent in the middle of the Sigsbee deep at Station 145. The C/N ratio is 7 to 10. The Brazos I profile is similar to Brazos II.

Galveston. The Galveston profile extends for 300 miles southward from Galveston Bay to the Sigsbee deep. (Stations 405 to 339, Fig. 6.) It cuts across the Brazos II profile at an angle of about 15°, the two sections running jointly between Stations 353 and 343A. The continental slope between miles 100 and 200 on this profile is irregular and traverses troughs more than 400 fathoms in relief. The Sigsbee deep is more irregular than it is on profile Brazos II, 30 to 50 miles to the east.

The texture on the shelf is poorly sorted sandy silt. It varies considerably in the first 25 miles of the continental shelf, but seaward is fairly uniform well-sorted fine sand having a median of 75 to 125 microns. The texture changes to clay with median of 1 to 2 microns on the continental slope and in the Sigsbee deep, except for sample 352, where the median is 8.6, and sample 343 where it is 25 microns. Sample 352 lies on the seaward slope of a trough but no apparent topographic irregularity is indicated for sample 343, which lies in more than 1000 fathoms of water. Sample 343A, adjacent to sample 343, has a median diameter of 1 micron.

The organic content, varies inversely with the texture. The nitrogen content is less than .04 percent in the sands on the continental shelf and is more than .08 percent on the upper part of the continental slope. It decreases slightly seaward, but even in the Sigsbee deep ranges between .07 and .08 percent. The C/N ratio is variable, decreasing from 10.5 on the continental shelf to 9.5 in deep water.

Heald Bank. This profile southward extends across the continental shelf from Galveston Bay to the upper part of the continental slope in

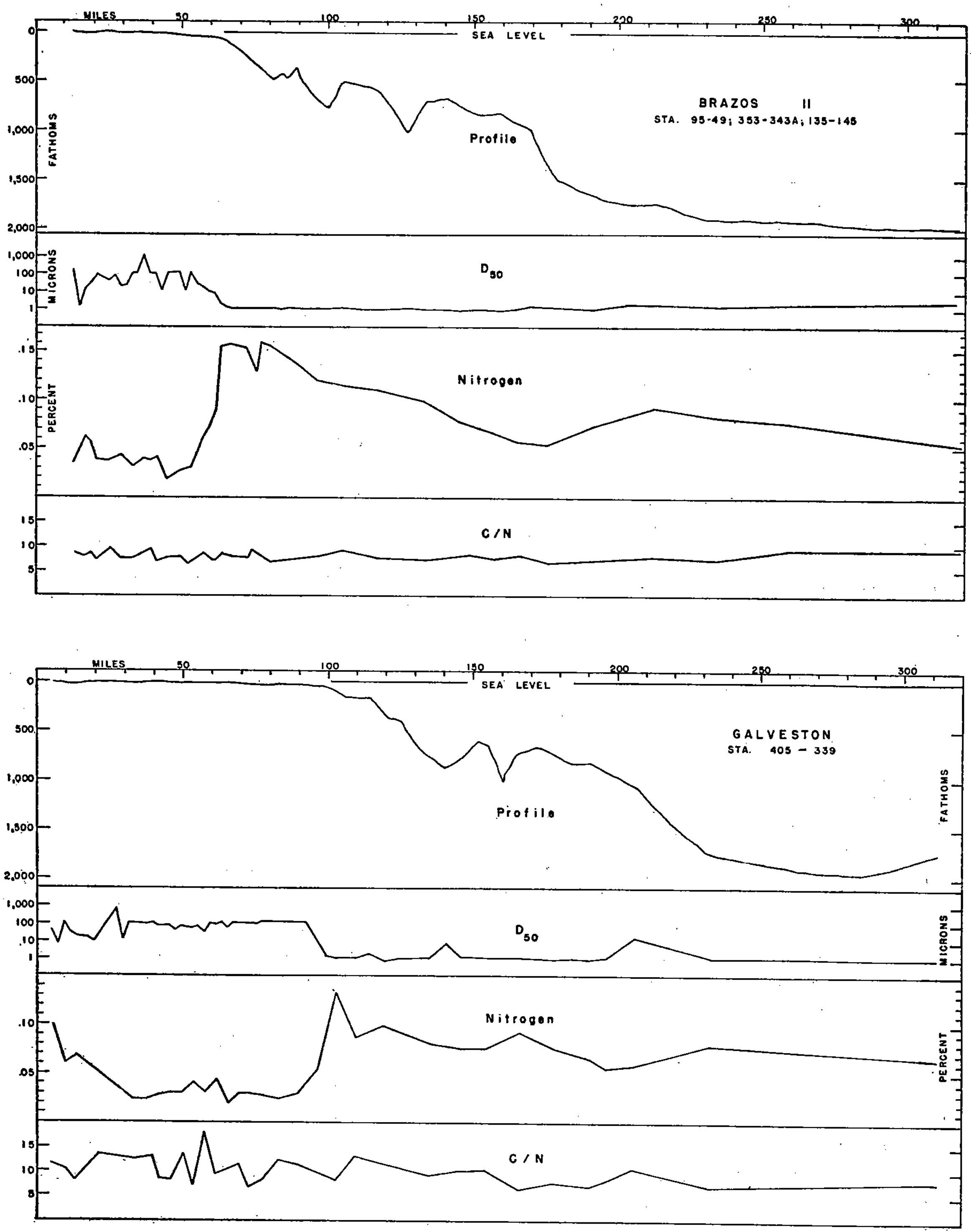


Fig. 6. Basic data on surface sediments along profiles, III. Brazos II and Galveston profiles. See fig. 1 for location and fig. 4 for explanation.

460 fathoms (Stations 7 to 43, Fig. 5). It lies 30 miles east of the Galveston profile. The continental shelf slopes gently and is smooth. The continental slope is irregular and is cut by numerous troughs 50 to 100 fathoms in relief.

The sediments are sandy silt with medians of 40 to 80 microns near shore, but seaward they coarsen to fine sand with medians of 75 to 175 microns. Near shore the sediments are poorly sorted. On the outer edge of the shelf the samples are well sorted. The sediments on the continental slope are clay with median of 1 micron and a sorting coefficient of 3.

The nitrogen content rises abruptly from .03 percent in fine sand at the outer edge of the shelf to 0.16 percent in clay on the upper part of the continental slope. The carbon-nitrogen ratio is variable, but in general is between 7 and 9.

Trinity I. The Trinity I profile lies 75 miles east of the Heald bank profile (Stations 406 to 451, Fig. 7). The continental shelf is wide in this part of the Gulf. The first station, taken in 10 fathoms of water (Core 406), is more than 30 miles from shore. The outer edge of the shelf is 150 miles from shore. The bottom on the outer part of the shelf is irregular, having a relief of more than 25 fathoms. The adjacent continental slope likewise is rough.

The texture on the continental shelf is variable. At least four areas of fine sand separated by areas of clay and sandy silt are indicated. The continental slope, as in other places, is underlain by fine clay with median of 1 to 2 microns. The sediments on the shelf vary in sorting. They are particularly poorly sorted between miles 90 and 100 on the outer edge of the shelf.

The nitrogen content similarly is variable. In the sand it is less than .05 percent, whereas in the clay near the outer edge of the shelf and on the continental slope it is more than 0.10 percent. The C/N ratio ranges between 7 and 19 on the landward side of the shelf, in general being more than 12. Seaward it is more constant, but averages 9.5, which is higher than on most other places on the continental shelf and slope.

Trinity I-A. This profile trends southeastward from a sea-mount on the outer edge of the continental shelf, 25 miles west of the line of Profile Trinity I (Stations 466–480, Fig. 7). The sea-mount does not show on the profile, and only one sample, No. 462, from the lower part of this mount was analyzed for organic matter. The samples on top of the mount in 9 fathoms of water are coarse coral and lithothamnium. The sediments coarsen down the slopes. Sample 462 in 127 meters contains .074 percent nitrogen, and 0.71 percent carbon. The C/N Ratio is 9.6 and the calcium carbonate content is 14.4 percent. The median diameter is 6.1 and the sorting coefficient 4.5.

The depth of water on the rest of the profile ranges from 75 to 1000 fathoms. The profile trends southeastward at an angle of approximately 45° with the contours. The topography as indicated by the fathometer is more irregular than shown in Fig. 7, the irregularities in general being of the order of 50 to 100 fathoms. The sediments consist of fine clay with medians of 1 to 2 microns, except for three samples: No. 466 with 76 microns, 470 with 131 microns, and 471 with 13 microns. All these samples are on the upper part of the continental slope in water less than 175 fathoms deep. The sediments shoreward from Station 471 vary considerably in sorting but the deeper samples are well sorted, with coefficients of about 3.

The organic matter varies greatly throughout the entire profile, ranging from .05 to 0.16 percent. The general average is about 0.10 percent. The organic content tends to decrease seaward. The C/N ratio ranges mainly between 8 and 11; the average being 9.5. The ratio for deeper samples is lower, about 7.5 (Stations 510 to 480, Fig. 7).

Trinity II. This profile lies 80 miles east of Trinity I. The continental shelf is broad and flat. The first sample, No. 510, is more than 50 miles from shore. The outer edge of the shelf and much of the continental slope are irregular, containing troughs more than 200 fathoms deep. The sediments on the shelf are more fine-grained than on the sections previously described. The median diameter ranges mainly between 3 and 10 microns. Sample 487 in 100 fathoms of water at the outer edge of the continental shelf about mile 90 is a very poorly sorted silt with a median of 26 microns and a coefficient of sorting of 12. The sediments on the continental slope are fairly uniform clay with a median of approximately 1 micron and a sorting coefficient of 3. The sediments on the landward part of the shelf range in sorting between 3 and 6.

The organic content varies greatly on the continental shelf and on the upper part of the continental slope, but in the lower part is fairly uniform. The range in nitrogen on the shelf is

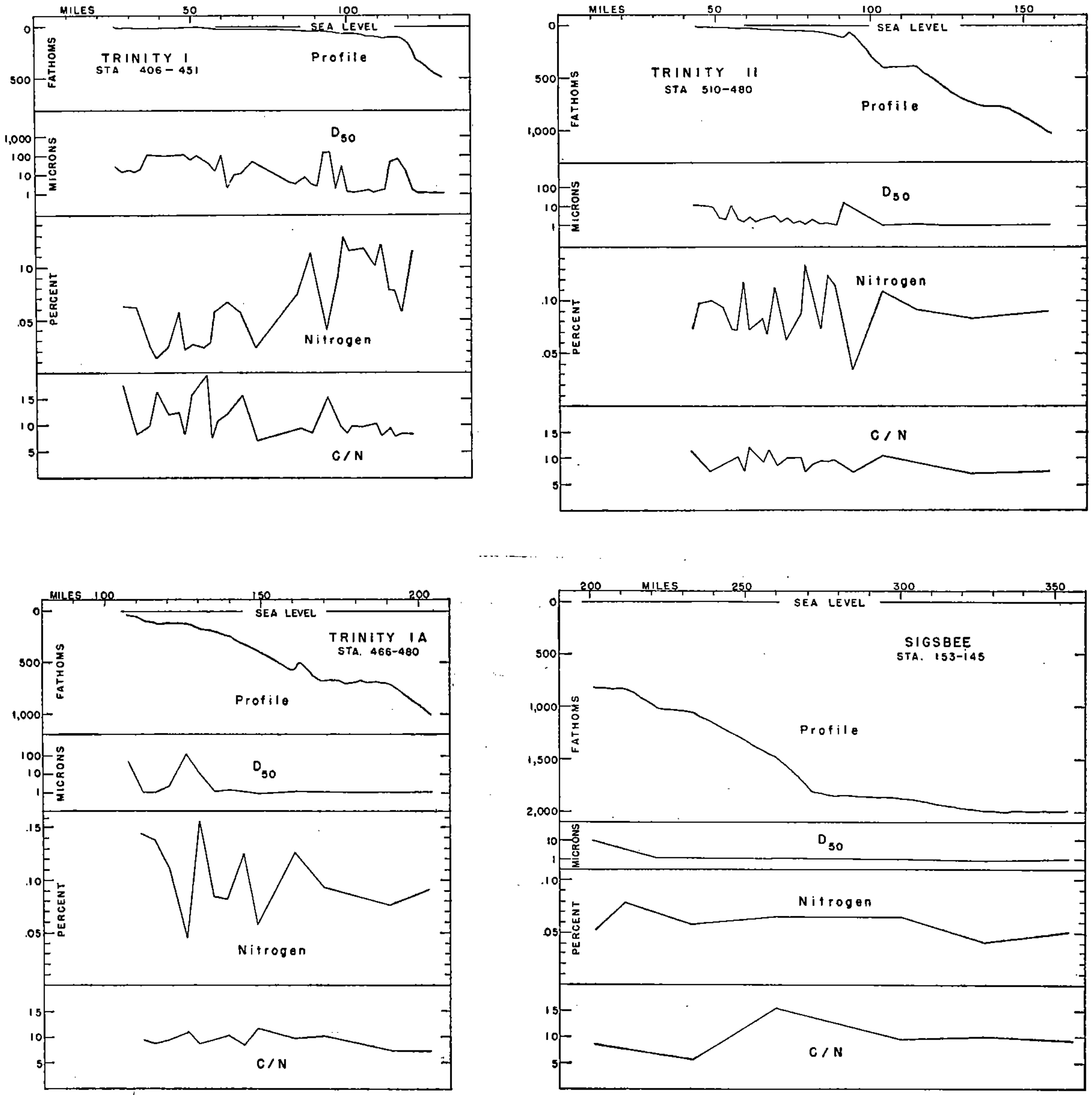


FIG. 7. Basic data on surface sediments along profiles, IV. Trinity I, I-A, and II and Sigsbee profiles. See fig. 1 for location and fig. 4 for explanation.

.07 to .13 percent and on the slope it is .09 percent. The C/N ratio is mainly between 8 and 12, and averages about 9. It tends to decrease toward the lower part of the continental slope where it is 7.5.

Ship Shoal. The eastermost profile, the Ship Shoal profile, extends 300 miles southwestward from the mouth of the Mississippi River (Stations 511 to 551, Fig. 8). The outer edge of the continental shelf shows an apparent terrace about 80 miles from shore in about 90 fathoms of water. The continental slope in general is regular except for a small trough 75 fathoms deep in 1000 fathoms of water near mile 140 and sample 541.

The samples are fine-grained. The median diameter is 25 microns near shore and becomes progressively finer until about 50 miles from shore where it is less than 2 microns. Seaward from this point the median ranges mainly between 1 and 2 microns. The coefficient of sorting is between 3 and 6 for the first 75 miles of the profile, beyond which it is fairly uniformly 3. The organic content on the shelf and on the continental slope is va-

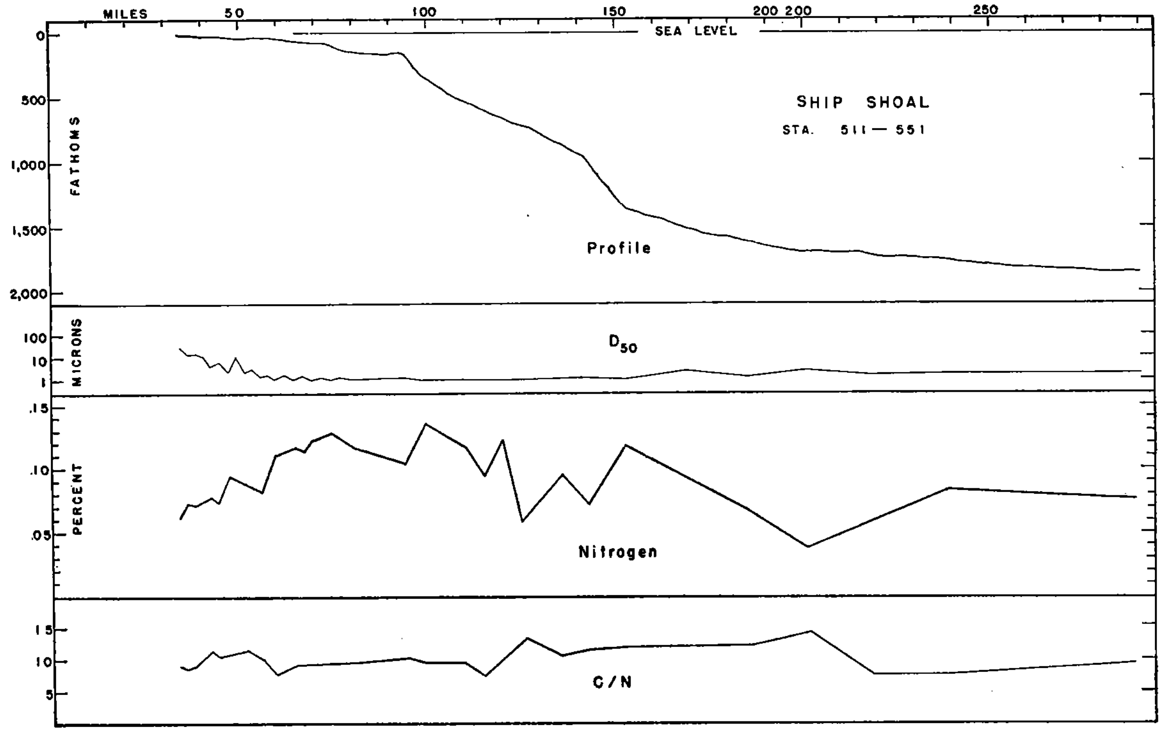


FIG. 8. Basic data on surface sediments along profiles, V. Ship Shoal profile. See fig. 1 for location and fig. 4 for explanation.

riable. In general it increases seaward from .06 percent near shore to 0.12 percent 70 miles from shore, and then ranges between .06 and .14 percent for the next 80 miles. The nitrogen content in the Sigsbee deep is .04 to .08 percent, being somewhat less than in other deep parts of the Gulf. The C/N ratio ranges mainly between 8 and 11 on the shelf, between 9 and 14 on the slope, and between 7 and 12 on the Sigsbee deep.

RELATION OF ORGANIC MATTER TO TEXTURE

The distribution of organic matter on the profiles just described shows that the organic content varies inversely with the texture. It is low in sands and high in clays. The texture, of course, is only one factor affecting the deposition of the organic matter, but if the other factors are more or less constant it is conceivable that a quantitative relationship might be found between organic matter and texture. In order to explore this hypothesis, the nitrogen content of samples on the continental shelf and on the adjacent upper part of the continental slope in water less than 500 fathoms in depth, was plotted against the median diameter. Samples on the lower part of the continental slope were omitted because in that area variation in texture is not a dominant factor controlling organic content. It is obvious from the profiles just described that organic content decreases down the slope, yet the texture remains constant. Perhaps the rate of production of organic matter is the controlling factor there.

The results of this compilation are shown in Fig. 9. Except for a few scattered samples which conceivably could be incorrectly analyzed, the nitrogen content exhibits a definite relationship to the grain size. The equation for the general trend, indicated by the solid line passing through the central part of the population of dots is indicated by the equation

$$N = .135 - .053 \log_{10} D_{50}$$

where D_{50} is expressed in microns

and nitrogen in percent of the total weight of the sediment. If the Phi scale of Krumbein (1938) is used the equation becomes

$$N = .016\,\phi - .025$$

If organic matter, M, is taken as 15.5 times

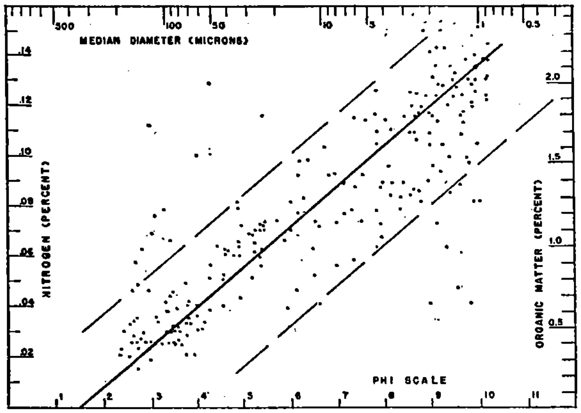


FIG. 9. Relation of organic content to texture of surface sediments. Organic matter is estimated as 15 times the nitrogen content. Nitrogen content is expressed in percent of total weight of sediments. Texture is presented in terms of average (median) diameter, D_{50}, in microns in upper scale and in Krumbein's Phi units in lower scale. Dots represent individual analyses; heavy line is average relationship; dotted lines indicate general limits for the relationship.

the nitrogen content, the equation in terms of median diameter in microns is:

$$M = 2.1 - .82 \log_{10} D_{50}$$

and in terms of Phi:

$$M = .25\,\phi - 0.4.$$

In all these equations nitrogen and organic matter are expressed as percent of the total weight of the sediments, D_{50} in microns and Phi in Krumbein's Phi scale (Krumbein and Pettijohn 1938, p. 233). Phi is the negative logarithm to the base 2 of the median diameter D_{50} as measured in millimeters.

Most of the dots on the chart fall between two lines, shown in dashed pattern on Fig. 9, which are essentially parallel to the line for the general average. The equation for these two boundary lines in terms of organic matter, M, and ϕ is

$$M = .25\,\phi + 0.1 \quad \text{and}$$
$$M = .25\,\phi - 1.0$$

The two boundary lines and the general average have a slope of $.25\,\phi$, which means that the organic content varies in a regular manner with the texture. The organic content of fine sand, silt, and clay on the continental shelf of the Gulf of Mexico stand in approximate ratio of 1, 2 and 4, just as do marine sediments from other parts of the world (Trask 1932, p. 77).

RELATION OF ORGANIC MATTER TO BOTTOM CONFIGURATION

The profiles shown in Figs. 4 to 8 do not indicate any relationship between organic content and details of topography. The samples evidently are too widely separated to show relationships if any exist. The broad topographic features of the Gulf however do influence the organic content. The continental shelf, continental slope and abyssal deep of the Gulf, each has its own particular effect upon the organic constituents. The essential characteristics of the organic matter in these three environments are summarized in Table 1 and in Fig. 10.

The calcium carbonate content on the shelf averages 5.3 percent compared with 21.3 and 28 percent upon the continental slope and the Sigsbee deep. Obviously decreasing dilution with terrigenous debris is a factor in the progressive increase in carbonate content seaward. It is very interesting that the increase in $CaCO_3$ is analogous to the increase in carbonate content within a similar distance in the geosyncline of the lower part of the upper Cretaceous in Wyoming (Trask and Patnode 1942, p. 211), where the carbonate

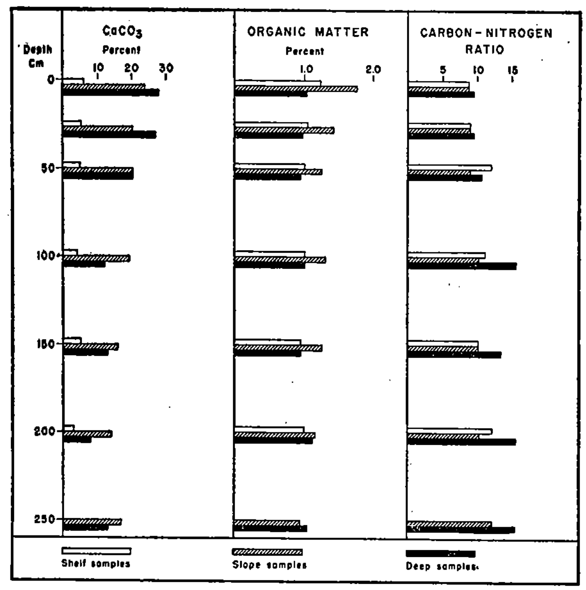


FIG. 10. Variation of organic matter and calcium carbonate with depth of burial of sediments.

content increases from about 5 percent in western Wyoming to 30 percent in southeastern Wyoming.

The organic content as indicated both by nitrogen and carbon is relatively low on the continental shelf, high on the continental slope, and intermediate in the ocean deeps. The average nitrogen content for the three depth zones is .063, .119 and .068 percent respectively and the carbon content, 0.53, 1.02 and 0.63 percent. The organic content as computed from nitrogen and carbon is about 1.0 percent on the shelf, 1.5 percent on the slope and 1.1 percent in the deep. The carbon-nitrogen ratio is essentially constant, 8.5, on the shelf and slope, but increases slightly seaward to 9.5 in the Sigsbee deep.

The above figures represent the average (median) of a fairly large number of determinations, more than 750 in all. Individual analyses deviate from these averages, but more than one-half the determinations are within 40 percent of the average. The maximum organic content is slightly more than 2.0 percent, the minimum is about 0.25 percent.

VARIATION OF ORGANIC MATTER WITH DEPTH OF BURIAL

Short Cores

The discussion thus far has dealt with the surface layers of the deposits. The cores, particularly the long cores, give information upon the distribution of organic matter with depth of burial. Two fundamental problems are connected with the organic content at depth in the sediments: 1, the change in quality and quantity of organic matter for given organic content, and 2, the areal variation of organic matter at given depths or at depths corresponding to given time zones of deposition.

Both problems are inter-related. The question of rate of decomposition of organic matter for given conditions and duration of burial is complicated by uncertainty as to original quantity of carbon in the organic matter at the time it was deposited. The question of areal variations for given depths, likewise is complicated by uncertainty as to variations in rate of decomposition of organic matter both areally and for given depths of burial.

In order to approach the problem, it is desirable to study conditions in an area in which similar environmental conditions prevail, with the hope that the initial rate of deposition of the organic matter would be essentially the same over a large part of the region for given periods of time. The continental shelf seemingly is the most favorable area in which to examine this problem. The fairly constant relationship between organic content and texture for the shelf sediments shown in Fig. 9 suggests a reasonably similar areal rate of deposition. By the same token, the continental slope and the abyssal deep, because of their quantitatively different relationship of organic matter to texture, could be considered as being separate environments of deposition.

With this object in mind the content of the organic constituents of the top and bottom parts of the short cores in the three depth zones,— shelf, slope and deep, have been compared in Table 2 and Fig. 10. In the preparation of Table 2 the ratio of the particular organic constituents in the sediments at the bottom of the core to the same constituents at the top of the core was computed. The individual ratios thus determined were then compiled statistically for each depth zone and the average change between the bottom and top determined.

The probable error of the averages as reported in the table was computed by dividing the semi-interquartile range by the square root of the number of samples. Strictly speaking, the top of the sediments is not represented in the averages, because the upper 5 to 10 centimeters of each core were removed by Phleger for foraminiferal studies. More precisely, the data can be considered as indicating the ratio of the organic constituents at 25 centimeters to the same constituents at 10 centimeters beneath the surface.

The carbon content of the shelf samples at a depth of 25 centimeters is 90 percent of the content at 10 centimeters. That is, in the 15 centimeters between depths of 10 and 25 centimeters, the carbon content of the shelf samples has decreased 10 percent on the average. The nitrogen content however at a depth of 25 centimeters is only 81 percent of the nitrogen content at 10 centimeters. In other words it has decreased 19 percent, or nearly twice as rapidly as the carbon. The carbon-nitrogen ratio has increased some 13 percent in this depth interval.

On the continental slope both nitrogen and carbon have decreased 13 percent on the average, though according to the data for carbon-nitrogen ratio, which has increased 5 percent, it might seem as if nitrogen on the slope samples also may decrease a little more rapidly than carbon. The data however are inconclusive, as the variations can be ascribed to (1) probable error in determination of the averages; (2) different conditions of deposition of organic matter in the deeper layers or (3) to different rate of decomposition of organic matter by bacteria between the time the sediments were collected and the time they were analyzed,— an interval of four months. Conceivably the rate of deposition of the sediments could be materially slower on the slope than on the shelf, with the result that the depth interval of 15 centimeters may represent a much longer interval of time than for a corresponding interval of distance on the continental shelf (see Phleger and Parker, 1951, p. 82).

The data for the abyssal deeps indicate a 5 percent increase in organic carbon, an 8 percent decrease in nitrogen and a 12 percent increase in carbon nitrogen ratio. The probable errors of the determinations are high, owing to variability in the distribution of organic matter and the relatively small number of samples. However, it seems obvious that nitrogen decreases more rapidly than carbon with depth of burial in the deep-water sediments, but the data do not give any convincing indication of the relative amount of decrease in organic matter, because of the fact that the average carbon content is greater at a depth of 25 centimeters than at 10 centimeters. It is hard to believe that the organic content would increase after it had been entombed in the sediments. It would seem as if the original organic content on the average was greater when the sediments at a depth of 25 centimeters were deposited than when those at a depth of 10 centimeters were laid down. Also the sediments in the deep water probably were deposited at an even slower rate than those on the continental slope, which being nearer shore would be supplied with a greater content of terrigenous debris for given intervals of time.

The calcium carbonate content on the average seems to be 5 or 6 percent less at a depth of 25 centimeters than it is at a depth of 10 centimeters in each of the three depth zones, the continental shelf, the continental slope, and the Sigsbee deep.

If the organic content of the sediments decreases 10 percent, between depths of 10 and 25 centimeters, as indicated by the data on carbon, the organic matter obviously must decrease between the surface and a depth of 10 centimeters. Adequate determinations of the organic content between depths of 0 and 10 centimeters are not available to give a figure for the decrease if any, but a statistical study of 14 cores for which nitrogen was determined at both of these positions indicates an average loss of 10 percent in the upper 10 centimeters. If nitrogen decreases twice as rapidly as carbon, as indicated by the data for the interval 10 to 25 centimeters, then the organic content has decreased 15 percent in the upper 25 centimeters. That is, 5 percent between 0 and 10 centimeters and 10 percent between 10 and 25 centimeters. These figures are similar to the data obtained in the writer's previous study of near-shore sediments (Trask 1932, p. 205), though the 1932 figures are based to a considerable extent upon nitrogen. The Gulf of Mexico sediment accordingly might be presumed to have a more rapid rate of decomposition than marine sediments as a whole. The warmer water in the shallow water of the Gulf might lead to a more rapid rate of decomposition.

Long Cores

The changes in the organic constituents with depth of burial in the long cores are summarized in a series of charts and tables (Figs. 11 to 14, Tables 3 to 9). The principal characteristics of the three depth zones,— shelf, slope and deep, are summarized in Fig. 10. This figure shows the organic content, the carbon-nitrogen ratio and the calcium carbonate content at the surface of the deposits and at 50 centimeter intervals beneath the surface for the three main types of sediments— shelf, slope and deep water. The table is based solely upon depth of burial and does not take into consideration rate of deposition of the sediments. In order to show changes with depth of burial for given environments of deposition, an attempt has been made to segregate the cores roughly according to rate of deposition. Table 3 shows the changes with depth of burial for sediments on the continental shelf. Tables 4 to 8 show the changes with depth in the temperature zones found in the continental slope and deep water cores. Phleger and Parker (1951, pp. 67–72) have found that the foraminifera in many of the cores on the continental shelf and the Sigsbee deep are found in temperature zones. The foraminifera in the cold zones are similar to those now found between Cape Henry and Cape Cod, suggestive of colder water

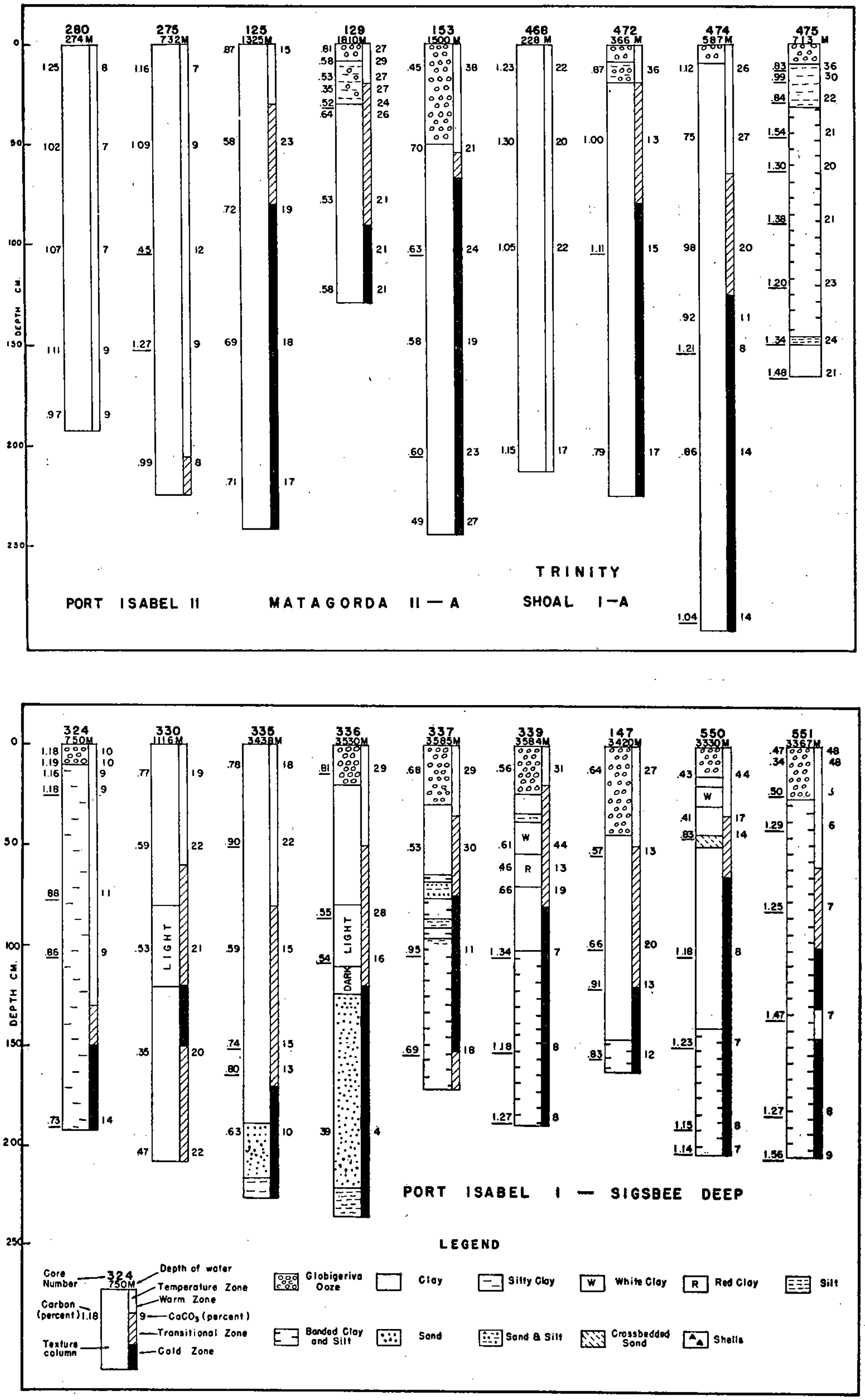


FIG. 11. Basic data on subsurface sediments along profiles, I. Port Isabel II — Trinity Shoal I-A, and Port Isabel I — Sigsbee deep profiles. See fig. 1 for location.

in the Gulf associated with glacial conditions. The sediments between the cold and warm zones are commonly associated with a transition fauna intermediate between cold and warm. A few of the cores show recurrent warm and cold zones beneath the upper cold zone. Phleger and Parker ascribe these variations to minor fluctuations in the last glacial stage. It could be presumed that the sediments deposited in the first warm zone, the first transition zone and the first cold zone represent comparable periods of time in each core. Thus changes of organic matter between the successive temperature zones and also within each temperature zone in part represent changes with respect to time.

In addition to the temperature zones, distinctive lithologic zones are encountered in a few places, each suggestive of similar conditions of deposition and therefore possibly indicative of time zones. Data from such zones are summarized in Table 9.

Detailed results of all the subsurface samples are presented in Figs. 11 to 14 which show for each long core, the carbon content, the texture, the type of temperature zone, and the calcium carbonate at each interval of depth that was investigated. The cores are arranged in sequence along the principal profiles shown in Figs. 4 to 8. A transverse profile along the upper part of the continental shelf in water 500 to 1000 fathoms in depth is shown in Fig. 14. The location of this profile is indicated on Fig. 1. Basic data on all analyses are given in Table 10. The information on texture shown in Figs. 11 to 14 was obtained by Trask shortly after the cores were opened. More detailed information on the texture of the long cores is presented by Stetson (1953).

General Distribution of Organic Matter with Depth

According to Fig. 10 which shows the distribution for depth of burial, without regard to time equivalents, the organic content of each environmental zone of deposition, namely shelf, slope and deep, decreases progressively with depth of burial, but the sediments even in the deepest zones do not differ greatly in organic content from those at the surface. In other words, during late glacial and post glacial time, the rate of accumulation of the organic matter per unit of thickness of sediment has been much the same. Similarly the organic content of the Tertiary deposits in the present Gulf coast have a similar organic content (Trask and Patnode, 1942, p. 341).

The carbon-nitrogen ratio increases with depth of burial, indicating the progressively greater rate of decomposition of nitrogen compounds than of carbon compounds. Calcium carbonate in the continental shelf samples is approximately 5 percent throughout the length of the cores. As the colder temperature zones are not encountered on the continental shelf, the shelf samples seemingly are all post-glacial in age. The carbonate content of the cores from the continental slope and Sigsbee deep decreases with depth of burial. The decrease is sharp at the change between warm and cold zones. The surface layers contain 20 to 30 percent calcium carbonate whereas the deep layers contain 8 to 15 percent.

Descriptions of Long Cores

Before commenting further upon the significance of the changes in the long cores, the individual cores are described in detail. Four types of information are presented for each core. The carbon content is expressed in terms of percent of total weight of the sample at the left side of the columns opposite the particular depth for the sample that was analyzed. As a rule, 5 centimeters of the core was taken for analyses. A line beneath the figure for carbon indicates the carbon-nitrogen ratio is greater than 11.

The texture was determined by Trask by hand lens inspection at the time the sample was fresh and undried. It is indicated by a pattern within the main part of the column. To the right is a narrow band representing the temperature zone for the foraminifera as determined by Phleger and Parker (1951, p. 67). No pattern indicates a warm zone, a barred pattern represents a transition zone, and a solid black pattern a cold zone. The percentage of calcium carbonate in the sediments is given at the right of the column. The depth of water for each core expressed in meters is given above.

Port Isabel— Sigsbee deep profile. The southernmost profile is shown in Fig. 11. It extends from Port Isabel at the mouth of the Rio Grande eastward to the middle of Sigsbee deep. It also includes cores 550 and 551 on the south end of the Ship Shoal profile, which cannot be shown on that profile because of lack of space. The data on

Fig. 11 are largely self explanatory, but a few comments can be given. All cores on this profile encountered the three temperature zones, mostly within 100 centimeters of the surface of the mud. A few cores encountered a second series of temperature zones.

The thickness of the post-glacial warm zone decreases toward the Sigsbee deep, with increasing distance from shore. Cores 335 and 336 in nearly 2000 fathoms (3500 meters) of water encountered well-sorted fine- to medium-grained sand in the cold temperature zone. According to Phleger and Parker (1951, p. 81) the benthonic foraminifera found in this sand zone normally live at much shallower depth than the depth in which these sediments now lie. In sample 336, more than 3 feet of sand are encountered. This sand is not stratified. It is very even in grain size throughout its entire length and it is well sorted (Fig. 16). Obviously peculiar conditions of deposition must have prevailed. Both samples 335 and 336 have silt below the sand.

The samples between cores 337 and 551 are peculiarly banded in the cold zones. The position of the banded zones is indicated by spurs on the sides of the main columns. This banded zone consists of alternating beds of clay and fine sand or silt (Fig. 17). The clay is fine-grained, probably as fine-grained as the clay now found on the continental slope. The silt is mostly between 10 and 20 microns median diameter. It commonly is as well-sorted as beach sand, yet it is a fine silt. Silts of such fineness found in other parts of the world ordinarily are not as well sorted as these silts. Most of the silt zones are much thinner than the clay zones. The clay zones on the average are 1 to 2 centimeters thick, though extremes of 20 or more centimeters are encountered. The silt zones, on the contrary, generally are only one or two millimeters thick, though zones up to 5 centimeters are seen. Some of the silt zones are moderately well sorted; others are coarse enough to be called fine sand. A peculiar mode of origin is most certainly indicated for these banded zones.

Core 339 in the west part of the Sigsbee deep in 2000 fathoms (3584 meters) contains three peculiar lithologic zones in the transitional temperature zone (Fig. 16): (1) a dark zone 1 centimeter thick consisting of fine clay at the top of the transition zone beneath the Globigerina ooze now being deposited, (2) a white clay, a short distance below, 15 centimeters thick and rich in calcium carbonate content, and (3) a red clay, immediately below the white clay, 10 centimeters thick, which looks much like red clay of the deep ocean abysses. The red clay has a low content of calcium carbonate,—13 percent compared with 44 percent in the white clay above. Immediately below the red clay is the top of the cold zone. The low calcium carbonate content as is discussed in Section II of the present report, suggests that the red clay was deposited during a period of relative undersaturation of the water with calcium carbonate at the close of the glacial times. The even lower carbonate content (8 percent) of the cold zone below, supports such a concept. In fact the carbonate content of all the cold zones on this profile is low. Another interesting feature of the cold zones is the generally high carbon-nitrogen ratio.

Port Isabel II — Matagorda II-A profile. This profile shown in Fig. 11 extends northeastward from the mouth of the Rio Grande across the continental slope and then eastward along the 1000 fathom line to sample 153 in the middle of the Sigsbee deep. Four other cores are shown on Fig. 11 but they belong to the Trinity I-A profile discussed below.

Cores 280 and 275 are on the upper part of the continental slope. The upper part of the transition temperature zone is encountered at the bottom of Core 275. The sediments consist entirely of clay. As a rule they decrease slightly in organic content from top to bottom. Calcium carbonate is essentially constant the entire length. It would seem as if conditions of deposition were similar during the deposition of these cores. Cores 125, 129 and 153 are typical of the lower part of the continental shelf. They contain the three temperature zones; two of the cores have Globigerina ooze at the top. The banded clay zone seen in the Port Isabel I profile to the south is absent. Organic content does not vary greatly from top to bottom and calcium carbonate decreases only moderately with depth.

Brazos II — Sigsbee profile. This profile, shown in Fig. 12, extends southeastward from the mouth of the Brazos River to the middle of Sigsbee deep at Core 145 and then doubles back along the Sigsbee profile to sample 149. Temperature zones are found in all cores, and three cores, Nos. 48, 348 and 343, have recurrent temperature zones. Banded clay is encountered beneath the top of the

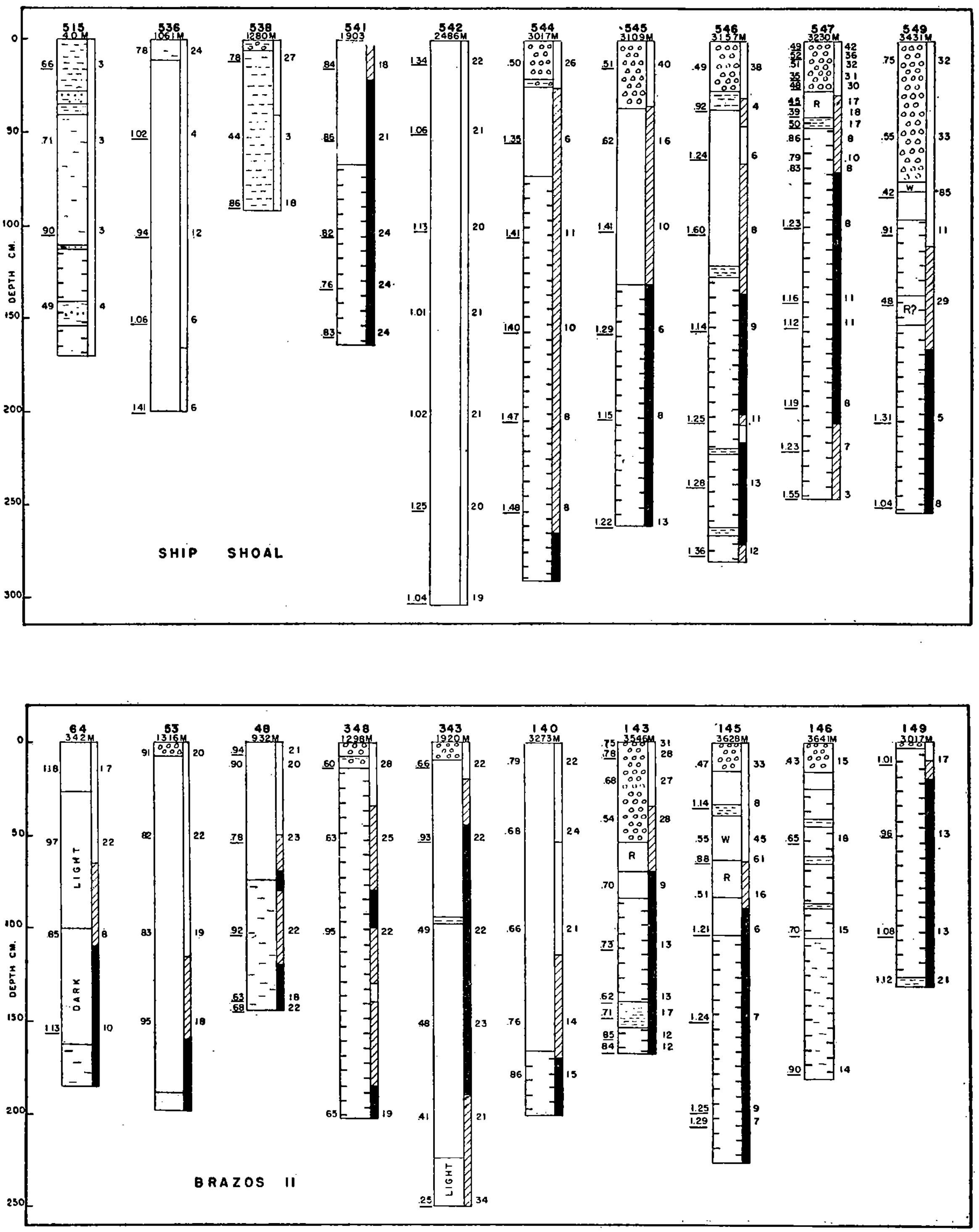


FIG. 12. Basic data on subsurface sediments along profiles, II. — Ship Shoal and Brazos II profiles. See fig. 1 for location and fig. 11 for explanation.

cold zone in most of the cores south of Core 48 on the upper part of the continental shelf. The white clay zone rich in carbonate is found at a depth of 40 centimeters in Core 145 just above the top of the transition zone. The red clay zone is found in Cores 143 and 145 at depths of about 60 centimeters immediately above the top of the cold zones (see Core 339, Figs. 11, 16 and 17). The organic content changes relatively little with depth of burial, though it varies from one core to another along the profile. The carbon-nitrogen ratio in the cold zones, as in the Port Isabel I profile, tends to be high. Calcium carbonate in the cores in deep water is considerably lower in the cold zone than in the warm zones, but in the cores on the continental shelf it is only moderately lower in the cold zone than it is in the warm zone.

Trinity I-A profile. This profile, shown in Fig. 13, extends southeastward from Core 14 on the Heald Bank profile on the continental shelf to Core 479 in 1317 meters (700 fathoms) on the upper part of the continental slope. The Trinity I-A profile cuts across a sea-mount at the edge of the continental shelf. The second core represented on Fig. 13, No. 462, is on the edge of the sea-mount in 126 meters (70 fathoms). The third core is on the seaward side of the mount in 157 meters and the other cores were taken at short intervals down the continental slope, which is characterized by topographic relief of as much as 400 fathoms in this vicinity. Owing to space limitations Cores 468, 472, 474, and 475 have been shown on Fig. 11.

Core 14 is sandy silt deposited on the continental shelf. It contains little organic matter and the quantity decreases with depth. Calcium carbonate also decreases with depth. Core 462 located on the side of the sea-mount, contains an alternating zone of silt and clay below a depth of 100 centimeters. This silt and clay is confined to the warm temperature zone and is different in appearance from the banded silt and clay of the cold water zone in other cores. The calcium carbonate content, however, is much lower in this banded zone than in the surface deposits. In this respect the zone is similar to banded zones in deep water. If this banded zone should represent late glacial time, then the rate of sedimentation on this sea-mount is slow.

The succeeding samples, shown on Figs. 13 and 11, are on the upper part of the continental slope. All except Cores 467 and 468, encounter temperature zones, but the thickness of the temperature zones varies from one core to another. Obviously conditions of deposition have not been constant on this part of the slope; perhaps in part owing to the varied topography of the sea bottom. The organic content in general decreases slightly with depth. The cold zones tend to have a higher carbon-nitrogen ratio, and the calcium carbonate content decreases in the cold zones, but not as great proportionately as it does in the cores in deep water. Banded clay is found in Cores 475, 476 and 477, but was not observed in the other cores. In Core 476 the bands extend through the transition zone into the warm zone.

Trinity Shoal II profile. This profile, shown in Fig. 13 extends southward across the continental shelf and down the slope to intersect Trinity I-A profile in Core 480 in 1000 fathoms of water. The first five cores, 422, to 486, are on the continental shelf. Core 422 in 20 fathoms of water, 75 miles off the west coast of Louisiana on Trinity I profile consists of grey silt for the first 60 centimeters, and of light and dark bands of silt to the bottom of the core at a depth of 180 centimeters. The sediments are poorly sorted throughout. The calcium carbonate content is 15 percent in the surface layers, and 5 percent at a depth of 3 centimeters. Below this depth, it decreases gradually to 2 percent at the bottom. The organic content increases slightly with depth, indicating a greater rate of deposition of organic matter for the older deposits.

Core 510 in 15 fathoms of water 50 miles east of Core 422 consists of uniformly dark grey clay, with a few sand partings from the top to the bottom of the core. A sand layer one centimeter thick is found at a depth of 152 centimeters, and another thin layer of sand at 174 centimeters. The organic content decreases slightly with depth. The calcium carbonate content is essentially 5 percent throughout the core. Core 504 in about 25 fathoms of water consists of silty and sandy clay, with a few sand lenses to a depth of 129 centimeters, below which it consists of green silty sand, in places containing shells. The organic content in general is low and variable. At a depth of 180 centimeters the sand is cross-bedded with an angle of 10°. Calcium carbonate except for the shell layers is less than 5 percent.

Core 498 in 35 fathoms of water consists of clay with occasional fine sand lenses to a depth of 70 centimeters, and silty clay at greater depth.

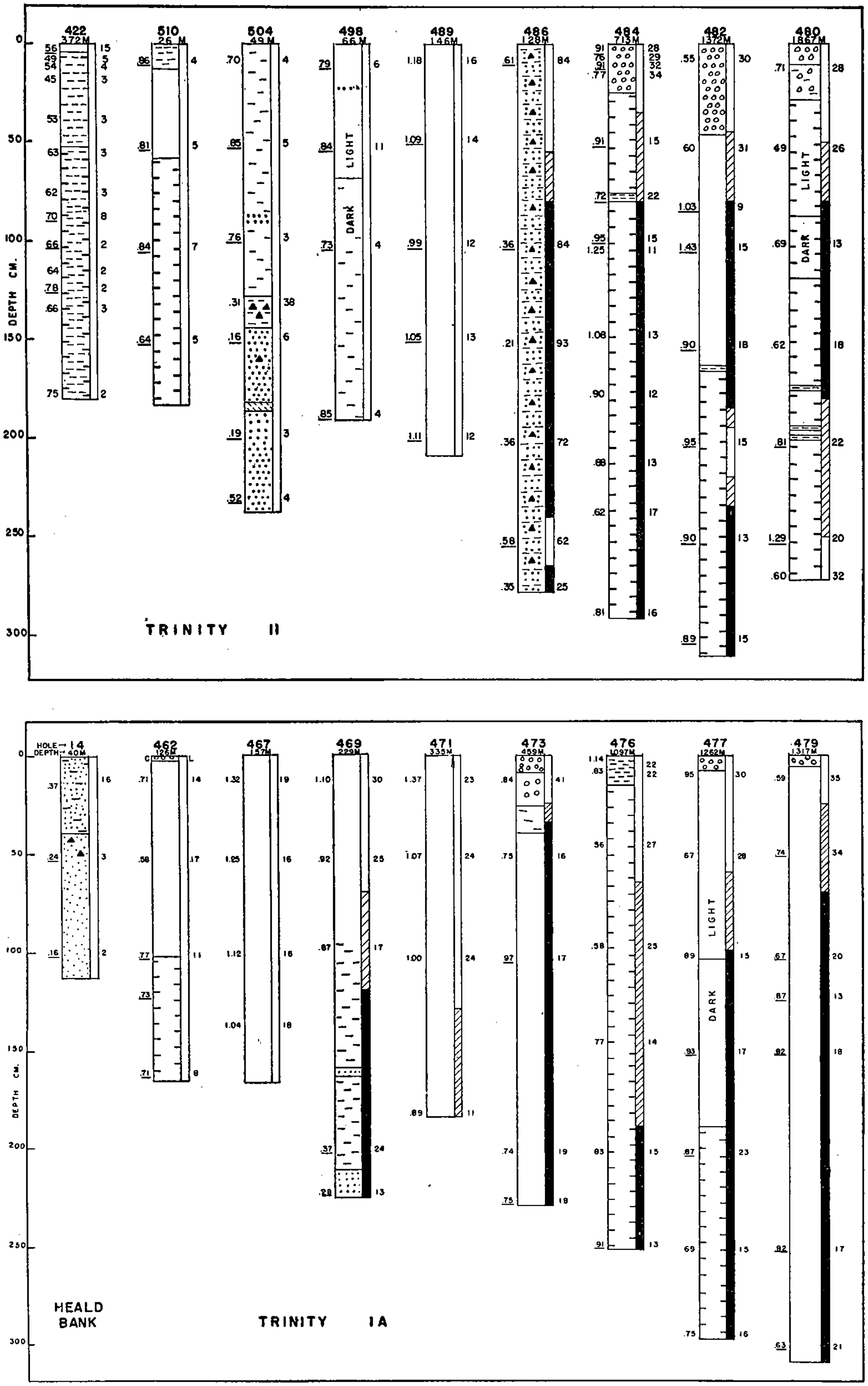


FIG. 13. Basic data on subsurface sediments along profiles, III. — Trinity I-A, and II profiles. See fig. 1 for location and fig. 11 for explanation.

The organic content and calcium carbonate are essentially constant throughout the core. Core 489 in 80 fathoms consists of grey clay of uniform carbon and calcium carbonate content from top to bottom. Core 486 in 127 meters near the outer edge of the continental shelf consists of a mixture of grey sandy clay and shells from top to bottom. Below a depth of 80 meters the sediments are in a cold water zone, except for a band of recurrent warm water zone between 240 and 255 centimeters. The organic content is low throughout the length of the core. Calcium carbonate is high, 84 percent in the surface layers, 72 to 92 percent in the upper cold zone, 62 percent in the second warm zone and 25 percent in the second cold zone at the bottom of the core. The carbon-nitrogen ratio is high in the lower part of the core. This core requires special explanation at is differs so much from other cores.

Core 484 in 400 fathoms of water consists of 25 centimeters of Globigerina ooze at the top, below which it consists of typical banded light and dark clay, with occasional silt zones. Most of the laminations are 1 to 2 centimeters in thickness. The organic content on the whole tends to decrease slightly with depth,— the carbon content being 0.91 percent at the surface and 0.81 percent at a depth of 290 centimeters. Calcium carbonate in the superficial Globigerina ooze is 30 percent and in the banded clay in the cold water zone, 11 to 17 percent. The greatest change in carbonate content is at the top of the transition zone.

Cores 482 and 480, farther down the continental slope, are similar to Core 484, except that they contain additional temperature zones beneath the upper cold zone. The organic content of the lower temperature zones is slightly greater than in the overlying zones. The carbon-nitrogen ratio of the lower temperature zones is high. Calcium carbonate is relatively low in the upper cold zone and underlying temperature zones, except that it is high,— 32 percent, in the second warm zone in Core 480 at a depth of 275 centimeters.

Ship Shoal profile. The easternmost profile in the Gulf, the Ship Shoal profile, is shown in Fig. 12. This profile consisting of Cores 515 to 551 extends from the mouth of the Mississippi River to the central part of the Sigsbee deep. Cores 550 and 551 are shown on Port Isabel I profile (Fig. 11). Core 515 in 20 fathoms of water on the continental shelf consists of silty clay with occasional lenses of sand. The organic content is moderately low, 0.7 percent, and fairly constant from top to bottom of the core. Calcium carbonate is low, 3 to 4 percent, throughout the core.

All other cores on this profile are on the continental slope or the abyssal deep. They encounter the temperature zones and with few exceptions are characterized by banded clay, silt, and sand in the cold zones. The warm zone is thickest in Core 536 in 600 fathoms on the upper part of the continental slope. The carbon content increases with depth, but the nitrogen content is essentially constant. The deeper sediments accordingly had a greater initial organic content than the surface deposits. Calcium carbonate is variable, but is much lower below a depth of 50 centimeters than at the surface.

Core 538 in 700 fathoms is a short core, only 90 centimeters in depth. It consists of silty clay of uniform texture from top to bottom. The top of the transition zone is encountered at 40 centimeters. The sediments at this point contain only 3 percent calcium carbonate, compared with 27 in the surface layers and 18 percent in the lower part of the transition zone. The organic content is moderately low and variable.

Core 541 in 1000 fathoms is chocolate grey clay with faint light and dark bands below a depth of 50 centimeters. This core is unusual in that the transition zone is found close to the surface and the cold zone lies only at a depth of 20 centimeters. The organic content is essentially constant, 0.8 percent, throughout the core. Calcium carbonate increases slightly with depth, being 18 percent in the transition zone near the surface and 24 percent near the base of the core in the cold zone. Carbon-nitrogen ratio is high in the cold zone.

Core 542, 10 miles seaward from Core 541 in 1350 fathoms is uniform grey clay throughout its entire extent of 300 centimeters. It contains no bands and is entirely in the warm zone. Both organic content and calcium carbonate are remarkably uniform from top to bottom of core. It is strange that this core situated only 10 miles seaward from Core 541 in 310 fathoms deeper water did not encounter the transition zone in 300 centimeters of sediment, whereas Core 541 contained no warm zone at all. It would almost seem as if the superficial Globigerina ooze and warm zone sediments in Core 541 had been removed by slumping or submarine erosion and the warm zone material piled up in Core 542 a short distance seaward.

Core 544 in 1600 fathoms seemingly is a normal deep-water core, except that the transition zone is 240 centimeters thick. Banded clay extends from a depth of 72 centimeters to the bottom of the core. The organic content increases with depth. Calcium carbonate is relatively low throughout the transition zone, being 6 to 10 percent, compared with 26 percent in the surface sediments. Cores 545 and 546 in essentially the same depth of water as Core 544 have no peculiar characteristics, except Core 546 encounters lower temperature zones at depth. Organic content and calcium carbonate in these secondary zones is similar to what it is in the overlying sediments.

Core 547 near the central part of the Sigsbee deep in 1750 fathoms contains a band of red clay 15 centimeters thick at a depth of 25 centimeters immediately below the superficial Globigerina ooze (Fig. 17). Like other red clay zones, this red clay is found near the top of the transition zone. A lower transition zone is encountered at a depth of 205 centimeters. The organic content of this zone is similar to the organic content of the overlying sediments but the calcium carbonate content is lower.

Core 549 in 1850 fathoms is similar to other deep-water cores, except that it contains a band of white clay, 5 centimeters thick, at a depth of 75 centimeters. This white clay, like the white clay in other cores, has a high carbonate content and lies near the top of the transition zone. A zone of reddish clay 15 centimeters thick is encountered at a depth of about 140 centimeters in the central part of the transition zone. This red clay is similar to the red clay observed in other cores. It occurs in the transition zone, but has a high carbonate content, 29 percent compared with approximately 15 percent in other cores.

Transverse profile. In order to trace lateral changes for given depth zones a transverse profile is shown in Fig. 14. This profile extends along the upper part of the continental slope in water 100 to 500 fathoms deep, from the south coast of Texas 100 miles north of the mouth of the Rio Grande (Core 261) to the mouth of the Mississippi River (Core 532). The continental slope along this

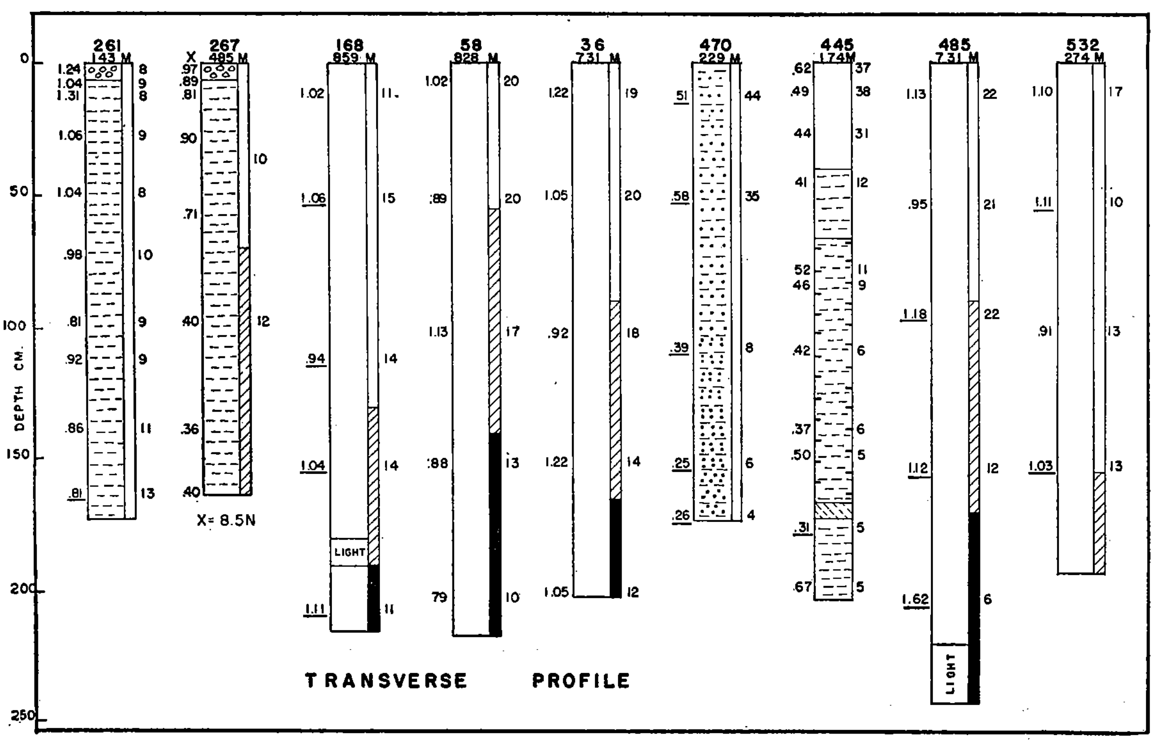


FIG. 14. Basic data on subsurface sediments along profiles, IV. Transverse profile. See fig. 1 for location and fig. 11 for explanation.

profile is irregular and is characterized by troughs and valleys up to 400 fathoms in relief.

Core 261 in 75 fathoms at the west end of the section, consists of poorly sorted silt from top to bottom. The organic content decreases moderately with depth; calcium carbonate rises slightly. Core 267 in 250 fathoms is silt throughout its extent. This core, however, encounters the transition zone at a depth of 70 centimeters, whereas core 261 is entirely in the warm zone. The organic content decreases markedly between the warm and transition zones in Core 267.

Core 168 in 500 fathoms encounters all three temperature zones. The surface sediments are clay instead of silt. The carbon content is high, 1 percent, from top to bottom. The carbonate content ranges between 11 and 14 percent. The carbonate content of Cores 261, 257, and 168 at the west end of the transverse profile ranges between 8 and 11 percent, compared with 20 to 44 percent in the central part of the profile and 17 to 22 percent at the east end. As the two ends of the profile are near the mouths of large rivers, perhaps the lower carbonate content is a reflection of greater admixture of terrigenous debris.

Cores 58 and 36 in the central part of the profile consist entirely of clay. The carbon content, as in other cores on the transverse profile, is relatively high, ranging mainly between 1.0 and 1.2 percent. The organic content decreases appreciably with depth in Core 58 but not in Core 36 in which it is essentially constant throughout. Core 470 along the line of samples taken down the continental slope off the sea-mount on the Trinity I-A profile consists of sandy silt and sand throughout its entire length. The coarse texture of this core perhaps may be a reflection of the irregular bottom topography in this area, though perhaps it represents submarine slumping, as the entire core is in the warm zone. The calcium carbonate content however decreases appreciably in the core, being 44 percent at the surface and 8 percent at a depth of 100 centimeters. The organic content also decreases markedly below a depth of 50 centimeters. Despite the similar texture, the lower sediments are of different character than the upper sediments. Thus if the sediments have slumped, they have slumped in a peculiar manner to give such different material in the lower part. Perhaps the sediments slumped and then were covered with layers of normally deposited sediments.

Core 445, some 15 miles east of Core 470 in 100 fathoms of water near the edge of the continental shelf varies in texture with depth. The upper 40 centimeters are clay, the next 125 centimeters consist of banded silt and clay and are poorly sorted. The bands are 1 to 4 centimeters thick. At a depth of 170 centimeters is a thin zone of fine-grained cross-bedded sand, below which is poorly sorted silt. The core is entirely in the warm zone. The variable lithology indicates varying conditions of deposition. The position of this core near the edge of the continental shelf would favor varying conditions of sedimentation. The organic content is moderately low, and decreases slightly with depth, though it is relatively high at the bottom of the core. Calcium carbonate is high, 31 to 38 percent in the upper clay zone, and is low, 5 to 12 percent in the lower banded clay and silt zones.

Cores 485 and 532 to the east have an essentially constant organic content throughout their extent, but the calcium carbonate content is considerably lower in the transition and cold zones than in the surface sediments.

Summary of Depth Changes

The changes that take place with depth in the individual temperature zones have been summarized in Tables 3 to 9. Table 3 shows changes in the warm temperature zone on the continental shelf. Owing to the effect of texture, the data have been classified with respect to sand, silt, and clay. Carbon decreases from 0.37 percent in the surface deposits to 0.16 percent at a depth of 150 to 200 centimeters in sand; from 0.83 to 0.52 percent in silt; and from 1.00 percent to 0.91 percent in clay. The organic content therefore seemingly decreases more rapidly with depth of burial in sand than in clay. This feature may be associated with the greater permeability of the sand which permits greater circulation.

Nitrogen shows similar changes, decreasing from .036 percent in surface sand to 0.005 percent at a depth of 150 to 200 centimeters; from .085 to .066 in silt; and .103 to .076 percent in clay. Carbon-nitrogen ratio as a rule increases with depth in sand, silt and clay, but the data are too variable to indicate definite relationships. It would seem as if the ratio increases more in sands than in clay, thus suggesting a greater rate of decomposition in sand of nitrogen with respect to carbon. Calcium carbonate tends to decrease with depth of burial, but the data are too conflicting to be convincing.

The cores on the continental slope and in the Sigsbee deep as a rule encounter the three temperature zones. The thickness of these zones both for the continental slope and deep water are summarized in Table 4. As the bottom of the cold zone was not reached in most of the cores, the data for the cold zones in the last column serve only to indicate the relative thickness of the column of sediment that has been considered.

The average thickness of the warm zone on the continental slope is 65 centimeters. This zone is 90 centimeters thick along the Port Isabel and Ship Shoal profiles off the mouths of the Rio Grande and the Mississippi Rivers, and is 55 centimeters in the intermediate areas.

The warm zone is about one-half as thick in the Sigsbee deep as on the continental shelf; presumably this difference in thickness reflects a slower rate of deposition of terrigenous material. No appreciable difference between the different profiles is indicated, except that in the Port Isabel profile off the Rio Grande, the average thickness is 50 centimeters, compared with the general average of 35 centimeters.

The average thickness of the transition zone on the continental slope is 50 centimeters and in the Sigsbee deep, 45 centimeters. Hence, the rate of sedimentation seemingly is not materially different in the deep water than on the continental slope. Also the thickness of the transition zone in cores near the Rio Grande and Mississippi Rivers is approximately the same as in the central cores. The transition zone is thickest, 80 centimeters, along the transverse profile located on the upper part of the continental slope, where presumably the supply of terrigenous material is enriched by sediment washed off the adjacent continental shelf. In the cold zones, the average thickness is 75 centimeters on the continental slope profiles and 110 centimeters along the profiles in deep water, but this difference is of little significance, as the entire thickness of the zone is not represented.

The carbon content of the temperature zones is summarized in Table 6. On the average, the carbon content, and therefore inferentially the organic content, decreases slightly,— about 10 percent, between the warm and transition zones, but is essentially the same in the transition and cold zones. The average carbon content is 0.95 percent in the warm zone, 0.89 percent in the transition zone and 0.83 percent in the cold zone.

No essential change is observed within a depth of 100 centimeters in the warm zone; a slight rise, 3 percent, between the upper and lower parts of the transition zone, and a moderate decrease, 10 percent, between the upper and lower parts of the cold zone. These differences perhaps are not distinctive, as the number of analyses is small, but they suggest general trends. The data for the individual profiles, being represented by fewer samples than the general average, accordingly are less reliable; but when fairly consistent trends are observed for each of the individual profiles, the conviction becomes strong that the differences indicated by the general averages are significant.

The data for the Sigsbee deep are based on few samples, and accordingly are less reliable than for the slope samples. The organic content of the upper part of the warm zone in deep water is materially less, about 40 percent, than on the continental slope. The organic content increases with depth of burial in the warm zone in deep water, where at a depth of 100 centimeters it is essentially the same as for the same depth of burial on the continental slope. This similar relationship may be due to the fact that the few samples represented in the statistical summary come from the shallower part of the Sigsbee deep, adjacent to the continental slope.

The upper part of the transition zone in deep water, like the upper part of the warm zone, has materially less organic matter, 30 percent, than on the continental slope. The lower part of the transition zone contains appreciably more organic matter than the upper part.

The cold zone has the same average carbon content, 0.88 percent, on both the continental slope and in the Sigsbee deep; but on the slope the lower part of the cold zone has slightly less organic matter than the upper part, whereas in the Sigsbee deep it has a slightly higher organic content. As the data for the individual profiles are somewhat conflicting, perhaps the differences are not significant. Accordingly it might be inferred that there was no appreciable difference between upper and lower parts of the deep zone.

Nitrogen shows relationships similar to carbon (Table 5). The average nitrogen content of the

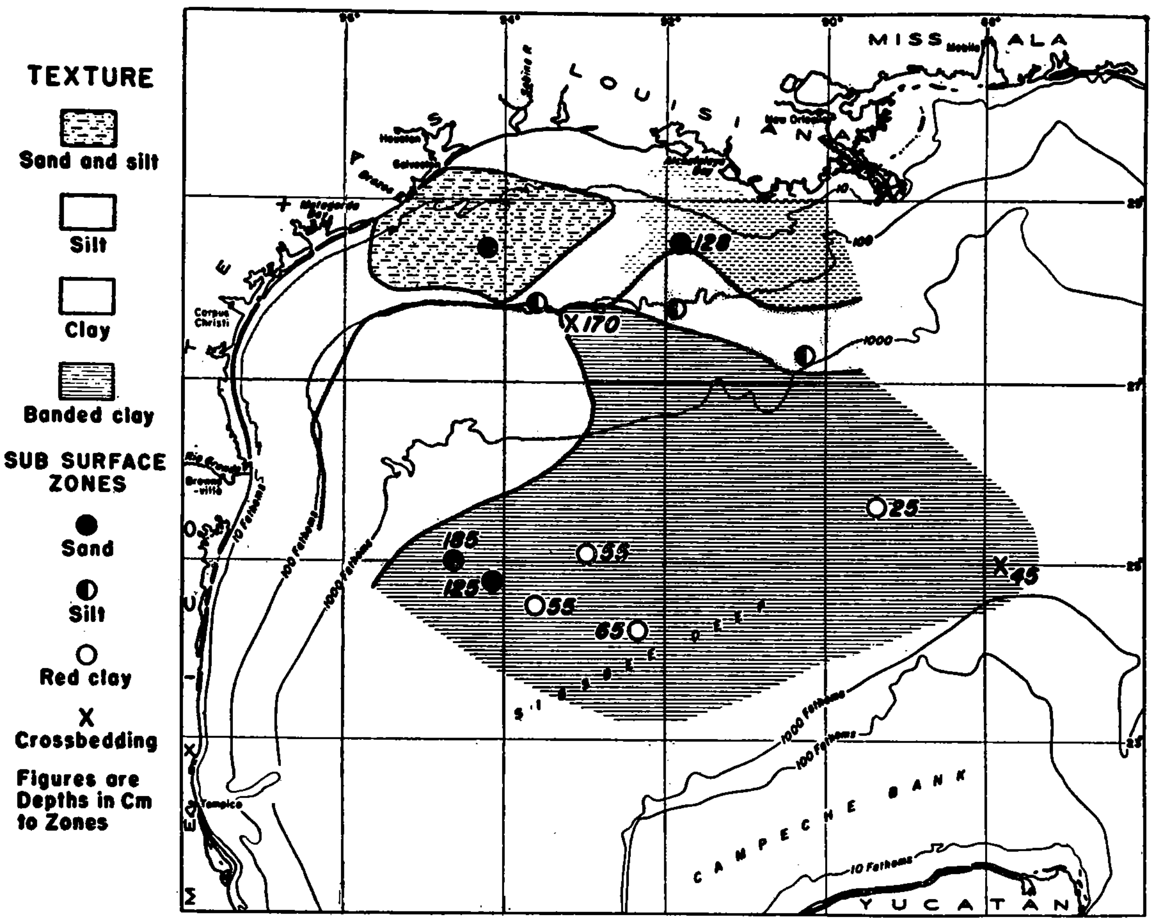


FIG. 15. Areal distribution of texture of sediments.

sediments on the continental slope is appreciably less, about 20 percent, in the transition zone than in the warm zone and seems to be slightly lower, perhaps 5 percent, in the cold zone than in the transition zone. No appreciable decrease with depth is observed in the warm zone, a slight increase is noted in the transition zone, and a corresponding decrease is seen for the cold zone.

The nitrogen content of the sediments in the temperature zones in deep water is materially less than on the continental slope, being 25 to 30 percent lower in the warm zone, 20 to 25 percent lower in transition zone, and 15 to 25 percent lower in the cold zone. The data are conflicting as to the changes with depth of burial; but if anything, the nitrogen content is slightly higher in the lower part of the warm and transition zones than in the upper part of the zones. Nitrogen seems on the whole to vary relatively little in the cold zone.

The carbon-nitrogen ratio increases from the warm to the cold zones both for the continental slope and for the deep samples (Table 7). The ratio increases from 8.9 in the upper part of the warm zone to 10 in the deep-water zone in the slope samples and from 8.6 to 13.3 in the corresponding parts of the deep-water samples. A similar increase with depth of burial is indicated for each zone. The greatest changes are noted in the deep water zones where sedimentation perhaps was slower than on the continental slope.

The calcium carbonate content decreases progressively from the warm to the cold zones (Table 8). The decrease is greater in the Sigsbee deep than on the continental slope. The average $CaCO_3$ content of the upper part of the warm zone and the upper part of the cold zone for the slope samples is 23 and 15 percent, respectively; and for the deep-water samples, 31 percent and 11 percent, respectively. The carbonate content of the transition zone is intermediate between that of the warm and cold-water samples. The carbonate content at a depth of 100 centimeters in the warm zones is 35 percent less than in the surface deposits, both for slope and deep samples. In the transition zone, the carbonate content is 15 percent less in the lower part than in the upper part of the zone; but in the cold zone it seems to be about 10 percent higher in the lower part than in the upper.

Special Sediments

The characteristics of a few special types of sediments encountered in the cores are averaged in Table 9. This table gives the depth below the surface, the thickness, the carbon, nitrogen, and carbonate content, and the carbon-nitrogen ratio of these special sediments. The Globigerina ooze found at the surface of the sediments in deep water and on the lower part of the continental slope averages 25 centimeters in thickness. The carbon content is 0.6 percent, corresponding to an organic content of 1 percent. The carbon-nitrogen ratio is 9.2, which is slightly higher than for the terrigenous sediments deposited on the continental shelf but is essentially the same as the average for the lower slope and deep water deposits.

The peculiar banded clay characteristic of the cold water zone is encountered at an average depth of 80 to 85 centimeters (Fig. 15). It has a mean carbon content of 0.9 to 1 percent, corresponding to an organic content of 1.6 to 1.8 percent. The carbon-nitrogen ratio is 10.9 on the continental slope and 15.3 in the Sigsbee deep, suggestive of a greater rate of selective decomposition of nitrogen in the deep water. The calcium carbonate content is 16 percent on the slope samples and 12 percent in the deep-water samples.

The organic content of the lower temperature zones is not materially different than in the overlying sediments, though if anything it is a little less,— carbon being 0.8 to 1 percent. The carbon content of the transition zone is 0.75 percent compared with 0.97 and 0.90 percent for the second warm and cold zones respectively. As the data are based upon very few samples, the differences should be considered as suggestive, rather than distinctive.

The white clay 15 to 20 centimeters thick found at an average depth of 35 centimeters near the top of the transition zone has a low organic content, carbon averaging 0.55 percent, and a high carbonate content, 44 percent. The carbon-nitrogen ratio is 9.2, which is essentially the same as is found elsewhere at that depth.

The red clay, 15 centimeters thick, found at an average depth of 50 centimeters in a few cores in the Sigsbee deep has an even lower organic content than the white clay, carbon averaging 0.46 percent. The carbon-nitrogen ratio is relatively low, 8.1. Calcium carbonate also is comparatively low; the average is 16 percent.

Layers of sand are found at an average depth of 140 centimeters in three cores in deep water. These sands have a low carbon content, 0.43 percent; and a low carbonate content, 8 percent. Silt zones found at similar depth in three other cores have essentially the same organic content as adjacent clays. The carbonate content is somewhat high for that depth of burial, the average being 21 percent.

DISCUSSION OF RESULTS

General Relationships

The following more or less definite relationships have arisen from this work:

1. The organic content on the continental shelf and the upper part of the continental slope varies inversely with the texture. It ranges from 0.5 percent in sand on the continental shelf to 2 percent in clay on the upper part of the continental slope.

2. The organic content decreases slowly down the continental slope, whereas the texture remains essentially constant. The organic content of the central part of the abyssal deep is 40 percent less than on the upper part of the continental slope.

3. The carbon-nitrogen ratio is essentially constant on the continental shelf and the continental slope, where it averages 8.5, but it increases seaward toward the center of the abyssal deep, where it is 9.5.

4. The organic carbon content decreases about 10 percent between depths of 10 and 25 centimeters, and presumably about one-half as much between 0 and 10 cm., or 15 percent in the upper 25 cm. Nitrogen decreases 15 to 20 percent between depths of 10 and 25 cm. The ratio of carbon to nitrogen accordingly increases 5 to 10 percent in the same interval.

5. Many of the cores on the continental shelf

and Sigsbee deep contain three temperature zones of sedimentation, as indicated by the foraminifera; namely,— a warm zone at the surface of the deposit, an intermediate transition zone, and a deep zone of relatively cold water. The cold-water sediments presumably are associated with Pleistocene glaciation.

6. The average thickness of the warm zone on the continental shelf is more than 200 centimeters. Except for Core 586 near the outer edge of the shelf, none of the underlying temperature zones is encountered.

7. The average thickness of the warm zone is twice as great on the continental slope as in deep water (65 centimeters compared with 35 centimeters); but the thickness of the underlying transition zone is only slightly greater on the continental slope than in the deep water, averaging 50 centimeters in the former compared with 45 centimeters in the latter. The cores do not penetrate sufficiently deeply to indicate the thickness of the cold zone.

8. The organic content is approximately the same in the three temperature zones, except that the sediments in upper parts of the warm and transition zones in the Sigsbee deep contain about 30 percent less organic matter than in the lower parts of the zones.

9. The carbon-nitrogen ratio increases with depth of burial,— the increase being more marked in the Sigsbee deep than on the continental slope.

10. The sediments in the transition and cold zones contain more coarse detrital material than in the overlying warm zones.

11. In a few cores the upper part of the transition zone contains a band of white clay 15 to 20 centimeters thick, containing approximately 50 percent calcium carbonate.

12. In some cores the transition zone contains red clay, low in carbonate and older than the white clay.

13. In other cores the cold zone contains bands of well-sorted fine sand. Some of the sand zones are crossbedded, others are 1 to 3 feet thick and contain shallow water benthonic Foraminifera (Phleger and Parker, 1951, p. 81).

14. The calcium carbonate increases seaward from 5 percent on the continental shelf to 30 percent in the deep water.

15. The calcium carbonate content decreases about 5 percent in the upper 25 centimeters of burial.

16. On the continental slope the average carbonate content of the transition and cold zones is 30 percent less than in the warm zone of the surface sediments. In the Sigsbee deep, it is 40 to 65 percent less than in the surface deposits.

17. The carbonate content of the transition zone is the same in sediments on the continental slope and in the abyssal deep, but in the cold zone it is only three-fourths as large in the abyssal deep as it is for the continental slope sediments.

Other generalizations have been mentioned in the text above, but they will not be discussed here.

Interpretation of Results

The question now arises,— what is the significance of these 17 generalizations? The clear-cut relationship between organic content and texture on the continental shelf and upper part of the continental slope indicates that the deposition and survival of the organic matter in the sediments of this area is influenced materially by the same processes as is the deposition of the inorganic constituents. As the conditions of sedimentation of the detrital constituents is being considered by Stetson (1953) in another paper, only a few remarks on texture are included in the present report, mainly in regard to its relation to the organic constituents.

Conditions of Deposition of Organic Matter

Basic Factors. The organic content of sediments, M, depends upon three factors (1) the quantity of organic matter produced in the surface water in a given unit of time, dP/dt; (2) the amount of organic matter that is deposited in the sediment in a given unit of time, dC/dt; and (3) the amount of detrital and chemically deposited material that is laid down in a given unit of time, dS/dt. A fourth factor that should be considered is the amount of organic matter that is destroyed between the time the organic matter is deposited in the sediments and the time that the sediment is collected and analyzed by the geologist. It is convenient in the present discussion to include the effect of this fourth factor with the second factor and let the second factor be a measure of the time rate at which organic matter accumulates in the sediment in the form as encountered by the geologist.

The first factor can be called the organic production rate, p; the second factor can better be considered as a ratio of the second factor to the first factor:

$$\frac{dC/dt}{dP/dt} = dC/dP. = F$$

In this form, the organic matter that finally is preserved in the sediment can be expressed in the form of its ratio to the original amount of organic matter produced in the sea, here called the organic conservation factor, F. In marine sediments this factor ranges mainly between .02 and .0002 (Trask 1939, p. 441). That is, the amount of organic matter ultimately preserved in the sediments is of the order of 2 to .02 percent of the quantity originally produced; the remainder is lost during processes of deposition, partly by decomposition in the water and partly by decomposition in the sediment. The third factor, dS/dt strictly speaking is a measure of the rate of sedimentation of the rock and chemically deposited particles, but since the rock particles and chemical precipitates form 98 or 99 percent of the Gulf sediments and the organic constituents the rest, this factor, actually for practical purposes, can be considered as the sedimentation rate for the entire sediment. Adsorbed water is not considered. It is convenient to call the third factor, the sedimentation rate, R.

Thus we have

Organic production rate

$$dP/dt = p$$

Organic conservation factor

$$dC/dP = F$$

Organic deposition rate

$$dC/dt = \frac{dC}{dP} \cdot \frac{dP}{dt} = Fp$$

Sedimentation rate $dS/dt = R$

Organic content $\frac{dC/dt}{dS/dt} = dC/dS = M = \frac{Fp}{R}$

By transposition $RM = Fp.$

Organic production and sedimentation rates are independent variables, or essentially in dependent variables. The remaining basic factor, the organic deposition rate, is only partially independent, because the amount of organic matter that accumulates in a sediment varies with the grain size, D_{50}, and with the rate of sedimentation of organic and inorganic constituents. As shown by Trask (1932, p. 77) in any single environment of deposition where organic production rate is essentially constant, the organic content of the sediments varies with grain size. This former study of near-shore sediments from many parts of the world indicates that on the average, the organic content of fine sand, silt and clay, stand in the ratios of 1, 2 and 4, respectively. An analogous relationship is found in the sediments on the continental shelf in the Gulf of Mexico, where as described above, the organic content is expressed by the equation $M = 0.25\phi - 0.4$, where ϕ is the median diameter, in ϕ units. In the writer's previous work (Trask and Patnode 1942, pp. 70–73), the effect of texture was discounted by dividing the organic content of sands by a factor of 0.5, silts by 1.0, and clays by 2.0. Appropriate factors were applied to intervening sizes. The resulting quotient is called the relative organic content and is a measure of the relative rate of deposition of organic matter.

In other words, with a given supply of organic matter reaching the surface of sediments, the relative quantity of organic matter that is deposited is influenced by the physical conditions of deposition of the detrital particles;—that is, by the bottom and other currents. Thus little organic matter is deposited where water movement is so strong that sands are laid down, and much organic matter where currents are so weak that clay is deposited. Relative buoyancy of organic matter seemingly is a pertinent factor.

The production rate in the surface water depends mainly upon sunlight and supply of mineral nutrients; the conservation factor depends upon the organisms living in the water that may devour or decompose it, and upon the temperature, depth, and oxygen content of the water. Decomposition subsequent to deposition depends upon the temperature and oxygen content of the water, the bottom fauna and bacteria, and upon the rate of sedimentation. If the rate of sedimentation is fast the sediments are soon buried so that decomposition can progress only slowly, whereas if the rate of deposition is slow the sediments are exposed for a long time to the bottom water, which as a rule, contains more oxygen than the connate water in the sediments after they are buried. Thus, if the sediments are exposed to the bottom water for a long time, the decomposition rate is relatively high and the conservation factor is low.

Variation of Factors in Gulf of Mexico. The generally consistent relationship between organic content and grain size observed on the continental shelf indicates that the production rate and conservation factor are relatively constant, or they fortuitously vary in the same way as grain size or sedimentation rate. Both of these latter possibilities seem unlikely. On the continental shelf and in the Sigsbee deep the grain size is constant but the organic content of the sediments varies. That is, the relative organic content varies. Both productivity rate and conservation factor accordingly for given rates of deposition, R, are different from what they are on the continental shelf.

Quantitative data on production rate and conservation factor are lacking. Data on the thickness of the temperature zones reported in Table 4, indicate that the sedimentation rate is slower in deep water than on the continental shelf. The average thickness of the warm zone sediments on the shelf, slope and Sigsbee deep are 200+, 65, and 35 cm. respectively. The corresponding sedimentation rates thus stand in the ratios of 6+, 2 and 1. If the sedimentation rate is slow, then the product of the production rate and the conservation factor Fp should also be relatively low. If the ratio of the organic deposition rate to the sedimentation rate, Fp/R, is low the organic content of the sediments is low and if it is high the organic content is high. Thus if we proceed in a horizontal distance x on the sea floor, and find that Fp decreases more rapidly than R, the organic content becomes smaller. In other words if d(Fp)/dx is less than dR/dx, or if d(Fp)/dR is small the organic content is relatively low.

As applied to the sediments deposited in the warm zone on the continental slope and Sigsbee deep, the organic deposition rate Fp is found to decrease more rapidly with respect to distance than the sedimentation rate. According to Table 4 the average thickness of the warm zone on the continental slope is 65 cm. and in the Sigsbee deep is 35 cm. Thus dS/dt in the Sigsbee deep is 35/65 or 0.56 dS/dt on the slope. The respective organic contents dC/dS, according to Table 5 are 0.95 percent for the slope and 0.67 percent, for the Sigsbee deep. The corresponding ratio between deep-water and slope samples is 0.67/0.95 or 0.70. If we take dS/dt and dC/dS as unity on the slope we have the following conditions for the deep-water sediments:

$$\frac{dS}{dt} \cdot \frac{dC}{dS} = 0.56 \times 0.70 = dC/dt = Fp = 0.39$$

That is the organic deposition rate in the abyssal deeps is only 39 percent of the rate on the continental slope.

As applied to the continental shelf sediments and on the assumption that dS/dt and dC/dS on the slope are unity, we have the corresponding figures for the continental shelf;— sedimentation rate dS/dt, is 200+ cm./65 cm. or 3.0+ (Table 4) and organic content dC/dS is 0.53/1.02 or 0.5 (Table 1). The organic deposition rate dC/dt is (dS/dt) (dC/dS) = 3.0+ x 0.5 or 1.5+. The figures for organic content are based on the surface samples rather than on the entire thickness of the zone, as in the previous calculation for the deep water sediments. The sedimentation rate of the surface sediments is assumed to be the same as for the entire zone, which may not be a valid assumption. Furthermore the organic content of 0.5 percent represents coarser sediments than found on the continental slope, which according to the relationship given in Fig. 9 might increase the organic content two- or three-fold, if the physical conditions of sedimentation permitted the deposition of material as fine as is on the continental shelf. Furthermore the average thickness of the warm zone sediments is probably considerably in excess of 200 centimeters. Thus the organic deposition rate, Fp, may be 5 or even more times the rate on the continental slope. For purpose of discussion in this paper an arbitrary figure of 4 will be taken.

Summarizing, we thus find that the organic deposition rate of the Sigsbee deep, continental slope and continental shelf stand in ratios of 0.4, 1 and 4, respectively. If the Sigsbee deep is taken as the basis of reference the respective ratios are 1, 2.5, and 10.

As the organic deposition rate is a function both of the organic production rate, p, and the conservation factor, F, the question arises as to which of these two factors exerts the greatest influence in the respective parts of the Gulf of Mexico. Organic production rate, p, over most of the continental slope and the Sigsbee deep can be considered as being relatively low except possibly over the upper part of the slope at the outer edge of the continental shelf where the more or less abrupt change in inclination of the sea floor conceivably might produce turbulent eddies with consequent upwelling and greater production of plankton. Some of the data of Phleger and Parker (1951, pp. 25–35) suggest such a possibility. Such a greater production rate conceivably could account for the high organic content on the upper part of the continental slope. The organic production rate on the continental shelf also might be greater than in deep water areas, because mineral nutrients are supplied the surface water during times of storms when the effect of waves may reach the sea floor. However, since the organic content varies so regularly with the texture on the continental shelf and upper part of the continental slope, as indicated in Fig. 9, organic production rate may not vary appreciably in this area.

As pointed out above, a faster sedimentation rate, dS/dt, might result in a higher conservation factor because the sediments do not lie on the sea floor as long, and hence not as much organic matter is destroyed before being buried by later sediment. The organic content of the fine-grained sediments on the continental slope, as indicated by Tables 1, 5, and 6 and by Fig. 2 differs by less than 50 percent from the maximum organic content, found in the Gulf (at the outer edge of the shelf and on the upper-most part of the continental slope). That is, the maximum and minimum relative organic contents of the sediments differ by less than a factor of 2. On the continental shelf the organic content varies closely according to texture (Fig. 9) which gives rise to the inference that the relative organic content on the shelf is essentially constant, or uniformly variable.

If the rate of deposition of organic matter, Fp, increases 5 or 10 fold from the abyssal deeps to the continental shelf, as the above discussion seems to indicate, it would seem as if the relative effects of the organic production rate, p, and the conservation factor, F, were of the same order of magnitude. That is, each causes from one-third to two-thirds of the total effect. In other words, the general range in magnitude is through a factor of 3, which means that the maximum value of both organic production rate and conservation factor is of the order of three times the minimum. Obviously this figure is no more than a crude approximation, and locally from one period of time to another or one part of the Gulf to another is subject to material change. The weakest part in this argument is the assumed rate of sedimentation dS/dt on the continental shelf, as the base of the post glacial sediments has not been penetrated.

In summary, the inferences are suggested: (1) the sedimentation rate, R, of the sediments of the warm zone increases at least six-fold and probably ten-fold or more from the abyssal deeps to the continental shelf, (2) the organic production rate, p, and conservation factor, F, each increase two- or three-fold and (3) the combined effect of the two factors increases five- or ten-fold.

Phleger and Parker present data (1951, pp. 60–64) based on their study of living foraminifera, which suggest the possibility that organic deposition rate, Fp, on the continental shelf is six times the rate on the continental slope and deeper water, and that deposition of sediment is 60 times greater. They state "A suggestion of the relative sedimentation rates can be gained by comparing the distribution of living benthonic population with empty tests which constitute essentially the total population. Traverse XII (Ship Shoal profile between the Mississippi and Atchafalaya rivers) may be used as an example. The greatest concentration of living specimens is between 40 m. and 84 m. where 59 specimens have been recorded from 10 samples, an average of about 6 specimens per sample. No living specimens are recorded from any greater depth in this traverse. The average production rate of foraminifera thus is six specimens per sample between depths of 40 m. and 84 m. in the traverse and less than 1 specimen per sample at greater depths. Thus the average rate of production of benthonic foraminifera is at least six times as fast between 40 m. and 84 m. as at greater depths. The average population of empty tests between 40 m. and 84 m. in Traverse XII is 67 specimens/sample, and in samples deeper than 84 m. about 700 specimens/sample. The accumulated tests of benthonic species are thus only about one-tenth as numerous in the same amount of sediment in shallow water as in the deeper water. Since tests are produced faster in shallow water than in deep water, frequency of benthonic specimens in shallow water is being diluted by a larger amount of inorganic sediment. The average rate of sedimentation is then at least 60 times as fast at 40 m. to 84 m. as at greater depths."

These rates of sedimentation are predicated upon a similar life span for the foraminifera in both deep and shallow water, which Phleger and Parker (1951, p. 64) assume to be one year, though they recognize it may be less.

The conclusions reached in the present study of organic content do not indicate any such disparity in rate of sedimentation. The present study however is based on averages for the entire Gulf, whereas Phleger and Parker's conclusions are based on the profile nearest to the Mississippi River, where conceivably present rates of sedimentation on the shelf may be much greater than in areas to the west. However, if one uses data on foraminifera in connection with the thickness of the sediments in the temperature zones in attempting to compute sedimentation rates, he arrives at somewhat anomalous results.

If on the shallow-water part of Traverse XII, six living and 67 dead foraminifera are found per sample, and if the average life span of the foraminifera is one year, then it took six to 12 years to produce the total population of 73 living and dead foraminifera, providing foraminifera are not destroyed or carried away during this time interval. It would take 12 years if all the foraminifera represent a one year's crop and six years if one-half the foraminifera are less than, and one-half more than six months in age. The foraminifera are visible during the period of time required for them to be covered by sediment. Thus the rate of sedimentation can be determined if the average diameter of the foraminifera is known. Phleger does not give the diameter of the foraminifera, but according to his photographs a diameter of 600 microns could be assumed. Thus, if the time is 12 years, the sedimentation rate is .06/12 or .005 cm. per year, and if it is six years the rate is .01 cm. This rate is equivalent to one centimeter in 100 to 200 years, say 150 years.

As the warm zone sediments are at least 200 cm. thick, and if the warm zone represents post glacial time, this period of time would be 20 to 40 thousand years, which though perhaps a little high, is reasonable. Of course the cores do not indicate how much thicker than 200 centimeters the warm post-glacial zone is. Now, if on the continental slope the sedimentation rate is 1/60 the figure for the shallow-water sediments on the shelf, the rate is 150 x 60 or 9,000 years per centimeter. The post-glacial warm sediments on the continental shelf average 65 cm. in thickness (Table 4), which would make post-glacial time 600,000 years, which is rather long.

The two approaches to sedimentation rates, one by means of living foraminifera and the other based on organic content thus lead to somewhat different but not incompatable conclusions. If the sedimentation rate, R, on the shelf is 60 times the rate on the continental slope and if the organic content, M, of the sediments on the shelf is one-half the organic content on the slope (Table 1), then the product of the production rate and conservation factor on the shelf, Fp, must be 30 times the corresponding product on the slope. We have the formula

$$RM = Fp$$

If one takes the respective factors for the sediments on the continental slope as unity, then the organic content, M, for the continental shelf is one-half and the sedimentation rate, R, is 60. We thus have for the shelf sediments the equation

$$Fp = 60/2 = 30$$

As mentioned above, both the production rate, p, and the conservation factor, F, should be greater on the shelf than on the slope and it is not impossible for their product to be 30 times the corresponding product on the continental slope, but the independent analysis of the problem as based on studies of the organic content leads to a smaller product and hence a smaller difference in organic deposition rate.

Both the approach by Phleger and Parker and the present approach are based on assumptions. Phleger and Parker's figure of 60 times the sedimentation rate on the shelf compared with the slope is predicated upon the following conditions: (1) the method of recording living foraminifera is reliable; (2) the foraminifera in shallow and deep water have the same life cycle; (3) the average life cycle is one year; (4) the activity of bottom organisms that might devour or destroy the foraminifera is the same; (5) the foraminiferal tests have the same average size; (6) the action of bottom currents in redistributing foraminifera is the same in shallow and deep water; and (7) the rates of sedimentation in the areas in which they made their quantitative studies are indicative of the general rates of sedimentation in the Gulf of Mexico. Phleger and Parker point out that their estimate of 60 times the sedimentation rate is based on relatively few samples, and is the best approximation that can be given from their data. As such it is a useful inference.

The conclusions as to a smaller differential rate of deposition on the continental shelf and slope, as derived from the present study of the organic content of the sediments, is subject to assumptions as to organic production rate, conservation factor, and sedimentation rates. These assumptions in part are supported by theoretical inferences. The study however is based on the average of a comparatively large number of measurements on bottom sediments from many parts of the northwest Gulf of Mexico beyond the 10-fathom line. If it were not for Phleger and Parker's analysis of the problem the sedimentation rates on the shelf would be indicated as being of the order of six to ten times the rate in deeper water, rather than 60. If one assumed that the production of calcium carbonate is the same on the shelf as in deep water, which of course is a dubious assumption, he arrives at the figure that sedimentation rate on the shelf is six times the rate in deep water. These rates are relative rates. Actual rates would have to be determined by some sort of a yard stick, such as Carbon 14, or some independent measure of post-glacial time. If for example post-glacial time, representing the accumulation of the 35 cm. of sediment in the warm zone in the Sigsbee deep, is 20,000 years, the sedimentation rate, R, for this period of time for Sigsbee deep, continental slope, and continental shelf would be 18, 33, and 100+ microns per year. In terms of number of years required to deposit one centimeter of sediment, the respective rates would be 600 years for the Sigsbee deep, 300 years for the continental slope and 100 years or less for the continental shelf. The question of sedimentation rate in the Gulf of Mexico is a matter for future study.

Miscellaneous Features

Carbon-nitrogen Ratio. The similar carbon-nitrogen ratio on the continental shelf and the continental slope requires special explanation, because if the rate of decomposition of organic matter is greater (organic conservation factor is smaller) on the slope than on the shelf, nitrogen should decrease with respect to carbon with time, which would cause a greater C/N ratio on the slope than on the shelf. Ancient sediments which have been buried for some millions of years have a C/N ratio of 14, compared with 8.5 for sediments recently deposited (Trask and Patnode 1942, p. 33). This difference indicates a selective loss of nitrogen. Similarly the carbon-nitrogen ratio of 9.5 for the deposits in the deep water of the Gulf, where the sedimentation rate of the warm zone presumably is slower than on the continental slope, is in accord with such a selective loss of nitrogen with time (Table 4). The similar C/N ratios for both the continental slope and continental shelf may indicate that in the early stages of time after deposition of the organic matter in sediments the relative loss of carbon and nitrogen is the same, but that with time the selective decomposition of nitrogen compounds increases.

Likewise the decrease in organic content of 10 percent, or slightly more, in the upper 25 centimeters of the surface sediments is accompanied by a proportionately greater decrease in nitrogen content. Thus the selective decomposition continues during burial, as nitrogen decreases more rapidly than carbon.

Characteristics of Sediments of the Temperature Zones

Pleistocene Deposits. The average thickness of the warm zone shown in Table 4 suggests that twice as much sediment has been deposited since the end of the ice age on the continental slope as in the Sigsbee deep, namely 65 cm. compared with 35 cm. The thickness of the transition zone averages 50 cm. on the continental slope and 45 cm. in the abyssal deep. In other words the decrease in sedimentation rate is much less between the two environments, perhaps occasioned by a greater supply of detritus during the waning stages of the ice age or possibly because of lower position of sea level, which may have caused the shore line to be a considerable part of the way across the continental shelf, thus causing a proportionately smaller difference in supply of detritus in the water over the two environments. Since the thickness of the transitional zone on the continental slope is of the same order as the thickness of the post-glacial warm sediments, it would follow that the duration of time for the two zones is roughly the same.

The thickness of the underlying deep zone is not clearly indicated, because many cores did not penetrate the bottom of the cold zone. Some of the cores encountered transitional zones at depths of 100 or more centimeters below the top of the cold zone (Figs. 11–14). Thus in some places the cold zone seems to be only 100 centimeters thick, whereas in others it is at least twice as thick. Variations in sedimentation rate may be the answer. However, the presence of transitional zones at depths of 100 centimeters below the top of the cold zone followed in turn by second cold zones at greater depth in the cores, suggests sizable fluctuations in surface water temperature in the waning stages of the Pleistocene. If the rate of sedimentation is the same in the cold zone as postulated for the post-glacial warm zone, namely 600 years per centimeter and if the cold zone is only 100 cm. thick, the total elapsed time is 60,000 years for the last cold stage of the Wisconsin. This estimate of 600 years per centimeter is based on 20,000 years for the duration of the post-glacial warm period. The transitional zone in whole or in part may represent post-glacial time. The figure of 20,000 years for deposition of the warm zone sediments hence may be too long. Furthermore, the rate of sedimentation probably was greater for the cold zone sediments than for the post-glacial warm sediments. Thus the interval of time presented by the last cold zone might be as short as 25,000 years. Bradley and others (1942, p. 11) report a series of cold water stages in North Atlantic sediments, which they conclude are more likely to be episodes in Wisconsin time rather than older glacial stages. Such an inference is supported by the cores from the Gulf of Mexico.

The organic production rate of the sea water during late glacial and post glacial time, as indicated by the organic content of the sediments, mentioned in point 8, seemingly has been of the same general order of magnitude, except that at the present time, organic deposition rate, dC/dt, in the abyssal deep is less than it was at the beginning of the warm zone.

White Clay. The white clay deposited at the end of the transition period is high in calcium carbonate, suggestive of a warm period during which the temperature of the water rose, thus increasing the degree of saturation of calcium carbonate in the water and favoring its precipitation. Such a warm period possibly could be associated with a period of extreme aridity, which according to Camp (1952) was 5000 to 10,000 years ago.

Red Clay. The red clay beneath the white clay has a relatively low calcium carbonate content and is associated with marked change to cooler surface water. A lower calcium carbonate content of the sediments suggests a lower degree of saturation of carbonate in the water, occasioned by colder temperature. The red color in this clay thus could be similar in origin to the red color of the red clay of the abyssal deeps of the oceans; that is, it may be due to residual iron left from the solution of calcareous tests of organisms. It should be borne in mind that the depth at which red clay is found in the ocean today is not necessarily a matter of depth per se, but rather is a critical depth with respect to present degree of saturation of the ocean water with calcium carbonate. If the level of effective saturation of the water with calcium carbonate should change, then the level at which red clay in the sea is encountered would change correspondingly. This subject is discussed in detail in Section II of the present report.

Banded Clay. The peculiar alternating bands of clay and fine silt in the cold-water zones require special explanation. The area and depths at which the bands are found are shown in Fig. 15. The thickness of the sediments above the banded zones in general increases landward from the Sigsbee deep. The west part of the Sigsbee deep, off the mouth of the Rio Grande, does not contain bands, even though the cold water zone is represented. The bands vary in color from light to dark. As a rule they are 1 to 4 cm. thick, and consist of silt and fine sand. Some of the silt is extremely well sorted, suggestive of a selective winnowing during deposition. A few of the sands are cross-bedded, as might be occasioned by bottom currents or ripple marks (Fig. 17). Obviously the supply of terrigenous debris was greater at the time the sands were deposited than now. During glacial time the shore line must have been closer to the edge of the continental shelf.

The cold-water zones of Cores 335 and 336 in the west part of the Sigsbee deep contain beds of well-sorted fine- to medium-grained sand. The sand in Core 336 is three feet thick and is well sorted throughout this entire thickness (Fig. 16). These cores were taken in nearly 2000 fathoms of water. According to Phleger and Parker (1951, p. 81) the sand in Core 336 contains shallow-water benthonic foraminifera, though whether or not the sand and foraminifera originated in the present place is problematical.

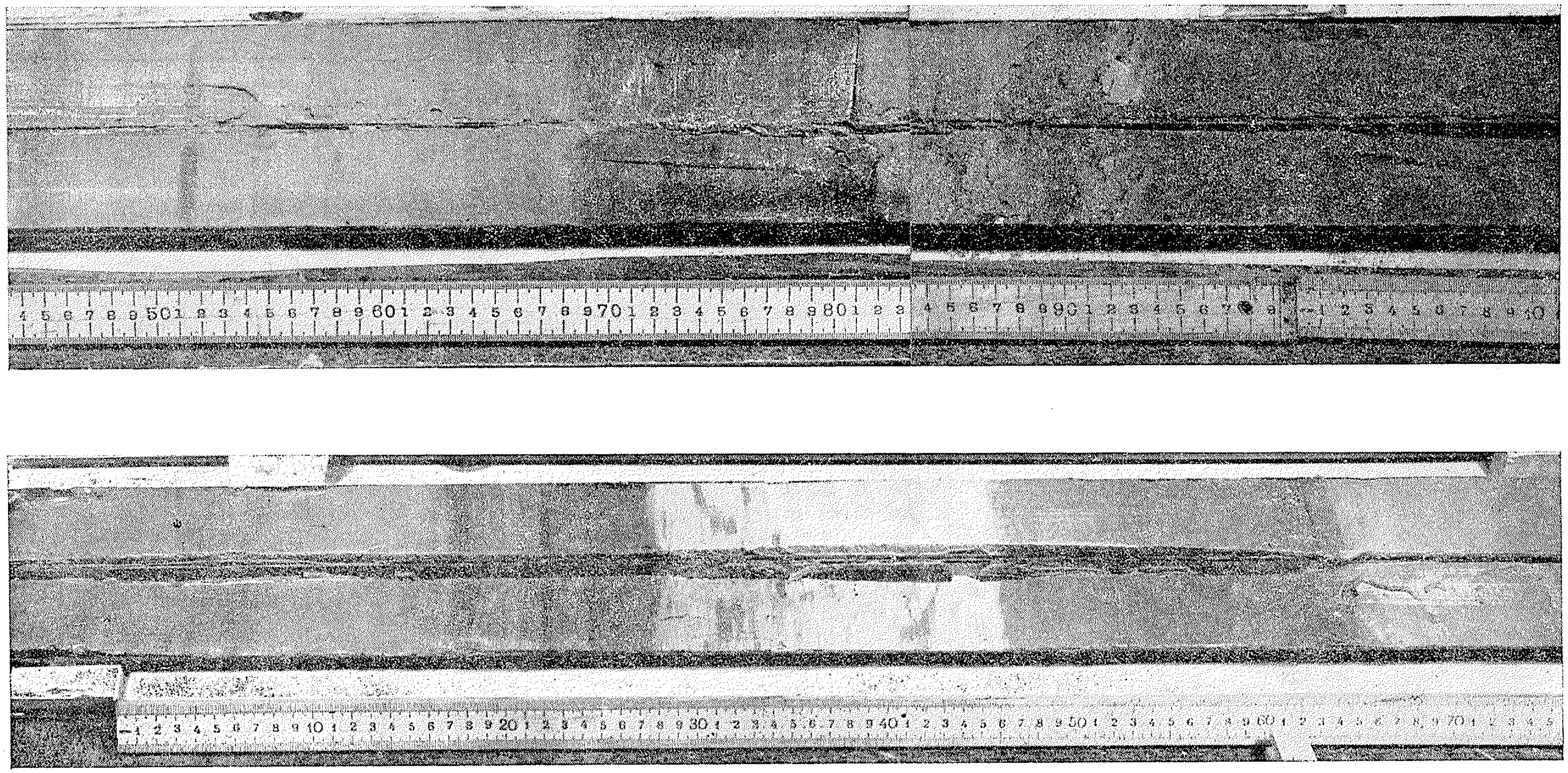


Fig. 16. Photographs of freshly opened cores 336 and 339. Upper picture (A) is core 336, depths 93 to 165 cm. Note dark bands in light upper part above 68 cm. on scale, dark zone 68 to 82 cm., transition zone 82 to 88 cm., and sand below 88 cm. Zero on scale at side of picture is at depth of 50 cm. below top of core. Lower picture (B) is core 339, depths 0 to 84 cm. Note light and dark bands in upper part. The very light band at position 43 to 46 cm. on scale is rich in carbonate (zone W in fig. 11); and upper part of the dark band between position 46 and 65 cm., is red clay (zone R in fig. 11). Lower part is dark grey clay representing cold water sediments low in calcium carbonate.

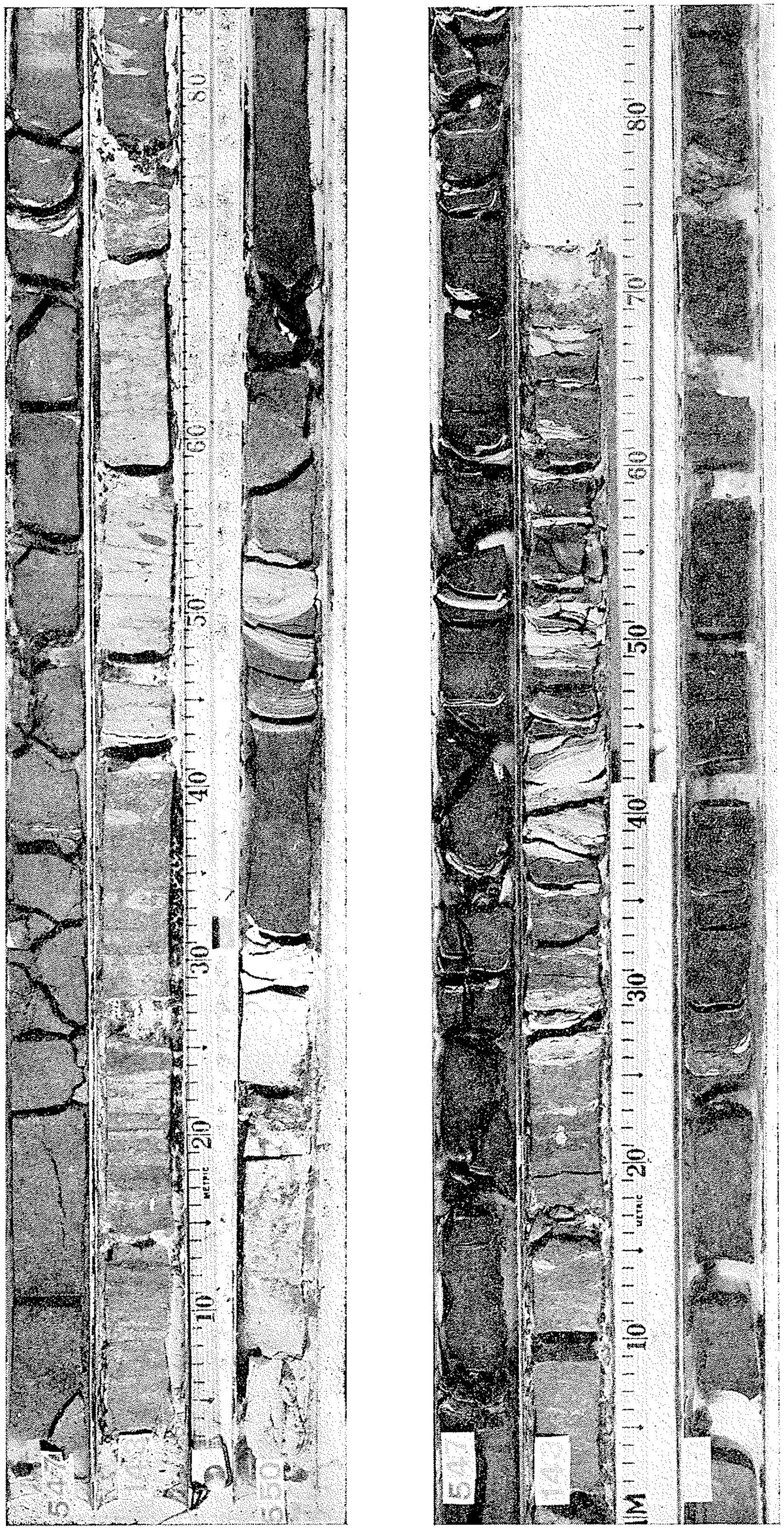


Fig. 17. Photographs of partially dried cores, 143, 547 and 550. Upper picture (A) represents depths 0 to 85 cm., lower picture (B) depths 100 to 187 cm. In core 143, foraminiferal ooze extends to depth of 57 cm., red clay, 57 to 70 cm., and banded clay below 100 cm. Note the alternating silt and clay bands (see fig. 12). Core 547 has foraminiferal ooze to 25 cm., red clay to 38 cm., and banded clay below 38 cm. Note that silt bands are far apart (see fig. 12). Core 550 has foraminiferal ooze to 20 cm., white clay 25 to 30 cm., cross-bedded sand 49 to 53 cm. and banded clay below 130 cm. Silt bands are thin (see fig. 11).

These sand layers in Cores 335 to 336 and the cross-bedded sands found in other cores (337, 550) raise very difficult questions to answer. Three possibilities can be considered: (1) the sediments were deposited in place in 1800 to 2000 fathoms of water, (2) sea level was much lower then than now, (3) sea bottom must have sunk since the deposition of the sediments. The presence of sand in long cores recently reported from many parts of the ocean, indicates that special conditions of deposition must have prevailed at times in the sea. Submarine slumping, density or turbidity currents, and internal waves have been invoked to explain such layers. These subjects are not yet well understood. Density and turbidity currents are at present popular ways of explaining them, but the difficult question to answer with such types of currents is why the sediments are so well sorted. Unless there are lateral currents in the water beneath the density currents, which can carry away the fine particles and let the coarse particles settle to the bottom, the deposits should be poorly sorted.

Diastrophism. The irregularities on the continental shelf shown in the various profiles, Figs. 4–8, indicate diastrophic activity at some time in the not too remote past. Perhaps some of the diastrophism may be relatively recent. If so, the sea bottom may have been depressed in late glacial time. In such an event one might expect to find sand zones more prevalently than the few that were encountered. Many of the deep water cores contain only a few thin layers of sand or silt, others contain none. If the sand and silt reflect the effect of diastrophism, it is difficult to account for their variability in distribution, in view of the present uniform depth of the deep water. Accordingly it would seem as if diastrophism is not the cause of the coarse sediments in deep water. Also, lowering of sea level can hardly be the explanation, because the water would have to be lowered 10,000 to 12,000 feet to account for the sands by normal shallow water processes of deposition. The main hope of explaining the distribution of these coarse sediments seems to lie in internal waves and tidal currents — subjects poorly understood.

Calcium Carbonate. The increase in calcium carbonate seaward seemingly reflects a diminution in supply of terrigenous debris. The distribution is similar to the distribution in the lower part of the upper Cretaceous in Wyoming (Trask and Patnode, 1942, p. 211). The lower carbonate content of the transition and cold zones presumably reflects a lower degree of saturation of the water in glacial time when the water was colder than it is now.

SECTION II — CHEMICAL COMPOSITION

INTRODUCTION

The work was carried out by a supplementary grant from the Penrose Bequest to the Geological Society of America. The analyses were made by F. A. Gonyer of Harvard University according to standard methods.

METHODS OF INVESTIGATION

Selection of Samples for Analysis

Chemical analyses of 14 samples from the long cores were made. Unfortunately the cores had been divided and sampled for other investigations before it became possible to make these chemical determinations. Consequently samples could not be procured from all desired parts of the cores, for the reason that no more material was available. In processing the cores, the brass tube containing the sediment was slit open by making two grooves 180° apart on the cores with a special tooling device; splitting the core in equal halves with a thin sheet iron plate; and laying the two halves face upward in a V-shaped trough. One-half of the core was placed aside for future reference; one-half of the remaining half was taken by Phleger for biological analyses. Thus one-quarter of the core was left for other studies, which included mechanical analyses and determinations of the organic and calcium carbonate content. Samples chosen for chemical analyses were taken as close as possible to samples that had been selected for mechanical analyses and organic content studies.

In planning the program of analysis, effort was made to procure material from different types of sediments from the three different depth zones in the Gulf,— namely the continental shelf, continental slope, and the Sigsbee deep. In addition, material from the temperature depth zones was obtained. As described by Phleger and Parker (1951, pp. 69–73) and in Section I of the present report the cores in the deep parts of the Gulf penetrated zones of sediment which contain surface-living foraminifera, whose prototypes now are found in much cooler water than the surface water of the Gulf. The uppermost of these zones of cool water is considered to represent the close of the glacial epoch. This zone is followed by an intermediate transition zone between the cool water of the glacial epoch and the warm water of the present time. The location and distribution of these depth zones are shown in Figs. 11–14, Section I of the present report.

The location of the 14 samples selected for analysis is given on Fig. 18. The results of the chemical analyses are shown in Tables 11, 12 and 15. Mechanical analyses of the samples are presented in Table 13. Results of analyses of comparable sediments from other parts of the world, made by previous investigators, are presented in Tables 14 and 15. For convenience of discussion the 26 analyses represented in these tables are indicated consecutively by number. With respect to Table 13, no mechanical analysis was made of Sample 5 from Core 330. For Samples 11 to 14 from

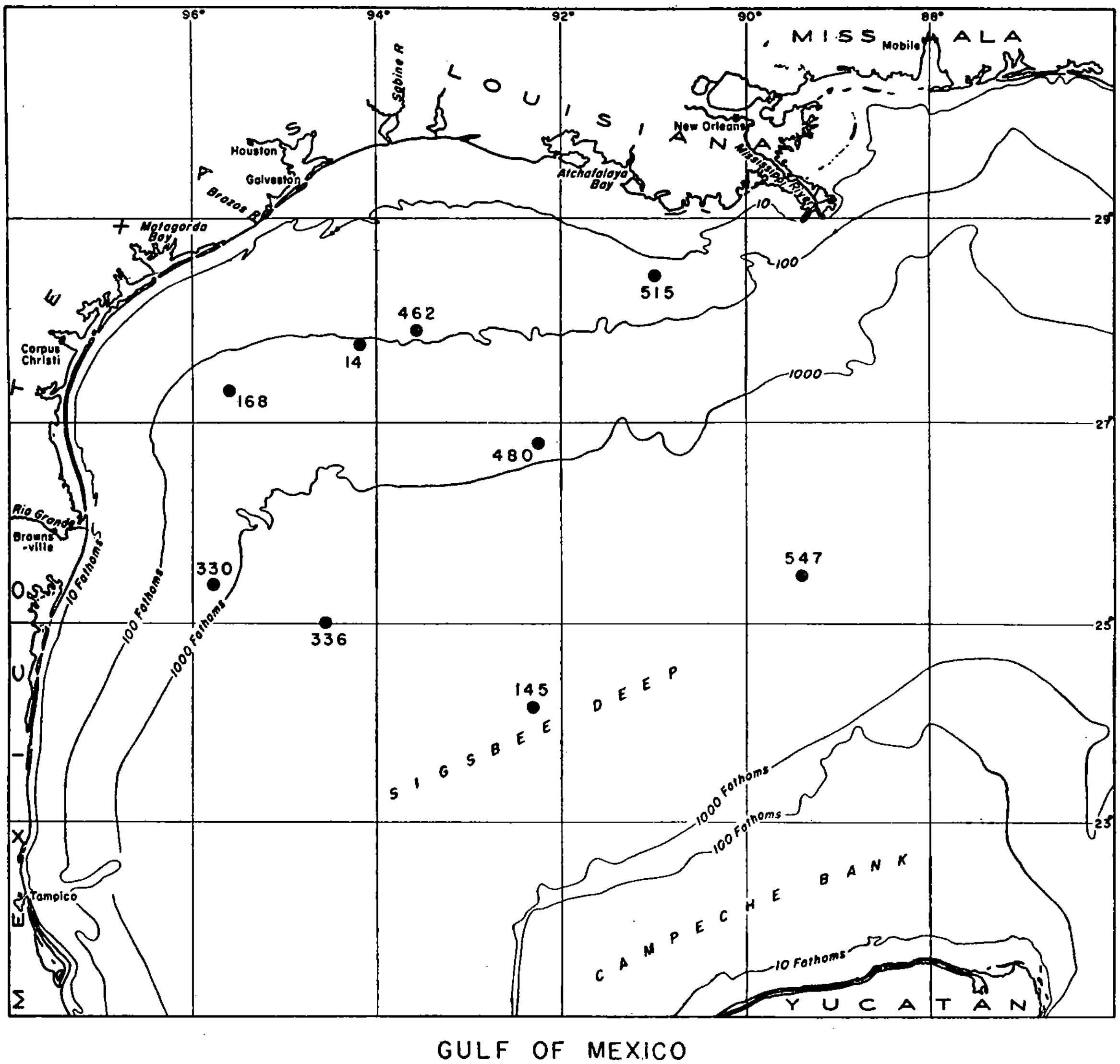


FIG. 18. Location of samples of sediments on which chemical analyses were made.

Core 547, mechanical analyses were made of sediment immediately adjacent to the material that was analyzed chemically.

LITHOLOGIC NATURE OF SEDIMENTS ANALYZED

Table 11 summarizes pertinent data on depth of overlying water, depth of burial of the sample, temperature zone of the sample, and lithology. Two of the 14 samples are sand; one (No. 1) from the upper warm zone of Core 14 on the continental shelf off Galveston in 40 meters of water is a very fine and well-sorted sand, with median diameter of 103 microns; the other (No. 7) is a well-sorted fine-grained sand from the central part of the upper cold zone in Sample 336 taken in 3530 meters of water in the Sigsbee deep. According to Phleger and Parker (1951, p. 81) this sand (No. 7) contains benthonic foraminifera whose prototypes now live in much shallower water. As discussed in Section I of the present report the mode of origin of this layer of sand is difficult to explain. The sand zone is more than 3 feet thick and is uniformly well sorted and of almost the same grain size from top to bottom. The uniformity of the sand is well illustrated by the photograph shown in Fig. 16.

One sample (No. 8) is a silt taken in 127 meters of water on the lower flank of a sea-mount rising some 400 feet above the floor of the Gulf near the outer edge of the continental shelf southeast of Galveston. The median diameter of the sample is 6.9 microns, its coefficient of sorting is 5.3 and logarithm of skewness is $-.163$. The sample thus is considerably coarser, less well sorted and more highly skewed than the sediments found on the flat part of the continental shelf at a comparable distance from shore. Obviously its mechanical composition indicates influence of currents of some sort, presumably occasioned by the effect of the sea-mount.

Five samples are clays taken from different parts of the upper warm zone. Sample 10 is from Core 515, a clay in 40 meters of water on the continental shelf off the mouth of the Atchafalaya River. Presumably its constituents in part are derived from the Mississippi River. The sample is typical of sediments on the continental shelf west of the Mississippi. Its median diameter is 1.8 microns, which indicates it is a moderately fine-grained clay. The sorting of 3.42 is about average for fine-grained clays. The logarithm of skewness, 0.013, indicates that the size distribution of the sediments is essentially symmetrical. Two of the clay samples come from the continental slope; No. 4 from Core 168 in 860 meters of water off Corpus Christi in the west part of the Gulf, and No. 5 from Core 330 in 1120 meters of water off the Rio Grande, 150 miles south of Sample 4. The continental slope in these areas is irregular but seemingly the roughness has little effect on the texture of the sediments, as they consist of normally sorted fine clay of similar grain size. The median diameter of Sample 4 is 1.9 microns. The deep part of the Gulf is represented by two samples, No. 2 from the lower part of the warm zone in Core 145 in 3630 meters of water in the middle of the Sigsbee deep, and No. 6 from the lower part of the warm zone in zone 336 in 3530 meters of water in the west part of the Sigsbee deep. Both sediments are normally sorted fine clays with median diameters of approximately 1.5 microns.

Two samples of calcareous deposits from the upper part of the warm zone were analyzed. One (No. 9) is a foraminiferal marl from Core 480 in 1865 meters of water near the lower edge of the continental slope southeast of Galveston; the other (No. 11) is a marl from Core 547 in 3220 meters in the middle of the Sigsbee deep. Sample 9 is a normal calcareous clay having a median of 1.4 microns and a sorting coefficient of 2.7. Sample 11 is coarser, having a median of 2.4 microns and a sorting coefficient of 4.2 and a log skewness of .117. The poor sorting and moderately large skewness in Sample 11 presumably represent the effect of foraminiferal shells upon the results of the analysis. The calcium carbonate of the samples according to data presented on Fig. 11, Section I, should be approximately 30 percent, but according to the chemical analyses given in Table 11, it is 24 percent in Sample 9 and 16 percent in Sample 11. The samples contain many foraminifera, but owing to their relatively low carbonate content are to be classified as marls rather than as globigerina oozes.

Three clay samples from the cold zones of late glacial age were analyzed; Sample 3 from the middle part of the uppermost cold zone in Core 145 in 3630 meters of water in the middle of the Sigsbee deep, and Samples 13 and 14 from the upper and lower parts of the uppermost cold zone in Core 547 from the eastern part of the Sigsbee deep, 250 miles east of Core 145. The texture of these cold water clays is essentially the same as the clays in the lower overlying warm zone. The median diameter is 1.1 to 1.5 microns, the sorting coefficient 2.5, and the logarithm of skewness is almost zero. The sediments seemingly have been formed by essentially one dominant process of deposition; for if two or more dominant processes had operated, the sorting would have been poorer and the skewness greater, unless of course the effects of both processes were identical.

In Core 547 at a depth of some 30 centimeters below the surface of the deposits, a zone of red clay, low in carbonate is encountered. This clay is similar in appearance to typical red clay of the open ocean. Analogous deposits were also found in Cores 143, 145, 339 and 549 in the Sigsbee deep at comparable positions in the cores. Mechanical analysis shows the clay in Core 549 has a median diameter of 2.1 microns, sorting coefficient of 2.7 and logarithm of skewness of .107.

Comparable Sediments from Other Areas

In order to understand better the chemical nature of the samples from the Gulf of Mexico, analyses of 12 other sediments and groups of sediments are presented in Table 14. In making comparisons, one would like as far as possible to compare the sediments with other sediments which are known to represent typical lithologic types, or with representative averages of groups of sediments. Averages of several analyses, however, are likely to be misleading because of variations in the properties of individual sediments represented in the averages. For example, dilution of sediments with calcium carbonate will reduce the content of silica and other elements, yet aside from the carbonate content, the physical constituents of the sediments may be the same. This particular difficulty of course, can be overcome to a considerable extent by using molecular ratios, as is discussed below. However when a person uses molecular ratios, he encounters the basic mathematical difficulty of averages of ratios, which can sometimes lead to anomalous results. When one uses individual analyses, he has the problem of the representativeness of the samples chosen. Both types of approach thus present difficulties. A compromise is a single analysis of a composite sample composed of equal parts of many samples. This recourse has been used by Clarke (1924, p. 518) as illustrated by analyses 19, 20 and 21 in Table 14.

The analyses selected for comparison are presented in Table 14. Pertinent information on these samples is given at the bottom of the table. All analyses are single analyses except the last four, which represent world-wide averages of the major sedimentary rock types,— sandstone, shale, and limestone, and the average composition of the lithosphere as reported by Clarke (1924, p. 34). The series of individual analyses includes Globigerina ooze from the Bartlett deep in the Caribbean Sea (No. 15) and the North Atlantic (No. 16), Pleistocene clay from the North Atlantic (No. 17), typical red mud from off the Amazon River (No. 18), analysis of a single composite sample of 51 red clays from different parts of the world (No. 19), a similar composite sample of 52 marine terrigenous muds from many different areas (No. 20), a composite sample of 245 samples of silt from the Mississippi Delta (No. 21), and a silt from the continental shelf in 338 meters of water off the coast of Maryland (No. 22). The first four analyses (Nos. 15–18) are fine-grained carbonate deposits having many features in common. The fourth and fifth (Nos. 18 and 19) are iron-rich fine-grained red deposits. The sixth represents fine-grained marine mud. The seventh (No. 21) is a silt from a warm-water environment similar to the present Gulf of Mexico deposits. The eighth (No. 22) is a silt from a latitude whose temperature corresponds to the temperature of the cold water deposits in the late glacial zones in the Gulf sediments.

Procedure of Computing Molecular Ratios

Calculations. The particles of a sediment, in contrast with the minerals of an igneous rock, have such a diverse origin that interpretation of chemical analyses is difficult. As mentioned above, dilution with calcium carbonate diminishes the proportion of detrital material in the sediments. Admixture of quartz lessens the relative quantities of other detrital minerals. The relative proportions of particles of clay and of silt-size affects the relative content of clay minerals, because clay minerals as a rule are of clay size, whereas detrital and non-clay minerals commonly are silt-size or larger. Carbon is found both in calcium carbonate and in the organic constituents. The amount of carbonate carbon can be ascertained by treating the sediment with dilute hydrochloric acid and determining the resulting carbon content, but strictly speaking, a small amount of the organic matter, at times as much as 20 percent, is also removed by the acid (Trask 1932, p. 302). The acid also dissolves some of the inorganic constituents. Hence treatment with acid does not give completely reliable results, though for practical purposes it is reasonably satisfactory. Water is another source of difficulty. All samples give off water above 105°C, which commonly is reported in the analyses as H_2O+, though in some analyses it is included with ignition loss.

The interpretation of chemical analyses of sediments thus is a difficult procedure. Sediments also are subject to the same complications as igneous rocks in that the molecular composition of the sediments is more important in understanding the chemical nature of the sediments than the weight percentages in which the analyses are reported. Treatment of the sediments in terms of molecular numbers overcomes many of these difficulties, as has been pointed out by many people, Washington (1917, p. 1163), Jenny (1941, p. 26), Revelle (1944, p. 57), and Reiche (1950, p. 89). The procedure is to divide the weight of the oxide or element by round numbers, which correspond to the molecular or atomic weight of the oxide or element. Thus in analysis 1, where silica, SiO_2 is reported as 84.34 percent the molecular number is 100 x 84.34/60 or 140.6. The following table gives the molecular numbers used in the present report:

Oxide	Molecular Number	Oxide	Molecular Number
SiO_2	60	MgO	40
Al_2O_3	102	CaO	56
Fe_2O_3	160	Na_2O	62
		K_2O	94

In the present report FeO has been presented in terms of Fe_2O_3, where Fe_2O_3 is 160/144 times FeO. Similarly MnO_2 has been converted to MnO so that results in all tables would be comparable.

Correction for Calcium Carbonate. As calcium carbonate was not determined on the samples, special correction had to be applied to CaO as reported in the analyses, because of the desirability of reporting CaO in terms of non-carbonate CaO. Calcium carbonate was determined on a large number of samples studied in Section I of the present report. The results of the analysis are plotted upon Figs. 11 to 14. The carbonate content varies with depth in the cores, but the carbonate content as estimated by interpolation between points of control gives anomalous results when applied to the correction for CaO, as is indicated in Table 11.

The content of organic carbon also provides a means for determining the carbonate content, but when the organic carbon content, as indicated by interpolation in Figs. 11 to 14, is applied to the analyses presented in Table 11, similar anomalous results are obtained. Obviously the carbonate content, and amounts of organic carbon and non-carbonate CaO must be as consistent as possible with the results of the analyses. By a system of trial and error, an arbitrary organic carbon content was assumed, which seemed to give the least objectionable results. This arbitrary organic content is reported in Tables 11 and 14 as "estimated organic content." On another line in these tables is given the "probable organic content", as estimated from Figs. 11 to 14 or as reported in the chemical analyses (Table 10, Section I).

The organic carbon forms a very definite but small part of all sediment (Trask 1939). It varies with the texture and it cannot be ignored. If too high values are assumed for organic carbon, the resulting carbonate content is low and the corresponding CaO content of the carbonate is too low and the non-carbonate content of CaO is high. The content of non-carbonate CaO in analyses in Tables 11 and 14, at best is an approximation and readers are cautioned against depending too much upon molecular ratios involving CaO. Calcium, however, is an important part of the chemical composition of sediments and some sort of an idea of its distribution is needed. As a general rule the ratios involving calcium probably are within 3/4 or 4/3 of being correct, and most of the ratios are more nearly correct than these figures.

Correction for Sea Salt. The content of sea salt is another source of difficulty. It is not practicable to leach the samples before analysis, because water dissolves material in addition to the salts contained in the sea water. In the present series of analyses the sediments were dried with their content of sea water and a special determination of chlorine was made and reported with other results of the analyses. As the sea water content of many of the sediments was more than 50 percent of the total weight of the samples as collected and as the chemical analyses are reported on the basis of the dried weight of the solid particles, the chlorine content of the sediments is high. The quantities expressed in Table 11 range between 1.5 and 2.5 percent, except for sand samples 1 and 7 which had a low water content. The water content, W/S, thus, except for sand, ranges between 65 and 125 percent. These figures accord with the data on water content reported in Section III, Fig. 20.

The chemical composition of sea water ranges between very narrow limits (Sverdrup, Johnson and Fleming, 1942, p. 47). The proportions by weight for the several constituents accordingly stand in essentially constant ratio with respect to chlorine, the respective proportions being: Na_2O – .75 Cl; MgO, – .11 Cl; CaO, – .03 Cl, and K_2O, – .024 Cl (see also Revelle 1944, p. 57). The respective quantities of these substances reported in Tables 11 and 14 were corrected for the sea-salt content by multiplying the chlorine content by these figures, in computing the molecular ratios shown in Tables 12 and 15. The sample of red mud (No. 18) shown in Table 14 contains 2.46 percent Cl, which when applied to Na_2O gives a nomalous results for the residual Na_2O content. Murray and Renard (1891, p. 236) in studying this analysis noted this discrepancy and made a separate determination of Na_2O after all the chlorine had been leached with water. The resulting figure, 0.70 percent Na_2O, was used in computing the molecular ratios of the sample presented in Table 15.

The content of Na_2O when corrected for sea-salt sodium in the analyses reported in Table 11 gives relatively low figures, which by analogy with the experience of Murray and Renard, perhaps may be too low, but in absence of evidence to the contrary, the data as corrected for chlorine have been used in computing the molecular numbers used in preparing Tables 12 and 15. As two samples reported in Table 14 (Nos. 19 and 20), are expressed on a carbonate-and chlorine-free basis, no correction is needed in computing molecular numbers.

Manner of Reporting Results. The molecular numbers are reported in the form of molecular ratios in Tables 12 and 15. Table 12 presents the ratios for the samples indicated in Table 11, the same order of samples being used. No comparable table of ratios for the analyses reported in Table 14 is given. Instead the corresponding ratios are included in Table 15 in a different order so that equivalent groups of sediments may be compared with one another. Table 15 contains the molecular ratios for all samples reported in Table 14. In addition, for purposes of comparison, averages of groups of similar lithologic and environmental properties represented in Tables 11 and 12, are included in Table 15. Six groups of sediments are reported in Table 15: 1, sand; 2, silt; 3, clay; 4, Pleistocene or glacial clay; 5, calcareous deposits; 6, red clay. *Glacial* is used in sense of geologic time, during which the water was cooler than now.

Eight molecular ratios have been computed in the preparation of Tables 12 and 15.

1. $\dfrac{SiO_2}{Fe_2O_3 + Al_2O_3}$ This is the ratio of silica to the sesquioxides.
2. $\dfrac{SiO_2}{Al_2O_3}$ This is most fundamental of the eight ratios, corresponding to the symbols *ki* and *sf* of soil physics. (Jenny 1941, p. 26).
3. $\dfrac{Fe_2O_3}{Al_2O_3}$ This is the ratio of the two sesquioxides.
4. $\dfrac{Na_2O + K_2O}{Al_2O_3}$ This is ba_1 ratio of soil physics.
5. $\dfrac{Na_2O + K_2O + CaO}{Al_2O_3}$ This is *ba* ratio of soil physics.
6. $\dfrac{Na_2O}{K_2O}$ This is the ratio of monovalent oxides.
7. $\dfrac{CaO}{MgO}$ This is the ratio of bivalent oxides.
8. $\dfrac{CaO + MgO}{Na_2O + K_2O}$ This is the ratio of the bivalent to the monovalent oxides.

Alumina forms the most satisfactory basis of comparison, because on the whole it is the most stable base and wanders relatively little during weathering and depositional processes. Iron, except in acid solutions is comparatively stable. Silica is stable under acid conditions but migrates in alkaline solutions. The ratios of the monovalent, bivalent oxides, and the sesquioxides give indications of the relative movement and alteration of the constituents of the sediments during their process of deposition and subsequent history. In view of the assumptions made in correcting the chemical analyses for sea salt and carbonate content, and in view of the possible diverse mode of origin of sediments and the small number of analyses, differences between ratios should be at least 20 percent to be considered as being definitely distinctive. Smaller differences should be regarded more as being suggestive rather than indicative.

INTERPRETATION OF ANALYSES

The main contribution of the present paper is the presentation of a series of chemical analyses of sediments from the off-shore waters of the Gulf of Mexico so that other geologists may interpret them for their own purposes. The sediments come from a little-known and poorly-accessible area. As such, the analyses constitute a basic record of value. The author's interpretation of the analyses is another matter. The subject of chemical analyses of sediments is at present poorly developed. Marine sediments are complex in origin. The reliability of the analyses as indices of the character of the types of sediments they are supposed to represent has not yet been established. Arbitrary assumptions have been made in computing molecular numbers. Accordingly the author approaches with diffidence the problem of analyzing the results. The concepts he expresses in the following discussion should be regarded more in terms of possibilities rather than as actualities.

Distribution of Oxides by Weight Percent

The silica content of the sediments ranges from 36.94 to 84.34 percent. It is lowest in sample 9, a calcareous clay in Core 480 from the lower part of the continental slope, and highest in a sand on the continental shelf (Sample 1, Core 14). The high silica content indicates a low percentage of feldspar in the sand. Even the sand from the cold zone (Sample 7) in Core 336 in 11,000 feet of water has 79.54 percent silica, likewise suggestive of a low or moderate feldspar content.

Alumina ranges between 4.78 and 16.04 percent. It is lowest in the sand on the continental shelf and highest in Pleistocene (post-glacial) clay deposits in the cold zone of Core 547 in the Sigsbee deep (Samples 13 and 14). The silt and clay deposits contain between 12 and 16 percent alumina, which compares with 15.40 percent alumina for the average shale (Analysis 23, Table 14).

Iron oxide Fe_2O_3, ranges mainly between 4 and 6 percent. It is low, 0.83 percent in sand in Core 14 on the continental shelf, and high, 9.16 percent, in the red clay in Core 547 (Sample 12). The iron content of the sediments in general is less than in the average shale. The shale contains 6.74 percent iron oxide compared with an average of 5 percent for the argillaceous sediments of the Gulf. Even considering dilution with calcium carbonate, the iron content in the Gulf sediments accordingly is low.

Magnesia is remarkably constant in the argillaceous sediments, ranging between 2.34 and 3.35 percent. The content thus is higher than the general average for shale, which is 2.44 percent. The quantity is low, 0.26 and 0.31 percent, in the two sand samples (Nos. 7 and 1), and high, 4.24 percent in the red clay (No. 12). The quantity of non-carbonate CaO as reported in Table 11, ranges between 1.19 and 5.80 percent in the argillaceous sediments, but most of the sediments contain between 1.5 and 2.8 percent CaO. The extreme figures of 5.8 percent for Sample 5 and 1.19 percent for Sample 10, perhaps are anomalous, owing to improper determination of non-carbonate CaO. The average CaO content of the sediments is similar to the average of 2.33 for shale reported in Table 14. It is interesting that the two averages are so close, as the computations of non-carbonate CaO were made independently of knowledge as to the general distribution of calcium oxide in sediments, but were based upon corrections made on the basis of probable distribution of carbonate and organic carbon.

Soda as corrected for sea-salt content ranges mainly between 0.8 and 1.3 percent Na_2O. It is high, 1.72 percent, in Sample 7,— the cold zone sand in Core 336,— and low, 0.53 percent in Sample 12, the red clay in Core 547. The corrections for sea salt perhaps are anomalous in these two samples. The soda content of average red clay, according to Table 14 is 2.05 percent, and for shale is 1.30 percent, which suggests that perhaps soda has been over-corrected for sea salt in the present computations.

Potash ranges between 2.1 and 2.5 percent except for sand sample No. 1, in which it is 1.46 percent. These quantities are much lower than the figure of 3.24 for the average shale, suggesting that the Gulf sediments contain clays and feldspar deficient in potash. Phosphorus ranges mainly between 0.10 and 0.25 percent, thus corresponding closely with the average of 0.17 percent for shale.

The content of TiO_2 in the silts and clays ranges between 0.5 and 0.9 percent compared with 0.65 for the average shale. The two sand samples (Nos. 1 and 7) contain 0.11 and 0.28, respectively. The sediments thus possess no particular abnormalities with respect to titanium oxide. The quantity of MnO ranges between .06 and 0.13 percent in the silt and clay; is .03 percent or less in sand; and .04 percent in the red clay.

Chlorine in the argillaceous sediments ranges between 1.33 and 2.53 percent, which corresponds to a sea water content of approximately 65 to 125 percent, where water is expressed in form of the ratio of weight of water to weight of solids. These water contents are comparable with the water content of sediments as shown in Fig. 20, Section III of this present report. Sulphate, SO_3 is fairly constant in the clayey sediments, ranging between 0.39 and 0.69 percent. It is low, 0.13 percent in the sand samples. Some of this sulfate evidently is derived from mineral constituents, because the ratio by weight of Cl to SO_4 in sea water is 7.2 (Sverdrup, Johnson and Fleming 1942, p. 173). As the molecular weight of SO_4 is 20 percent greater than the molecular weight of SO_3, the ratio of Cl to SO_3 by weight is 8.64. As the ratio of Cl/SO_3 in the present analyses is less than 8.64 it follows that part of the SO_3 is derived from the solid constituents of the sediments. However since the total content of SO_3 in the Gulf of Mexico sediments including sea-salt SO_3 on the whole is less than the figure of 0.64 percent for average shale, it would follow that the solid constituents of the Gulf sediments are relatively low in SO_3.

Water driven off above 105° C ranges mainly between 6 and 10 percent in the argillaceous sediments. The quantity thus is higher than the average for shale, which according to Table 14 is 5 percent; but it is close to the figure of 7.17 percent for the composite sample of 52 marine muds (Sample 20). It should be borne in mind that this figure applies to water given off when the sediments are heated above 105° C and not to the water given off below 105°. This latter water represents sea-water in pore spaces of the sediment, whereas the former refers mainly to chemically combined water in the minerals.

The organic content as estimated from data presented in Table 10, and Figs. 11 to 14, in Section I, is given in Table 11 under the heading "probable organic carbon". These figures are somewhat higher than the assumed organic carbon content given under the heading "estimated organic carbon." For example, in the argillaceous sediments it ranges between 0.55 to 1.24 percent compared with 0.28 to 0.80 percent for "estimated organic content". The figures for probable organic carbon represent interpolations between analyses of the organic carbon content of adjacent samples on the assumption that carbon is uniformly variable between the samples analyzed. Obviously this is not a strictly correct assumption. Furthermore some of the samples rich in carbonate have high carbon-nitrogen ratios, which suggests anomalously high organic carbon content. It is difficult to obtain reliable organic carbon determinations on carbonate-rich samples. As mentioned above, a compromise organic carbon content had to be assumed, in order to reconcile the respective contents of CO_2 and CaO in the chemical analyses reported in Table 11. The content of calcium carbonate as computed from the analyses in Table 11 is less than the content as indicated by the analyses on comparable samples made specifically for organic carbon at an earlier date (Table 10, Section I). The latter were specially designed to measure calcium carbonate and organic carbon; the former were designed to give the overall chemical composition of the sediments. Since different but adjacent samples were analyzed for the two purposes, it is possible that both organic carbon and carbonate carbon in the samples chosen for detailed chemical analysis are lower than in the contiguous samples; it is also possible that total CO_2 as reported in the analyses in Table 11 is low. However, the data for CO_2 cannot be appreciably low, because the total of the analysis is close to 100 percent. Also if CO_2 becomes too high, non-carbonate CaO becomes improbably low. Furthermore the organic carbon content as assumed for "estimated organic carbon" for most samples is not appreciably different from the figure for "probable organic carbon." Calcium carbonate as estimated from the chemical analyses and as determined on adjacent samples as shown in Table 11 are somewhat different. For the chemical analyses, computed $CaCO_3$ ranges between 0.2 and 24.13 percent, and in the analyses for organic content, probable $CaCO_3$ ranges from 3 to 30 percent. However, both methods of determination indicate the same relative difference in carbonate content from one sample to another.

Molecular Ratios

Reliability of Results. The molecular ratios as discussed above form a much better basis for interpreting the analyses than do the weight percentages, as they give the relative proportions of individual components or groups of components of the sediments. If the chemical composition of the average shale as reported in Table 14 and if the average composition of the silt and clay in the Gulf of Mexico are similar, the following anomalies may exist. Magnesia may be 10 or 15 percent too high in the Gulf sediments. Calcium on the average is the same in the Gulf and in the other sediments, but in consideration of the assumptions used in computing non-carbonate CaO, individual determinations may be subject to considerable unreliability. In Sample 5 (Core 330) CaO may be anomalously high and in Sample 10 (Core 515) it may be appreciably low.

Soda as corrected for sea-salt content may be generally low, perhaps by as much as 25 percent. This concept is based on the idea that soda should be the same in Gulf of Mexico sediments as in average shale, but this assumption need not be true. Potash, similarly may be 25 or 30 percent low, but here again potash in the average shale may actually be materially greater than in Gulf of Mexico sediments. As the apparent anomaly for both potash and soda is essentially the same, the ratios between them presumably are comparable with other sediments. With these comments in mind, the following discussion has been written.

Silica-alumina Ratio. As shown in Table 15, the ratio of silica to alumina, SiO_2/Al_2O_3, ranges from 30 in sand (Sample 1) in Core 14 on the continental shelf to 3.9 in the red clay (sample 12) in Core 547 in the Sigsbee deep. This ratio is also high, 18, in the sand from the cold zone of glacial age in Core 336 in the Sigsbee deep. The ratio similarly is high in the average sandstone, in which it is 27.8 (Analysis 24). The ratio is lower in silt, being 7.7 in Sample 8, a silt from the lower part of a seamount on the continental shelf. The silica-alumina ratio in composite silt from the Mississippi delta is 11.3 (Sample 21) and in the silt from the continental shelf off Ocean City, Maryland (Sample 22) it is 10.8. The clays, whether on the continental shelf, continental slope, or in the Sigsbee deep have a relatively low ratio, ranging between 5.5 and 6.7. These ratios are similar to the ratio of 5.6 for marine mud from other parts of the world and to 6.4 for the average shale (Analyses 20 and 23). In fact the average ratio for clay in the Gulf of Mexico is essentially the same as for the average shale and the average lithosphere (Analyses 23 and 26). For that matter, except for a relatively low content of monovalent and bivalent oxides, the average shale is remarkably similar to the average lithosphere, as reported by Clarke (1924, p. 34).

The high silica-alumina ratio in sand, intermediate ratio in silt and low ratio in clay presumably reflects the greater admixture of quartz and high silica minerals in the coarse-grained sediments.

The silica-alumina ratio in the Pleistocene clays in the cold zones, as represented by Samples 3, 13 and 14, is 5.5 which is essentially the same as for the overlying warm zone clays. Similarly the ratio in the calcareous clays or marls, represented by Samples 9 and 11, averages 5.2, which is slightly lower than the average for other argillaceous sediments (Analyses 18, 20 and 23, but well within the range for such deposits. However the conditions of deposition of foraminiferal marls, such as Samples 9 and 11, perhaps favor the formation of a low-silica alumina ratio, because the Globigerina ooze (Analysis 15) from the Caribbean Sea has a correspondingly low ratio of 4.4. The Globigerina ooze (Analysis 16) from the North Atlantic, on the other hand has a higher ratio of 6.6. Revelle (1944, p. 62) reports an average ratio of 6.6 for Globigerina oozes from the Pacific. The average limestone (Analysis 25) has a silica-alumina ratio of 10.9, which is much higher than for the calcareous deposits of the Gulf of Mexico. These latter deposits however contain less than 30 percent calcium carbonate, whereas the average limestone contains more than 75 percent. The silica-alumina ratio of the red clay (Sample 12) is 5.5. This is approximately the same as for the average red clay in the ocean and for red mud off the Amazon River (Analyses 19 and 18), in which the ratio is 5.8 and 5.9 respectively.

Silica-sesquioxide Ratio. The ratio of silica to the sesquioxides, Fe_2O_3 and Al_2O_3, expressed in column 1 in Tables 12 and 15 varies in much the same way as the silica-alumina ratio, being high in sands and low in clay. The ratio ranges from 27 in sand to 4.5 in clay on the continental slope and in cold zones in the Gulf of Mexico. It is relatively low, 4.1 in the foraminiferal marls (Samples 9 and 11) and the red clay, 3.9 (Sample 12). Similarly the ratio is low in Globigerina ooze in the Caribbean Sea and in average red clay, where it is 3.4 and 4.2 respectively. The ratio for Globigerina ooze of the Pacific Ocean, according to Revelle (1944, p. 62), is 2.0, which indicates a relative concentration of iron. It would seem as if iron is a residual product in the formation of red clay and some Globigerina oozes.

Iron-alumina Ratio. The ratio of iron oxide to alumina, that is, the ratio between the two principal sesquioxides, ranges within relatively narrow limits, from 0.11 for sand to 0.42 for red clay. The increase in ratio is more or less regular with decrease in grain size from sand to clay, being 0.11 in sand, 0.21 in silt, and approximately 0.23 in surface clays. The ratios vary in a similar way with respect to grain size in comparable sediments from other areas, but on the whole the increase is higher for comparable grain size. The ratio is 0.19 in average sandstone, 0.21 in Mississippi River silt and silt on the continental slope off Maryland, and 0.28 in marine mud and average shale. The ratio is high, 0.31 in one sample of marl (No. 11) but low, 0.21 in the other (No. 9). Globigerina oozes from the Caribbean Sea and the North Atlantic have ratios of 0.31 and 0.27 respectively, which as mentioned above in connection with the silica-sesquioxide ratio, indicates a selective enrichment with respect to iron in Globigerina ooze. In the Pacific according to Revelle (1944, p. 62) the ratio averages 3.1. The iron-alumina ratio is particularly high in red clay, being 0.42 in Sample 12 from the Gulf of Mexico and 0.39 for red clay in general. The red mud (Sample 18) from the Amazon River interestingly has a low ratio of 0.31.

Alkali-alumina Ratio. The ratio of the monovalent alkalies to alumina, $(Na_2O + K_2O)/Al_2O_3$, varies considerably. This is the ratio ba_1 of the soil physicists (Jenny, 1941, p. 26). It ranges from 0.23 in red clay to 0.70 in Pleistocene sand in Core 336. The respective averages for surface sand, silt, and clay in the Gulf of Mexico are 0.63, 0.37, and 0.32 percent, indicating a lessening of ratio with increasing fineness of grain. Comparable ratios from other areas are 0.45 for average sandstone, 0.41 for Mississippi River silt, 0.61 for continental slope silt off Maryland, 0.24 for marine muds, and 0.37 for average shale. This decrease in ratio with fineness of grain reflects a relative increase in alumina, perhaps because of the greater content of clay minerals. The ratio in the Pleistocene clay (Samples 3, 13, and 14) and calcareous clay (Samples 2, 4, 5, 6, and 10) is close to 0.31. The Globigerina ooze in the Caribbean Sea has a ratio of 0.27, which is only slightly less than in the Gulf of Mexico calcareous deposits; but the ratio is 0.41 in the North Atlantic Globigerina ooze and 0.54 for limestones in general. The ratio is low in the red clay from the Gulf of Mexico, 0.23, whereas in the average red clay it is 0.41 percent. The ratio in the Gulf of Mexico red clay thus is closer to the ratio for red mud than for typical red clay.

Temperature may be a significant factor in the ratio of monovalent alkalies to alumina. Jenny (1941, p. 146) presents data to show that in soils this ratio decreases from northern latitudes toward the equator. It is interesting that all sediments of comparable lithology have lower ratios in low latitudes than in high latitudes. For example, Globigerina ooze in the Caribbean, has a ratio of 0.27 and in the North Atlantic, 0.40. In Mississippi River silt, it is 0.41 and in Ocean City, Maryland silt, 0.61. This influence of temperature may account for the higher ratio for red clay from all parts of the world compared with red clay from the Gulf of Mexico. Similarly it may explain the general average of 0.37 for shale compared with approximately 0.31 for the Gulf of Mexico. The relatively low ratio of 0.28 for the Pleistocene clay in the cold zones compared with 0.32 in similar clay in the overlying warm zones is not in accord with this generalization.

ba Ratio. The *ba* ratio, the ratio of the sum of potash, soda, and CaO to alumina is one of the most significant ratios used by soil physicists. This ratio is indicated by the symbol B/Al_2O_3 in Tables 12 and 15. This ratio involves calcium and is subject to the anomalies caused by the basic assumptions in the computation of the molecular number for CaO. The ratio decreases as the texture becomes finer, presumably because of the presence of minerals containing appreciable quantities of alumina. The average ratios for surface sand, silt, and clay, are 1.20, 0.73, and 0.66 percent, respectively. The average ratio of 0.66 for clay perhaps is anomalous, as it in part is based on samples 5 and 10, which as stated above may have not been adequately corrected for CaO. The corresponding ratios for average sandstone, Mississippi River silt, marine mud and average shale are 0.83, 0.68, 0.46, and 0.64 respectively. These ratios vary in the same way with respect to texture as do the Gulf of Mexico sediments, but average shale has a higher ratio than marine muds. The ratio in the calcareous deposits in the Gulf of Mexico averages 0.62 whereas it is 1.01 and 0.84 in the Globigerina ooze from the Caribbean Sea and North Atlantic, respectively. The ratio of 0.45 in the red clay from the Gulf of Mexico is lower than the ratio of 0.63 in average red clay from the rest of the world, but this may reflect the influence of temperature, though it may just as well be due to some other effect. It certainly is a distinctive difference. The red mud of the Amazon delta has a ratio of 1.21. This red mud obviously differs very definitely from red clay of the Gulf of Mexico in this respect. The sediments of the cold zone in the Gulf of Mexico have a relatively low ratio of 0.46. The composite sample of marine muds from many parts of the world has a similarly low ratio. The *ba* ratio does not seem to exhibit the definite relationship to temperature as does the ba_1 ratio. The addition of CaO to the ratio masks any apparent relation, if any should exist. Perhaps the molecular numbers of calcium are too anomalous to be distinctive.

Soda-potash Ratio. The ratio of soda to potash, Na_2O/K_2O, in general ranges between 0.6 and 0.9 in the Gulf of Mexico sediments. The ratio is 0.9 in sand on the continental shelf (Sample 1), 0.82 in silt on the continental shelf (Sample 8) and ranges between 0.6 and 0.8 in surface clays, with an average of about 0.7. The ratio thus decreases as the texture decreases. The ratio in Mississippi River silt is 0.76, which is approximately the same as in the silt in sample 8. In the average marine mud it is 0.71, which is equivalent to the average for surface clay in the Gulf. Even the average of 0.61 for shale is well within the range for this ratio in the Gulf of Mexico. The calcareous deposits in the Gulf are similar to ordinary clays. The cold-zone sand in Core 336 has a very high ratio of 1.28 and the red clay has a low ratio of 0.41. The sodium content thus is relatively low in this red clay. On the contrary the soda-potash ratio is high, 1.09, in the composite sample of red clay from many parts of the world represented by Analysis 19,— much higher than in the red mud (Sample 18), in which the ratio is 0.77. According to Revelle (1944, p. 62), the average red clay in the Pacific Ocean has a ratio of 0.61. Data presented by Sverdrup, Johnson, and Fleming (1942, p. 992), indicate that a red clay reported by Correns (1937) has a ratio of 1.45. The soda-potash ratio in red clay accordingly varies between wide limits.

Lime-magnesia Ratio. The ratio of calcium oxide to magnesia, CaO/MgO varies considerably. The variations are greater than are indicated by possible errors in determination of molecular number for CaO. The ratio is high, 3.70, in sand on the continental shelf (Sample 1), but low, 0.63, in sand in the cold zone in Core 336 (Sample 7). It is approximately 0.75 in the silt samples:— No. 8 in Core 468 in the Gulf; No. 21 in Mississippi River silt; and No. 22, Ocean City, Maryland silt. In the surface clays the ratio ranges between 0.33 and 1.82,— the average of 5 samples being 0.9. In marine muds the world over, the ratio is 0.67 and in average shale it is 0.68. The average for the calcareous deposits in the Gulf is 0.65 which is similar to the average for marine mud and for shale, but is lower than for Globigerina ooze from the Caribbean Sea. The ratio is low, 0.30 in red clay from the Gulf; whereas it is 0.42 in the composite sample of red clay from different parts of the world and is 1.71 in the Amazon River red mud. The ratio also is low in the three cold-zone clays in the Gulf (Samples 3, 13, 14), for which the average is 0.38 percent. It would seem that in general the Gulf of Mexico sediments had a lime-magnesia ratio of 0.5 to 0.8, which is roughly similar to other sediments of comparable lithology.

Ratio of Bivalent to Monovalent Oxides. The ratio of the sum of principal bivalent oxides, CaO and MgO to the principal monovalent oxides Na_2O and K_2O, in general ranges between 2 and 3. The ratio is low, 1.1 in surface sands on the continental shelf, and high, 4.1, in red clay in Core 336. The ratio in average shale is 1.9 and in marine muds, 2.2. A similar ratio of 2.2 is found in sandstone. The calcareous deposits have variable ratios, but on the whole do not have particularly high ratios, except for the sample from the Caribbean Sea (No. 15) which has a ratio of 5.1. The bivalent oxides obviously are more plentiful in marine sediments than are monovalent oxides.

Collective Molecular Composition of Sediments. Having considered the individual molecular ratios in sequence, we can now attempt to appraise the sediments collectively with respect to the entire series of ratios for each sample or type of sediment. The sand samples in general are similar to average sandstone throughout the world. The most notable exception is in $CaCO_3$. The average sandstone as reported by Clarke (1924, p. 34) has 8 percent calcium carbonate, whereas the sands in the Gulf of Mexico in general have less than 4 percent. The silica-alumina ratios are similar, as are all ratios indicated in Table 15 except lime-magnesia in the surface sands in Core 14 (Sample 1). As this ratio is much higher than for any other sediment represented in Table 15, it perhaps is anomalous.

The silt samples occupy an intermediate position between the sands and clays both in the Gulf of Mexico and elsewhere. No large differences between silt samples are observed, except that the soda content in the silt from off Ocean City, Maryland is high. The clays in the Gulf of Mexico in general are similar to one another and to marine mud and average shale. Collectively they seem to be normal fine-grained marine deposits. The underlying glacial clays deposited under cooler-water conditions are very similar to overlying warm water post-glacial clays.

The calcareous clays in the Gulf are similar to the other (non-calcareous) clays. They resemble Globigerina oozes in having a moderately high iron-alumina ratio and a low silica-alumina ratio, but they contain much less soda than the Globigerina oozes. The two Globigerina ooze samples (Nos. 15 and 16) exhibit rather marked differences, one of which is a relatively low alkali-alumina ratio (ba_1 ratio) in the warm water deposits compared with the cold water deposits. This low ratio for the warm water deposits is in accord with the low ratio for low-latitude deposits discussed above. The Pleistocene clay sample from the North Atlantic (No. 17), and the red mud off the Amazon River (No. 18) are similar in molecular ratios to the other Globigerina oozes. Possibly they should be so classified. The calcareous clays in the Gulf perhaps are incipient Globigerina ooze, but seemingly they have too high a clay content to be regarded as typical. They are more closely related to terrigenous muds than they are to Globigerina ooze.

Sample 12, the red clay from the upper part of Core 547, has many of the characteristics of typical oceanic red clay. It occupies a transition position in (1) temperature of water as indicated by its planktonic foraminifera and (2) calcium carbonate content. This deposit obviously represents a period of time when conditions were changing in the Gulf of Mexico. The increase in calcium carbonate content upward in the sediments immediately above this zone indicates that it was deposited during a time of changing solubility with respect to calcium carbonate. It seemingly was laid down in a zone somewhat analogous to deposits in the present oceanic abysses, which lie just below the zone of saturation of water with respect to $CaCO_3$. The sample looks very much like red clay. Its calcium carbonate content is similar to red clay. As shown in Table 15 most of its molecular ratios, especially the low silica-sesquioxide, high iron-alumina, and low lime-magnesia ratio, are similar to the corresponding ratios in typical red clay. A fundamental difference is the high sodium content of the composite sample of red clay compared with the Gulf of Mexico red clay. Data with respect to sodium in other analyses of red clay from different parts of the ocean are conflicting. Some have a high sodium content, some have a low content. When considering soda in analyses of marine sediments, the question of adequate correction or compensation for sea salt is serious. At present one cannot say whether this material discrepancy in soda is or is not a vital objection in classifying this red clay in the Gulf of Mexico as a typical red clay. In all other respects the clay appears to be typical red clay. If so, this red clay, now found at a depth of 11,000 feet was formed at a much shallower depth than red clays in other parts of the world, most of which now lie below 20,000 feet. It would accordingly follow that depth of water is not a distinctive criterion of red clay, but rather, relative solubility with respect to $CaCO_3$ (Trask, 1937, p. 297). Hence the absence of red clay among ancient geologic sediments should not be considered as an indication of the absence of abyssal deep-sea deposits in by-gone time. The ocean water may well have been saturated with calcium carbonate all the way to the bottom throughout much of pre-glacial time. The present state of undersaturation of the deep ocean water may be due to addition of cold water during the ice age. Thus, since the end of the ice age the ocean may not yet have had a chance to be again saturated with calcium carbonate to all or to great depths.

Concluding Remarks

The interpretation of chemical analyses of sediments is difficult. Special attention to reliable determination of calcium carbonate and sea-salt content would materially help the interpretation of the problem. Also some measure of the probable error of the determination of the individual components of the chemical analyses would enable one to ascertain more reliably the significance of small differences in molecular ratios. Separate analyses of the coarse and fine fractions, as Murray and Renard (1891, p. 213–227) long ago pointed out for studies of Globigerina ooze, are particularly useful. Similarly, supplemental mineralogical determinations would indicate more clearly the significance of small differences in molecular ratios. Finally, a detailed study of existing chemical analyses of sediments, which would present a background of knowledge as to the range in molecular ratios for different types of deposits, would overcome many of the difficulties that have arisen in the present attempt to interpret these chemical analyses of the Gulf of Mexico deposits.

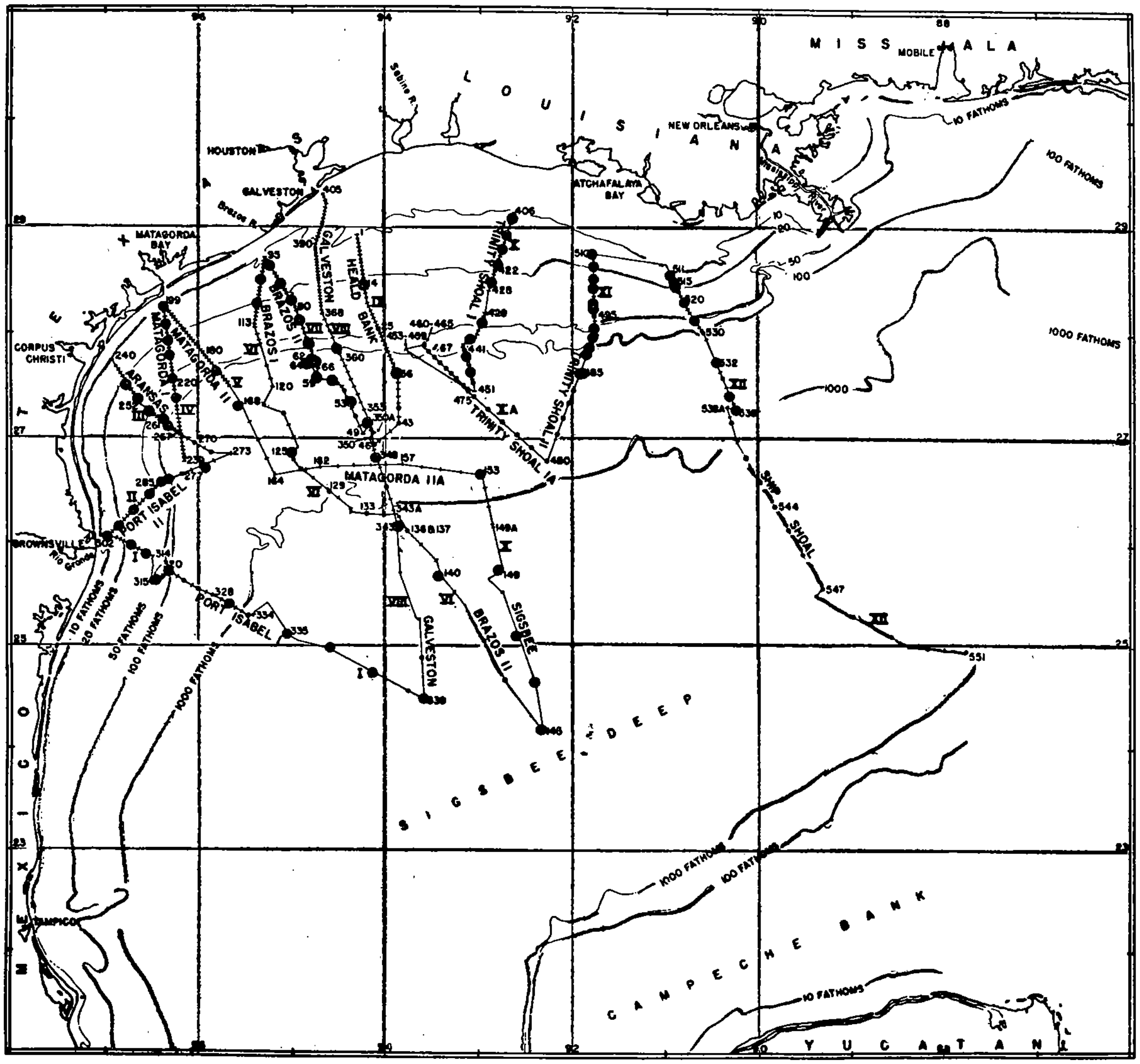
SECTION III

WATER CONTENT OF GULF OF MEXICO SEDIMENTS

In the course of the *Atlantis* Expedition to the Gulf of Mexico in 1947, sponsored jointly by Woods Hole Oceanographic Institution and the Geological Society of America, a series of 83 samples were specially collected by H. C. Stetson and Fred B. Phleger for determination of the water content of the sediments. The location of the water content samples is shown by large dots upon Fig. 19. During this expedition, 12 traverses were run across the northwest Gulf of Mexico and 551 short cores were taken at intervals of five miles or less. These samples were collected with the Phleger sampler and ranged in length from 6 to 20 inches. The upper 2 inches of each sample was impregnated with formalin as soon as the sample was collected, in order to preserve the organic material for biologic studies carried on by Phleger and Parker (1951). The presence of the formalin and the desirability of examining undisturbed samples in the biologic work precluded the use of the routine short core samples for water determinations. Hence at representative places an extra sample was collected for water content. These extra cores, like the other short cores, ranged in length from 6 to 20 inches. The samples were stoppered, the ends taped and sealed with paraffine as soon as they were collected. The tubes were stored in moist sawdust to inhibit loss of water through the walls of the plastic tubes. The water content was analyzed in the laboratory of H. C. Stetson by Constance Klebba shortly after the samples were collected. The moisture content is reported as the ratio of the water content to the dry weight of the samples, expressed as percent. The water content thus is 100 times the ratio W/S, and is given in the form regularly used in soil mechanics practice (Terzaghi and Peck, 1948, p. 25).

The results of the determinations are presented in Table 16. This table gives the core number, the depth of water in fathoms, the water content of the sediments at the top and at the bottom of the cores, and for a few samples the water content of the middle part of the sample. The texture of the upper part of the sample is expressed in terms of median diameter, D_{50}. The texture of the bottom of the sample relative to the texture of the top of the sample is given in the last column by a series of symbols. In this column, the symbol *S* means that the texture of the top and bottom is essentially the same as determined by inspection with a hand lens; the symbol *C* indicates the bottom is distinctly coarser than the top; and *F* means that the bottom is finer than the top. Unfortunately it was not practicable to make mechanical analyses of the bottom parts of the samples. As the water content among other things varies with the grain size, the texture should be known when one compares variations in water content in different parts of the cores.

The areal distribution of the sediments is shown in Fig. 20. The water content of the sediments on the inner part of the continental shelf is less than 100 percent, and in an elliptical area between the



GULF OF MEXICO, WESTERN PART

STATIONS OCCUPIED DURING ATLANTIS CRUISE, 1947

FIG. 19. Location of water samples. Large circles indicate position of samples collected for water content determinations. Small dots represent long cores, dashes refer to short cores.

Brazos and Atchafalaya rivers it is less than 50 percent. The sediments in this elliptical area, as shown on Fig. 15 of this report consist of coarse silt and fine sand. The water content thus follows the general rule of a low content for coarse sediments. The water content increases seaward from the central part of the continental shelf, reaching a maximum of more than 200 percent on the uppermost part of the continental slope just beyond the outer edge of the continental shelf. In this area the sediments are fine grained (average diameter approximately 1 micron) and have a high organic content (2 percent). (See Fig. 2 of this report.) The high water content in the organic-rich sediments is in accordance with the general relationships for near-shore marine sediments reported by Trask (1932, p. 35).

The relationship of water content to grain size is illustrated by the lower curve in Fig. 21. Almost all the data lie within two parallel bands upon this figure centering about a line which has the relation $\log_{10} W^3 = 1 - \log_{10} D_{50}$, where D_{50} is expressed in microns. The upper curve on Fig. 21 represents the relationship of water content to grain size for

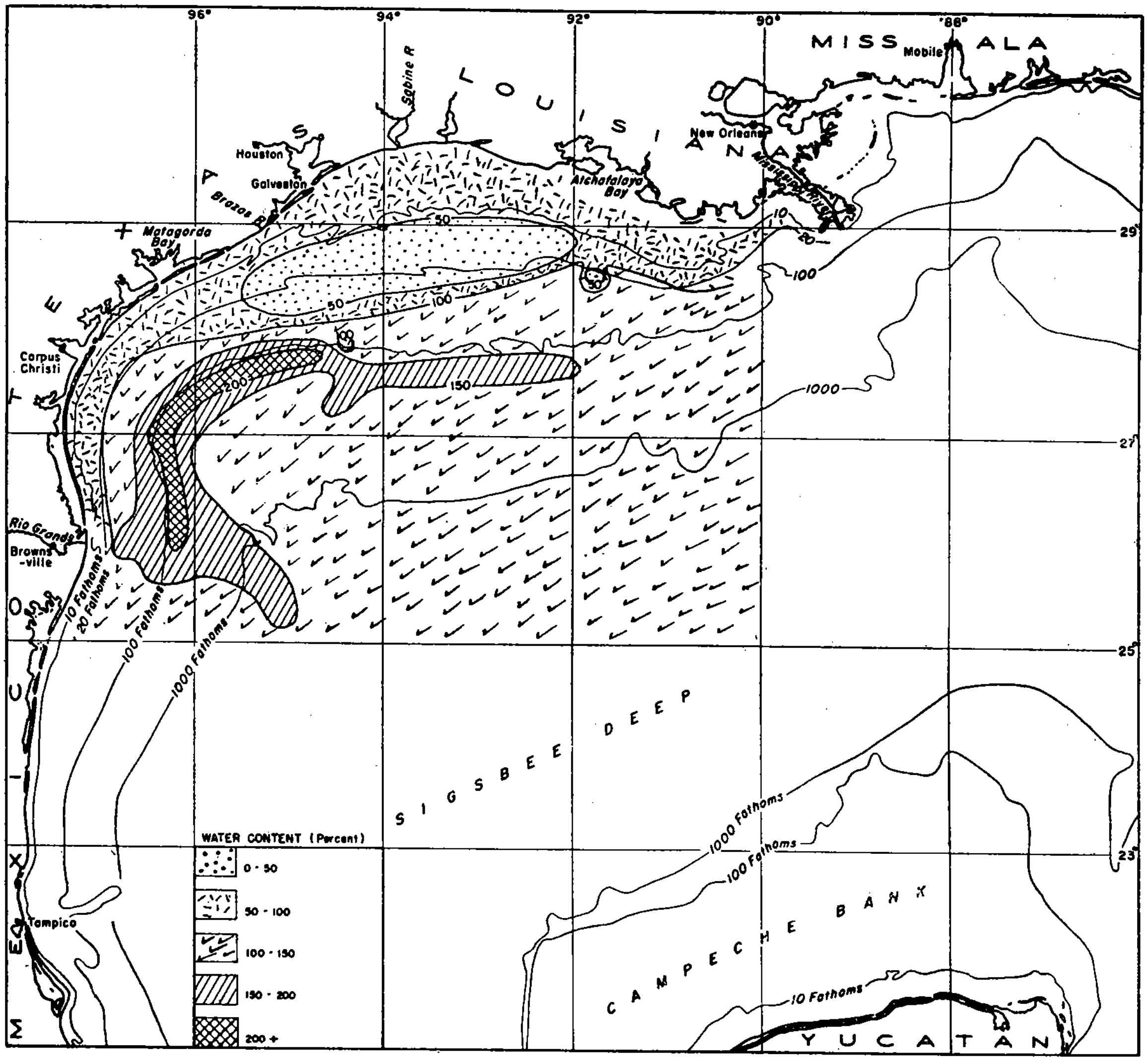


FIG. 20. Water content of sediments, Gulf of Mexico.

freshly deposited sediments. This curve is based on laboratory experiments of sediments which had essentially no time to consolidate under their own weight (Trask, 1931). The Gulf of Mexico deposits, though high in water content and soft in nature, have consolidated somewhat with respect to their own load, and hence have a lower water content for given grain size than do the freshly deposited sediments illustrated in the upper curve. The sediments, however, have consolidated relatively little, as the decrease in water content between top and bottom parts of cores, having the same texture at top and bottom, is 30 percent, whether for sand, silt or clay. For a discussion of consolidation see Terzaghi and Peck (1948, p. 66–73).

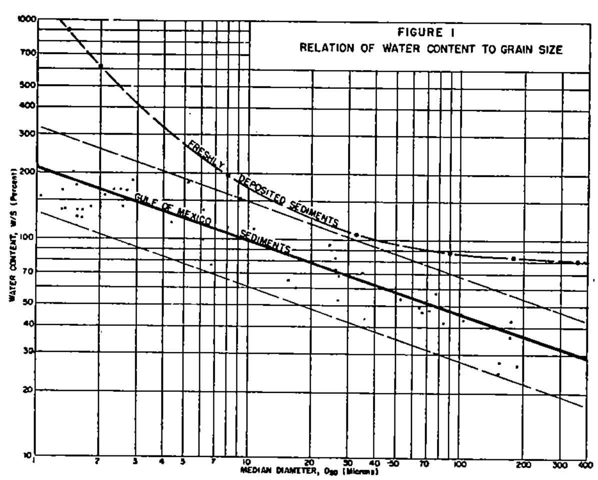


FIG. 21. Relation of water content to grain size of sediments, Gulf of Mexico.

The engineering application of the water content of the sediments of the Gulf of Mexico is described in a companion paper (Trask, 1952). The general relationship of water content to strength and engineering properties of sediments are described by Terzaghi and Peck (1948, pp. 82–110). The lower is the water content, the greater is the strength of the sediments. The strength of sediments also is related to grain size. In San Francisco Bay, Trask and Rolston (1950) have found that the shear strength of the sediments varies both with water content and grain size. Application of their results to the surface sediments in the Gulf of Mexico gives a probable shear strength of 150 pounds per square foot, which is a low strength. However, as the sediments in the Gulf on the whole are very fine grained it is obvious that they should be weak.

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TABLES

Table 1

Summary of Characteristics of the Surface Layers of Sediments in Different Depth Zones in the Northwestern Gulf of Mexico

Depth Zone	Depth of Water in Fathoms	No. of Samples	Lower Limit	First Quartile	Median	Third Quartile	Upper Limit
Calcium Carbonate Content (percent)							
Shelf	0–100	248	0.3	3.4	5.3	8.0	38.4
Slope	100–1000	152	4.5	13.3	21.3	28.2	47.2
Deep	1000–2000	46	14.8	21.8	28.0	32.0	50.8
Nitrogen Content (percent)							
Shelf	0–100	149	.005	.039	.063	.099	.135
Slope	100–1000	79	.035	.098	.119	.136	.158
Deep	1000–2000	16	.036	.060	.068	.085	.117
Carbon Content (percent)							
Shelf	0–100	45	.17	.36	.53	.81	1.29
Slope	100–1000	13	.31	.82	1.02	.115	1.21
Deep	1000–2000	16	.35	.47	.63	.077	1.34
Carbon-nitrogen ratio							
Shelf	0–100	45	4.0	7.5	8.5	9.9	20.0
Slope	100–1000	13	4.0	7.4	8.6	9.7	17.0
Deep	1000–2000	16	6.0	7.6	9.5	10.8	20.0
	Total	838					

One-fourth of analyses are lower than first quartile; one-fourth are larger than third quartile.

Table 2

Change in Organic Content in Upper 25 Centimeters of Sediments

Depth zones	Carbon (Percent)	Nitrogen (Percent)	Carbon-nitrogen ratio	Calcium carbonate Percent
Shelf samples.....	90±2	81±1	113±2	94±3
Slope samples.....	87±2	87±1	105±2	95±4
Deep-water samples	105±5	92±3	112±4	94±5
Number of samples (i.e. cores)......	113	258	118	141

Percentages in this table represent 100 times the ratio of the parameter for depth of 25 centimeters to the parameter for depth of 10 centimeters; that is they are $100\ d_{25}/d_{10}$, where d refers to depth.

Table 3

Variation of Organic Matter with Depth of Burial on Continental Shelf Gulf of Mexico

Sediment Type	Depth of burial (cm.) 0–30	30–100	100–150	150–200	200–250	Number of cores
Carbon content (percent)						
Sand......	.37	.24	.16	.16	.19	1
Silt.......	.83	.84	.88	.52	–	3
Clay......	1.00	.90	.87	.91	–	4
Nitrogen content (percent)						
Sand......	.036	.010	.005	.005	.015	1
Silt.......	.085	.073	.067	.066	–	3
Clay......	.103	.085	.078	.076	–	4

Sediment Type	Depth of buriel (cm.) 0–30	30–100	100–150	150–200	200–250	Number of cores
Carbon-nitrogen ratio						
Sand......	10.3	24.1	32.0	32.0	12.6	1
Silt.......	9.7	11.5	13.3	7.9	–	3
Clay......	9.7	10.6	11.3	12.0	–	4
Calcium carbonate (percent)						
Sand......	16	3	2	6	3	1
Silt.......	5	6	5	8	–	3
Clay......	14	15	10	11	–	4

Table 4

Thickness of Temperature Zones Gulf of Mexico Sediments

(Based on zones of Phleger and Parker 1951)

Profile	Warm Min.	Warm Ave.	Warm Max.	Transition Min.	Transition Ave.	Transition Max.	Cold Min.	Cold Ave.	Cold Max.
	Thickness in centimeters								
Continental slope (200–1500 meters)									
Port Isabel I..	60	90	125	20	40	60	30	40	45
Brazos II.....	30	60	205	20	45	70	0	75	160
Trin.Shoal I...	20	65	210	10	60	125	65	165	240
Trin.Shoal II-A	35	45	50	30	35	45	100	105	210
Ship Shoal....	40	100	165	35	45	50	–	–	–
Transverse....	55	90	130	40	80	95	25	55	80
All profiles....	20	65	210	10	50	125	0	75	240
Ocean basin (1500–3600 meters)									
Port Isabel I..	20	50	80	30	60	90	40	105	140
Brazos II.....	10	35	15	15	30	70	30	100	175
Trin.Shoal II-A	–	50	–	–	30	–	–	100	–
Ship Shoal....	0	30	300	20	75	240	25	130	145
All profiles.	0	35	300	15	45	240	40	110	140

Table 5

Nitrogen Content of Temperature Zones, Gulf of Mexico Sediments

Depth (cm.) Profile	Warm 0–30	Warm 30–100	Warm 100+	Transition Upper	Transition Lower	Cold Upper	Cold Lower
	Average (median) percent nitrogen						
Continental slope (200–1500 meters)							
Port Isabel I ..	.100	.103	.142	–	.067	.088	–
Brazos II	.115	.099	.110	.078	.095	.064	.086
Trin.Shoal I....	.114	.101	.114	.088	.093	.078	.069
Trin.Shoal II-A	.084	–	–	.072	.072	1.05	.075
Ship Shoal.....	.076	.083	.089	–	.065	–	–
Transverse.....	.108	.100	.088	.082	.098	1.03	.085
All samples.....	.107	.099	.108	.083	.094	.088	.077
Ocean basin (1500–3600 meters)							
Port Isabel I ...	.056	.069	–	.063	.051	.068	.064
Brazos II......	.074	.069	.077	.063	.073	.062	.057
Trin.Shoal II-A	.093	–	–	.072	–	.067	.072
Ship Shoal.....	.073	.075	.094	.067	.084	.075	.063
All samples.....	.069	.070	.091	.063	.072	.065	.063

Table 6

Carbon Content of Temperature Zones, Gulf of Mexico Sediments

Depth (cm.) Profile	Warm 0–30	30–100	100+	Transition upper	lower	Cold upper	lower	Number of analyses
	Average (median) percent carbon							
Continental slope (200–1500 meters)								
Port Isabel I	1.18	.74	.86	–	.53	.54	–	9
Brazos II(a)	.92	.97	.95	.63	.92	.69	.70	24
Trinity Shoal I	.95	.84	1.05	.87	.89	.88	.78	43
Trinity Shoal II-A	.74	–	–	.60	.88	.95	.85	20
Ship Shoal	.78	.98	1.06	–	1.13	–	–	7
Transverse	1.06	1.00	.91	1.04	1.13	1.08	.79	30
All samples	.95	.94	.95	.87	.90	.88	.78	
No. of samples	29	20	11	15	18	19	21	133
Average for zone		.95		.89		.83		
Ocean basin (1500–3600 meters)								
Port Isabel I	.56	1.09	–	.58	.74	1.08	1.18	40
Brazos II	.68	.70	.66	.54	.53	.73	.71	49
Trinity Shoal II-A	.71	–	–	.49	–	.69	.62	5
Ship Shoal	.51	.80	1.02	.72	1.24	1.14	1.12	53
All samples	.58	.78	.96	.58	.80	.88	.98	
No. of samples	31	13	6	20	19	22	36	147
Average for zone		.67		.69		.94		

See Figure 1 for location of profiles. Data represent average (median) organic carbon content for the respective depth zone.
(*a*) Includes analyses from cores 125, 275, and 280.

Table 7

Carbon-Nitrogen Ratio of Temperature Zones, Gulf of Mexico Sediments

Depth (cm.) Profile	Warm 0–30	30–100	100+	Transition Upper	Lower	Cold Upper	Lower
	Average (median) c=n ratio						
Continental slope (200–1500 meters)							
Port Isabel I	10.2	7.5	5.5	–	8.7	6.6	–
Brazos II	8.9	9.4	9.2	7.8	9.5	6.4	8.6
Trin. Shoal I	9.3	8.5	9.2	9.8	9.5	11.0	11.8
Trin. Shoal II-A	7.7	–	–	7.8	11.7	10.9	10.1
Ship Shoal	10.7	12.0	12.0	–	20.4	–	–
Transverse	9.8	10.0	10.3	11.3	10.0	10.5	9.3
All samples	8.9	9.4	9.2	9.8	9.6	10.0	10.1
Ocean basin (1500–3600 meters)							
Port Isabel I	9.8	15.9	–	9.9	13.0	16.4	17.6
Brazos II	9.1	9.6	8.5	9.3	8.6	10.5	13.0
Trin. Shoal II-A	7.7	–	–	6.8	–	10.3	8.6
Ship Shoal	8.0	11.8	11.0	11.1	16.0	15.7	15.0
All samples	8.6	11.0	10.6	9.8	12.1	13.3	15.0

Table 8

Calcium Carbonate Content of Temperature Zones, Gulf of Mexico Sediments

Depth (cm.) Profile	Warm 0–30	30–100	100+	Transition Upper	Lower	Cold Upper	Lower
	Average (median) $CaCO_3$ (percent)						
Continental slope (200–1500 meters)							
Port Isabel I	10	17	9	–	21	17	–
Brazos II	17	22	19	23	8	20	18
Trinity Shoal I	30	27	22	17	15	16	18
Trin. Shoal II-A	29	–	–	26	16	13	17
Ship Shoal	26	8	6	3	12	–	–
Transverse	20	20	13	13	14	12	10
All samples	23	23	15	17	14	15	17
Ocean basin (1500–3600 meters)							
Port Isabel I	31	17	–	15	13	9	7
Brazos II	32	21	21	27	16	14	18
Trin. Shoal II-A	28	27	–	26	–	13	18
Ship Shoal	32	21	20	6	10	9	13
All samples	31	21	20	17	14	11	12

Table 9

Organic Content of Special Sedimentary Units, Gulf of Mexico

Sedimentary unit	Depth of burial (Centimeters)	Thickness of unit (Centimeters)	Carbon (Percent)	Nitrogen (Percent)	C/N ratio	$CaCO_3$ (Percent)	Number of cores
Globigerina ooze	0	25	.60	.065	9.2	30	22
Banded clay							
Continental slope, 200–1500 meters	80[1]	175	.88	.081	10.9	16	5
Sigsbee deep 1500–3600 meters	85[1]	125	1.01	.066	15.3	12	17
Recurrent (lower) temperature zones							
Warm	175	22	.97	.065	14.9	18	3
Transition	105	80	.75	.068	11.0	18	8
Cold	170	45	.90	.057	15.8	16	4
White clay	35	18	.55	.060	9.2	44	3
Red clay	50	15	.46	.057	8.1	16	3
Lower sand zone	140	40	.43	–	1.87	8	3
Lower silt zone	140	8	1.06	.067	15.7	21	3

Average of thickness of sediment penetrated. The base of the zone was not encountered in most samples.

TABLE 10

TABULATION OF BASIC DATA ON ORGANIC CONTENT

(Analyses made by H. N. Cooper
U. S. Bureau of Mines)

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50b Microns
7	0–5	28	.054*	–	–	82.
	15–20		.047	.117	2.1	
9	0–5	31	.069*	–	–	36.
	22–27		.056	.336	5.0	
11	0–5	33	.082*	–	–	54.
	17–22		.031	.359	6.3	
13	0–5	38	.046*	–	–	102.
	5–10		.036	.276	13.7	
14c	10–15	40	.036	.370	16.0	84.
	50–55		.010	.241	2.9	
	100–105		.005	.159	1.8	
15	0–5	40	.046*	–	–	121.
	14–19		.035	.254	19.6	
16	0–5	44	–	–	–	71.
17	0–5	46	.066*	–	–	40.5
	22–27		.041	.328	12.6	
19	0–5	46	.040	–	–	159.
	12–17		.031	.371	15.9	
21	0–5	48	.046	–	–	148.
	6–11		.041	.317	31.3	
23	0–5	57	.040	–	–	128.
	5–10		.027*	.248	9.6	
25	0–5	57	.035	–	–	161.
	4–9		.020	.148	17.2	
27	0–5	68	.025	–	–	172.
	6–11		.030	.143	19.9	
29	0–5	82	.025	–		131.
	5–10		.028*	.203	10.6	
31	0–5	205	.119	–	–	2.03
	21–6		.130	1.066	16.5	
33	0–5	326	.157	–	–	1.2
	25–30		.152	1.293	17.5	
35	0–5	586	.098	–	–	1.19
	30–35		.083	.632	12.2	
36c	10–13	732	.141	1.219	19.1*	1.07
	50–53		.115	1.046	19.6	
	100–103		.110	.922	18.1	
	150–154		.123*	1.222	13.7	
	200–203		.099	1.050	12.0	
37	0–5	787	.152	–	–	0.925
	20–25		.120	.979	20.2	
39	0–5	879	.136	–	–	1.06
	21–26		.114	.919	23.6	
41	0–5	823	.120*	–	–	1.00
	18–23		.099	.767	26.8	
43	0–5	870	.120	–	–	1.12
	17–22		.099	.683	28.8	
45	0–5	860	.083	–	–	1.13
	19–24		.083	.566	39.8	
47	0–5	1005	.120	–	–	
	28–33		.094	.618	26.3	
48c	5–10	1040	.109	–	20.8*	1.68
	10–15		.104	.895	20.0*	
	50–55		.073	.780	23.1	
	100–105		.061*	.923	21.9	
	139–144		.046	.630	17.9*	
	143–148		.051	.675	22.1	
49	0–5	952	.110*	–	–	1.0
	30–35		.088	.684	30.9	
51	0–5	915	.115	–	–	1.71
	4–9		.104	.957	27.4	
53	0–5	1320	.125	–	–	
	32–37		.104	.832	21.3	
53c	5–10	1320	.120	.912	19.6	1.34
	50–55		.088	.819	21.6*	
	100–105		.083	.829	19.2	
	150–155		.110	.954	17.8	
55	0–5	695	.136	–	–	1.26
	25–30		.119	.882	23.6	
57	0–5	732	.147	–	–	1.23
	28–33		.131	.915	19.7	
58c	3–8	825	.147	1.016	20.4	1.82a
	50–55		.106	.891	19.5	
	100–105		.117*	1.129	17.0*	
	150–155		.103	.884	12.5	
	200–205		.085*	.791	10.0	
59	0–5	705	.158	–	–	1.31
			.141	.987	15.3	
w	0–5		.144	1.187	16.3	
	26–31		.119	1.014	17.2	
61	0–5	348	.106*	–	–	2.60
	29–34		.079	.603	10.6	
62w	0–5	340	.105*	.850	29.3	1.06a
	33–38		.077	.694	22.8	
63	0–5	360	.168	–	–	
	32–37		.123	1.071	15.0	
64c	10–15	345	.130	1.180	17.1	2.20a
	50–55		.099	.972	21.5	
	100–105		.095	.851	8.4	
	150–155		.085	1.131	10.1	
65	0–5	365	.152*	–	–	
	26–31		.136	1.064	16.7	
67	0–5	320	.162	–	–	
	26–31		.133	1.068	15.4	
w	0–5		.156	1.305	14.5	
			.135	1.103	16.1	
69	0–5	159	.157	–	–	2.01
	25–30		.135	.998	13.9	
71	0–5	97	.092	–	–	9.20
	36–41		.082	.590	11.9	
72w	0–5	91	.071	.539	13.3	10.8a
	24–29		.056	.476	12.0	
73	0–5	80	.064*	–	–	36.0
	20–25		.044*	.359	10.5	
75	0–5	57	.035	–	–	120.0
	4–9		.045	.302	23.2	
77	0–5	47	.023*	–	–	190.0
	13–18		.040	.363	23.5	
77w	0–5		.030*	.189	25.6	
			.028	.227	25.7	
79	0–5	44	.018*	–	–	132.0
	3–8		.018	.143	11.0	
81	0–5	42	.041	–	–	103.0
	17–22		.035	.248	29.4	
82w	0–5	40	.038	.363	8.5	104.0a
			.030	.345	16.3	
83	0–5	31	.040	–	–	1350.
85	0–5	31	.031	–	–	98.0
	14–19		.030	.221	13.5	
87	0–5	31	.046	–	–	35.8
	17–22		.057	.379	4.7	
87w	0–5		.043	.341	6.6	
			.039	.366	8.4	
89	0–5	31	.036	–	–	66.0
	9–15		.041	.390	3.4	
91	0–5	27	.039	–	–	90
	19–24		.051	.362	3.1	
92w	0–5	25	.056	.456	2.6	53.0a
	20–25		.044	.349	2.5	
93	0–5	23	.062	–	–	23.2
	15–20		.051	.411	3.2	
95	0–5	23	.035	–	–	157.0
	13–18		.041	.349	2.9	
97	0–5	22	.049	–	–	78.5
	23–28		.046	.328	2.6	
99	0–5	24	.068	–	–	28.2
	23–28		.049	.389	3.1	
101	0–5	29	.072	–	–	26.0
	16–21		.056	.351	3.1	

TABLE 10 — *continued*

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50b Microns
101W	0–5		.059	.441	2.8	
			.056	.547	3.4	
103	0–5	32	.070*	–	–	24.0
	24–29		.035	.218	3.3	
105	0–5	33	.025	–	–	99.0
	14–19		.020*	.205	1.7	
106W	0–5	35	.033	.384	9.7	72.0a
	16–21		.018	.246	0.7	
107	0–5	29	.040*	–	–	75.0
	12–17		.034	.345	7.3	
109	0–5	33	.052*	–	–	44.1
	13–18		.041	.327	5.6	
111	0–5	38	.051*	–	–	44.0
	18–23		.042	.396	6.3	
113	0–5	46	.062	–	–	42.0
	16–21		.041	.333	7.7	
115	0–5	57	.046	–	–	92.0
	11–16		.035	.337	9.1	
117	0–5	73	.066	–	–	96.0
	6–11		.041	.233	30.8	
119	0–5	775	.129*	–	–	1.14
	24–29		.111	.906	17.6	
121	0–5	1075	.120	–	–	1.17
	23–28		.103	.753	20.3	
123	0–5	1372	.110	–	–	1.27
	18–23		.087	.644	26.2	
125	0–5	1330	.105*	–	–	1.35
	28–33		.078	.768	24.0	
125C	0–5	1330	.110	.874	15.4	
	49–52		.089	.580	23.2	
	83–86		.079	.719	18.5	
	150–155		.088	.691	17.9	
	213–217		.071*	.710	17.2	
127	0–5	1355	.099	–	–	1.41
	29–34		.083	.579	27.6	
129	0–5	1810	.099*	–	–	1.29
	32–37		.088	.690	28.4	
129C	0–9		.095	.805	27.4	
	9–14		.079	.582	28.9	
	14–19		.074	.528	26.7	
	20–25		.078*	.347	27.0	
	26–32		.048	.520	24.4	
	32–37		.063	.637	25.6	
	75–80		.073*	.524	20.5	
	100–105		.054	–	20.7	
	121–124		.063	.577	20.5	
	124–130		.057	–	20.6	
132	0–5	1866	.091	–	–	1.1
	35–40		.065	.690	26.6	
134	0–5	1605	.086	–	–	1.01
	25–30		.070	.452	31.2	
136	0–5	2750	.054*	–	–	
	16–21		.049	.345	46.5	
138	0–5	3054	.073*	–	–	1.01
	23–28		.063	.479	26.4	
140	0–5	3270	.093	–	–	17.2
	36–41		.076	.605	21.2	
140C	10–15		.098	.785	21.8	
	47–52		.088	.683	23.7	
	100–105		.077	.655	21.0*	
	150–155		.078	.760	13.9	
	179–183		.082*	.863	15.2	
142	0–5	3250	.083	–	–	1.81
	27–32		.078	.590	24.1	
143C	0–2	3530	.078	.750	30.5	
	5–10		.068	.779	27.6	
	17–22		.068	.683	27.4	
	40–47		.063	.541	27.8	
	75–78		.068	.703	9.2	
	110–120		.047	.726	13.1	
	134–141		.036	.619	13.1	

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50 Microns
143C	146–150		.051	.705	16.8	
	153–161		.068	.846	11.6	
	162–164		.057	.844	12.2	
145C	10–15	3630	.052	.474	33.0	1.95
	30–35		.069	1.140	8.0	
	50–55		.062	.546	45.3	
	62–67		.061	.883	60.7	
	80–85		.053	.509	16.2*	
	100–105		.074*	1.204	5.7*	
	150–155		.069	1.241	7.4*	
	200–205		.063	1.245	9.4	
	200–205		.083*	1.286	7.0	
146C	10–15	3630	.041	.427	14.8	1.17a
	50–55		.047	.647	17.9	
	100–105		.025	.696	15.3	
	175–180		.041*	.898	14.3	
147C	9–14	3295	.065*	.638	26.7	1.64a
	52–57		.041	.514	12.8	
	96–100		.046	.659	20.0	
	113–118		.057	.905	12.8	
	146–151		.059*	.833	12.1*	
149C	10–15	3040	.065	1.011	16.6	1.91a
	50–55		.061	.956	12.9*	
	100–105		.056	1.075	12.5	
	128–132		.073	1.117	21.1	
150	0–5	1890	.057*	–	–	2.2
	9–14		.057	.323	33.5	
152	0–5	1645	.078	–	–	
	14–19		.077	.602	43.5	
153C	10–15	1500	.052	.446	38.0	11.5a
	50–55		.073	.700	21.1	
	100–105		.052	.631	23.6	
	150–155		.063	.578	18.5	
	200–205		.046	.598	22.6	
	235–240		.052*	.488	26.4*	
154	0–5	1390	.088	–	–	1.99
	23–28		.073	.427	32.6	
156	0–5	1318	.092	–	–	1.77
	22–27		.068	–	32.3	
158	0–5	1207	.091	.470	–	1.95
	25–30		.073	–	32.1	
160	0–5	1245	.075*	.511	–	1.49
	22–27		.078	.618	23.4	
162	0–5	1520	.099	–	–	2.85
	29–34		.071	.437	29.8	
164	0–5	1550	.108*	–	–	0.97
	27–32		.082	.595	24.6	
166	0–5	1255	.110	–	–	1.00
	25–30		.089	.647	20.4	
168	0–5	860	.141	–	–	1.08
	25–30		.121	.983	11.7	
168C	10–15	860	.116	1.021	10.8	
	49–54		.111	1.061	15.2	
	110–115		.105	.943	14.4	
	150–155		.108	1.043	13.8	
	204–208		.106	1.109	11.1	
170	0–5	568	.135	–	19.2	1.92
	29–34		.126	1.041	11.2	
172	0–5	353	.156	–	–	1.81
	25–30		.135	1.108	10.6	
174	0–5	128	.109	–	–	4.55
	24–29		.091	.741	10.1	
175W	0–5	92	.064	.486	12.8	35.3a
	15–20		.059	.513	11.3	
176	0–5	80	.039*	–	–	45.1
	26–31		.050	.483	20.8	
178	0–5	62	.025*	–	–	168
	10–15		.020	.148	21.5	
180	0–5	58	.023	–	–	198.0
	7–12		.025	.301	26.3	
182	0–5	57	.033	–	–	115.0
	17–22		.045*	.277	5.8	

TABLE 10 — *continued*

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	CaCO3	D50b Microns
184	0–5	49	.081	–	–	16.3
	18–23		.044	.511	4.7	
186	0–5	43	.062	–	–	42.0
	27–32		.049	.441	4.2	
188	0–5	38	.056	–	–	26.0
	23–28		.039	.331	4.6	
190	0–5	33	.072	–	–	36.3
	25–30		.054*	.407	3.8	
192	0–5	27	.033	–	–	58.0
	9–14		.046	.537	2.0	
194	0–5	24	.060	–	–	35.3
	23–28		.036	.324	2.7	
196	0–5	24	.103*	–	–	4.04
	38–43		.039	.195	2.4	
198	0–5	20	.116	–	–	24.8
	14–19		.041	.312	4.2	
199w	0–5	15	.033	.333	3.9	78.0a
	8–13		.049	.519	3.4	
200	0–5	18	.074	–	–	20.2
	17–22		.033*	.246	4.2	
202	0–5	24	.029	–	–	30.1
	15–20		.023	.172	1.5	
204	0–5	25	.039	–	–	66.2
	22–27		.033*	.303	2.3	
204w	0–5		.030	.173	3.6	
			.039	.286	2.4	
206	0–5	31	.070*	–	–	39.0
	19–24		.054	.485	2.8	
208	0–5	35	.020	–	–	69.2
	14–19		.065	.508	3.6	
209w	0–5	36	.070	.436	3.4	27.0a
	11–16		.059	.395	3.5	
210	0–5	38	.035	–	–	72.0
	12–17		.081	.605	4.1	
212	0–5	51	.089	–	–	7.2
	22–27		.081	.542	5.5	
214	0–5	60	.104	–	–	12.7
	27–32		.093	.695	5.1	
214w	0–5		.098*	.774	4.4	
			.096	.731	4.8	
216	0–5	70	.093	–	–	8.22
	25–30		.088	.752	6.0	
218	0–5	84	.126	–	–	4.73
	32–37		.071	.600	7.4	
219w	0–5	90	.091	.671	8.3	14.4
	30–35		.075	.564	7.8	
220	0–5	99	.110*	–	–	3.64
	30–35		.081	.544	8.7	
222	0–5	119	.124	–	–	2.58
	29–34		.104	.779	8.9	
224	0–5	152	.130	–	–	2.01
	23–28		.063	.867	15.6	
224w	0–5		.130	1.103	11.7	
			.104	.818	14.6	
226	0–5	201	.143*	–	–	1.94
	28–33		.125	.983	14.7	
228	0–5	304	.148	–	–	2.29
	18–23		.135	1.120	11.7	
230	0–5	415	.157	–	–	2.47
	23–28		.148	1.165	12.2	
232	0–5	505	.140	–	–	2.08
	18–23		.130	1.262	8.5	
234	0–5	495	.128*	–	–	1.83
	26–31		.130	1.012	7.5	
236	0–5	530	.130	–	–	1.13
	35–40		.063	.799	13.1	
238	0–5	660	.095	–	–	1.91
	17–22		.074	1.018	6.6	
241	0–5	22	.090	–	–	2.1
	21–26		.044	.363	3.3	

Station	Position of Sample in Core cm.	Depth of Water Meter	Nitrogen	Carbon Percent	CaCO3	D50 Microns
243	0–5	27	.087	–	–	25.8
	29–34		.065	.499	3.2	
245	0–5	36	.089	–	–	4.15
	32–37		.074	.541	3.7	
246w	0–5	42	.087	.882	3.5	6.1a
	25–30		.078	.535	3.7	
247	0–5	48	.093*	–	–	5.5
	26–31		.086	.617	3.5	
249	0–5	48	.108	–	–	3.15
	25–30		.090	.746	3.8	
251	0–5	57	.103	–	–	1.55
	28–33		.095	.757	4.5	
251w	0–5		.099	.914	3.8	
			.093	.697	4.7	
253	0–5	70	.128*	–	–	1.78
	29–34		.102	.755	4.6	
255	0–5	78	.130	–	–	1.60
	37–42		.081	.670	3.8	
257	0–5	93	.109	–	–	2.80
	21–26		.098	.733	5.7	
259	0–5	110	.117*	–	–	1.77
	29–34		.103	.827	8.6	
261	0–5	143	.126	–	–	1.49
	35–40		.110	.871	7.5	
261w	0–5		.123	.965	8.0	
			.113	.932	7.9	
261c	0–2		.127	–	–	
	2–3		.121	1.242	7.8	
	5–10		.121	1.039	9.0	
	10–15		.121	1.305	7.6	
	15–20		.105	–	–	
	25–30		.126	1.062	8.8	
	45–50		.100	1.043	8.0	
	70–75		.110	.980	9.7	
	95–100		.078	.807	9.2	
	110–115		.089	.915	8.5	
	135–140		.120	.859	10.5	
	160–165		.120	.807	13.1	
	170–172		.116	–	–	
263	0–5	229	.132	–	–	1.67
	26–31		.128	1.077	13.1	
263w	0–5		.144*	1.289	11.8	
			.117	.955	12.5	
265	0–5	357	.143*	–	–	0.92
	22–27		.136	1.165	14.2	
267	0–5	485	.147	–	–	1.15
	32–37		.137	1.180	9.7	
267c	0–2		.116	–	–	
	3–5		.105	–	–	
	10–15		.095	–	–	
	28–36		.106	–	–	
	52–60		.084	–	–	
	90–100		.047	1.100	11.9	
	130–140		.042	–	–	
	160–163		.047	1.003	9.0	
269	0–5	680	.140	–	–	1.02
	30–35		.120	.960	9.3	
271	0–5	823	.123	–	–	0.89
	34–39		.131	.988	11.7	
273	0–5	980	.122	–	–	0.84
	28–33		.108	.862	8.4	
275	0–5	732	.126	–	–	1.05
	21–26		.117	.973	4.5	
275c	10		.125	1.160	7.4	
	52		.125	1.085	8.9	
	100		.115	.445	12.4	
	152		.115*	1.272	9.4	
	204		.104	.990	8.3	
277	0–5	585	.138*	–	–	.089
	28–33		.127	.919	5.1	
280	0–5		.140	–	–	1.00
	25–30		.131	1.045	7.1	

TABLE 10 — *continued*

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50b Microns
280c	10–15	275	.137	1.250	7.6	
	50–55		.127	1.015	7.2	
	100–105		.128	1.068	7.3*	
	151–156		.115*	1.109	8.9*	
	188–193		.115	.972	9.2	
2.82	0–5	132	.130	–	–	2.83
	20–5		.114	.922	7.1	
282w	0–5		.125	1.044	7.2	
			.104	.874	6.0	
284	0–5	92	.115*	–	–	3.05
	33–38		.106	.823	5.2	
286	0–5	82	.116	–	–	2.4
	30–35		.094	.706	4.2	
287w	0–5	70	.113	.936	4.6	1.32
	41–46		.113	.703	3.2	
288	0–5	59	.056	–	–	—
	6–11		.051	.301	4.1	
290	0–5	46	.030*	–	–	169.0
	17–22		.041	.274	3.2	
292	0–5	40	.044	–	–	165.0
	20–25		.025	.171	4.4	
292w	0–5		.046	.453	5.1	
			.015	.058	4.4	
294	0–5	37	.109	–	–	2.74
	29–34		.071	.533	4.2	
296	0–5	37	.105*	–	–	4.54
	34–39		.079	.616	5.4	
297w	0–5	35	.063*	.620	3.6	1.65a
	32–37		.096	.864	4.7	
298	0–5	35	.116	–	–	4.75
	13–18		.024	.125	2.5	
300	0–5	27	.046	–	–	15.0
	15–20		.041	.330	4.6	
302	0–5	23	.041*	–	–	165.0
	5–10		.039	.364	5.4	
302w	0–5		.034	.361	7.9	
			.018	.253	11.6	
304	0–5	27	.033	–	–	167.0
	17–22		.025	.181	6.5	
306	0–5	37	.020	–	–	200.0
	13–18		.067	.470	6.5	
307w	0–5	38	.086	.687	5.3	2.50a
	23–28		.025	.220	5.6	
308	0–5	40	.058*	–	–	6.3
	25–30		.023	.222	3.5	
310	0–5	44	.083	–	–	13.6
	24–29		.044	.359	9.2	
312	25–30	53	.046	.489	8.5*	18.0
312w	0–5		.066*	.639	4.3	
	25–30		.044	.413	5.8	
315	31–36	91	.047	.559	10.3	1.4
317	24–29	120	.106	.946	7.7	1.56
317w	0–5	120	.125	.963	7.85	
	24–29		.109	.900	7.3	
319	31–36	148	.101	.935	8.3	0.90
321	39–44	366	.111	1.066	7.7	0.95
321w	0–5		.138	1.069	8.3	
	39–44		.130	1.081	7.1	
324c	0–3	750	.116	1.178	10.4	1.34a
	3–8		.153	1.193	9.5	
	10–15		.106	1.160	9.0	
	20–28		.100	1.182	9.4	
	70–80		.137	.879	11.2	
	100–110		.142	.862	9.3	
	190–192		.131	.730	14.0	
325	30–35	895	.075	.804	12.2	0.88
327	29–34	1110	.077*	1.800	8.1	1.02
329	33–38	1100	.058	2.079	11.2	1.01
330c	10–14	1120	.091*	.766	19.2	1.10a
	46–49		.069	.585	22.0	
	99–103		.067	.528	21.4	

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50 Microns
333c	150–153		.046	.347	20.0	
	199–202		.061	.465	21.7	
331	0–5	1285	–	–	–	0.96
	31–36		.068	–	–	
333	23	1620	.058	.563	23.6	1.03
335c	8–13	3440	.081*	.777	17.9*	
	42–47		.069	.895	21.5	
	100–105		.066	.589	14.9	
	147–152		.067	.736	15.3	
	161–163		.041	.802	12.9	
	188–193		.000	.624	9.7	
336c	9–14	3530	.072	.810	29.0	2.43a
	82–85		.046	.553	28.0	
	104–109		.041	.536	16.1	
	188–193		.000	.385	3.8	
337c	10–15	3570	.068	.678	28.8	1.70a
	50–55		.054	.533	29.5	
	100–105		.057	.948	11.3	
	150–155		.054	.692	17.6	
338	20–25	3630	.069	.447	14.1	1.2
339	0–5	3550		–	–	0.94
	22–27			–	–	
339c	10–14		.067	.563	31.1	
	46–50		.062	.608	43.9	
	59–62		.050*	.462	12.9	
	71–74		.072	.657	18.6*	
	100–105		.078	1.338	7.3	
	151–155		.078	1.178	7.7	
	182–186		.073	1.268	7.6*	
341	35–40	3475	.082*	.621	23.9	1.01
343A	21–26	1750	.058	.480	25.1	1.03
343c	10–15	1920	.060*	.657	21.7	
	50–55		.078	.928	21.9	
	100–105		.062	.494	22.4	
	150–155		.062	.482	23.1	
	200–205		.057	.406	20.7	
	246–251		.055*	.248	34.0	
344	27–32	1490	.068	.516	28.9	0.935
346	26–31	1340	.079	.648	31.2	0.96
348	24–29		.089	.630	28.4	1.18
348c	10–15	1300	.099	.603	27.6	
	50–55		.078	.634	25.4*	
	100–105		.093	.951	21.9	
	200–203		.072	.651	18.9	
350	19–24	1200	.079	.845	26.5	1.08
351	13–18	1490	.078	.799	9.2	1.86
353	15–20	1430	.082*	.759	20.4	1.13
356	10–15	657	.101	–	–	0.88
358	29–34	298	.088	1.146	12.6	1.33
360	30–35	183	.132	1.109	13.2	1.41
362	12–17	87	.051	.594	13.9	26.10
362w			.063*	.537	13.5	
	12–17		.049	.478	11.0	
364	5–10	57	.025	.292	21.3	152.0
366	2–7	57	.020	.244	20.6*	178.0
368	10–15	55	.028*	.224	14.8	167.0
370	16–21	46	.030	.208	9.7	97.0
372	16–21	42	.030	.343	5.7	113.0
374	0		–	–	–	
	14–19	35	.020	.393	15.0	
376	14–19	33	.044*	.405	13.6	94.5
377	15–20	31		–	–	99.0
378	12–17	31	.031	.562	3.3	60.0
380	22–27	27	.041	.291	3.7	76.3
382	10–15	24	.031	.408	2.9	85.5
384	16–21	29	.031	.259	3.8	88.0
386	6–11	22	.030*	.254	2.3*	90.0
388	6–11	22	.025	.323	2.6	96.
390	4–9	20	.025	.310	5.3	108.0
396	0–5	13	.051	–	–	52.5
	14–5		.031	.418	2.6	
398	0–5	20	.061*	–	–	27.5
	26–31		.048	.237	5.5	

TABLE 10 — *continued*

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50b Microns
401	0–5	20	.078	–	–	36.5
	15–20		.036	.300	2.1	
402	0–5	20		–	–	56.5
403	0–5	17	.062	–	–	
	17–22		.049	.497	2.3	
405	0–5	13	.100	–	–	64.5
	27–32		.052	.618	1.5*	
407	0–5			–	–	27.9
	10–15	22	.020	.136	0.3	
407w	0–5	26	.065	1.119	2.5	
	10–15		.029	.455	0	
409	35–40	26	.069	.575	1.2	29.2
411	17–22	26	.025	.249	3.2	168.0
412w	0–5	24	.015	.240	3.5	154.0a
	12–17		.018	.362	2.6	
414	0–5	24	.025	–	–	122.0
	12–17		.023*	.303	0.7	
416	27–32	27	.058	.736	1.9	158.0
417w	0–5	27	.023	.201	10.2	152a
	7–12		.028*	.105	0	
418	16–21	29	.026	.416	1.6	85.0
420	18–23	35	.025	.492	5.1	84.5
421w	0–5	37	.028	.218	7.6	67.5a
	20–25		.018	.098	2.8	
422	13–18	37	.057	.754	2.5	28.8
422c	0–3		.051	.562	14.5	
	3–5		.114	.484	4.8	
	8–13		.109	.535	3.9	
	18–23		.047	.449	3.2	
	33–38		.052	.534	3.0	
	53–58		.064	.631	2.7	
	73–78		.059	.619	2.8	
	83–88		.058	.698	7.9	
	108–113		.052	.659	1.9	
	115–117		.062	.639	2.1	
	116–117		.052	.778	1.7	
	130–135		.068	.662	2.9	
	179–180		.069	.750	1.8	
424	29–34	42	.066*	.816	2.2	4.0
426	28–33	47	.057	.893	2.5*	17.0
426w	0–5		.039	.675	1.6	
	28–33		.046	.509	5.2	
428	6–11	47	.025	.176	8.6	140.0
430	28–33	75	.074	.722	2.2*	5.67
432	0–5	84	.115*	–	–	6.2
	29–34		.083	.908	8.8	
432w	0–5		.113	.838	11.6	6.2a
	29–34		.081	.706	11.7	
434	18–23	167	.041	.637	7.3	217.0
436	22–27	114	.089	.927	19.4	3.64
437w	0–5	123	.129*	1.047	18.2	52.0a
	29–34		.057	.766	7.9	
438	26–31	127	.116	1.113	14.6	2.01
440	24–29	157	.118*	1.161	18.7	2.32
442	21–26	198	.104	1.072	29.4*	1.75
443w	0–5	200	.123	1.088	30.6	2.21a
	29–34		.094	.839	29.6	
444	23–28	205	.078	.749	34.6	3.3
445c	0–3	175	.077	.623	37.4	71.0a
	8–15		.051	.492	37.5	
	25–35		.056	.439	30.6	
	43–50		.046	.408	11.9	
	69–78		.051	.522	11.2	
	78–88		.052	.456	8.7	
	110–115		.039*	.416	6.4	
	137–139		.036	.371	5.7	
	139–150		.047	.497	5.1	
	173–181		.026	.307	5.4	
	190–203		.041	.670	4.7	
446	13–18	210	.056	.466	47.2	81.0
448	22–27	430	.115	.690	28.5	1.91

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50 Microns
448w	0–5		.124	1.053	28.0	
	22–27		.113	1.109	23.8	
451	0	915	–	–	–	1.20
	32–37		–	–	–	
462c	10–15	127	.074	.713	14.4	6.1a
	50–55		.068*	.582	16.8	
	100–105		.064	.769	10.8	
	120–125		.048	.731	7.0	
	160–165		.054	.710	7.7	
467c	10–15	157	.145	1.319	18.9	1.39a
	50–55		.120	1.245	16.2	
	100–105		.109	1.122	16.1	
	155–160		.104	–	18.0	
468c	10–15	230	.138*	1.225	22.2	1.27a
	50–55		.132	1.297	19.9	
	100–105		.114	1.045	22.1	
	200–205		.114	1.151	17.0	
469c	10–15	225	.114	1.096	29.8	4.00a
	50–55		.098	.918	25.1*	
	95–100		.088	.865	16.7	
	200–205		.031	.366	24.0*	
	200–225		.015	.280	13.4	
470c	10–15	230	.046	.505	43.7	131.a
	50–55		.046	.583	35.2	
	105–110		.025*	.392	8.0	
	150–155		.020	.249	5.5*	
	170–175		.015	.263	3.7	
471c	10–15	330	.157	1.372	23.0	13.0a
	50–55		.130	1.071	23.8	
	100–105		.109	.995	24.4	
	180–185		.094*	.890	11.3*	
472c	10	365	.085*	.871	36.1	1.58a
	50		.094	1.002	12.5	
	100		.078	1.105	14.7	
	200		.077	.789	16.7	
473c	10–15	460	.082	.835	40.7	2.4a
	50–55		.078	.746	15.7	
	100–105		.062	.965	16.5	
	200–205		.077	.742	19.1	
	225–230		.067*	.746	17.8	
474c	10–15	445	.120	1.116	25.5	1.6a
	50–55		.094	.750	26.9	
	100–105		.106	.982	19.5	
	135–140		.091	.918	11.2	
	150–155		.107*	1.212	7.6	
	200–205		.079	.857	14.3	
	280–285		.083	1.044	14.4	
475c	0–2	715	.057	–	46.1	0.96a
	5–8		.046	–	46.0	
	8–10		.062	–	–	
	10–13		.057	.825	36.3	
	13–16		.067	.988	29.6	
	25–31		.062	.839	21.9	
	46–52		.083	1.547	20.6	
	61–66		.072	1.300	20.4	
	85–95		.078	1.381	21.2	
	115–125		.072	1.204	22.8	
	145–154		.072	1.342	24.0	
	164–166		.078	1.476	21.2	
476c	0–2	1100	.125	–	–	1.36a
	2–4		.115	1.136	22.0	
	4–6		.115	–	–	
	6–8		.115	.827	22.3	
	12–15		.104	–	–	
	44–52		.104	.560	27.4	
	90–100		.083	.580	24.6	
	140–150		.105	.765	13.6	
	195–205		.083	.828	15.1	
	245–253		.073	.909	13.1	
477c	10–15	1270	.094	.945	29.9	1.18a
	50–55		.078	.673	27.8	
	100–105		.089*	.893	14.8*	
	150–155		.082*	.933	17.2*	

TABLE 10 — *continued*

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50b Microns
4770	200–205		.061	.867	22.6	
	250–255		.067	.692	14.6	
	290–295		.072	.754	15.7	
479c	12–16	1320	.077*	.586	34.2	1.10a
	51–55		.067	.738	34.0*	
	101–105		.061	.668	20.0	
	120–125		.051	.873	12.6	
	149–154		.056	.819	17.6*	
	250–253		.058*	.820	17.2	
	298–303		.056	.626	20.5	
480	33–38		.066*	.562	26.4	1.33
480c	10–15	1865	.093	.711	28.1	
	50–55		.072	.487	25.7	
	100–105		.067	.693	13.0	
	150–155		.072	.617	18.2	
	200–205		.068	.805	21.9	
	250–255		.072	1.291	20.1	
	265–270		.067	.600	32.0	
482	31–36	1375	.068	.512	31.0	1.18
482c	5–10	1375	.084	.551	30.2	—
	50–55		.077	.602	31.0	
	80–85		.093	1.026	8.5	
	100–105		.105*	1.429	14.5	
	150–155		.066	.902	17.6	
	200–205		.061	.952	15.3	
	249–254		.066*	.895	12.9	
	299–302		.052	.887	15.4	
484c	0–3	715	.094	.911	28.1	
	3–5		.099	.761	29.4	
	5–7		.083	.910	32.3	
	10–12		.083	.766	33.7	
	25–26		.084	–	–	
	46–52		.068	.913	14.6	
	75–79		.051*	.718	22.4	
	98–102		.083	.952	15.4	
	102–103		.115	1.247	11.4	
	146–152		.109	1.080	12.6	
	188–191		.089	.900	11.6	
	209–305		.088	.879	12.6	
	238–242		.062	.620	17.1	
	288–292		.077	.805	15.6	—
484	40–45		.073	.883	15.8	1.80a
485c	10–15	232	.108	1.130	22.2*	1.32a
	52–56		.091	.952	20.7	
	95–98		.091	1.175	21.5	
	152–155		.098	1.122	11.9	
	200–204		.103	1.617	6.1	
486	0–5	127	.040	.311	83.5*	
486c	10–15		.035	.611	84.3	
	100–105		.028*	.362	84.3	
	150–155		.030	.206	93.3	
	200–205		.035	.361	72.0	
	250–255		.030	.578	61.5	
	275–280		.066	.351	25.2	
487w	0–5	192	.070*	.576	27.6	26.2a
	21–26		.067	.611	26.2	
488	21–26	187	.110	1.075	20.2	1.48
489c	7–12	147	.124	1.180	15.9	2.12a
	48–53		.088*	1.094	14.4*	
	96–101		.083	.989	11.8	
	148–153		.083	1.049	12.6	
	196–201		.088	1.108	11.8	
490	27–32	125	.072	.694	35.8	1.90
491	25–30	114	.100	.911	9.4	3.34
492w	0–5	100	.135	1.025	12.8	1.53a
	25–30		.072	.754	38.4	
493	24–29	90	.089*	.888	12.5	3.05
			.116	1.257	9.6	
495	35–40	79	.063	.648	9.3	4.34
497	39–44	68	.063	.703	4.1	5.25

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50 Microns
497w	0–5		.114	.795	8.9	
	39–44		.087	.762	3.5	
498c	10	66	.067	.792	6.2	4.39a
	50		.065*	.835	10.7	
	99		.063	.725	4.2*	
	185		.062	.847	4.0	
499	31–36	66	.084	.762	7.9	3.80
501	29–34	64	.063	.773	4.6	4.51
502w	0–5	59	.119*	.918	5.4	2.70a
	31–36		.079	.729	1.0	
503	29–34	57	.073	.754	4.2	4.14
504c	7–11	50	.072	.696	3.7	11.20a
	46–51		.059*	.849	5.0	
	95–100		.046	.761	3.4	
	130–135		.031	.311	37.6	
	146–151		.005	.160	5.7	
	196–201		.015	.188	2.6	
	230–235		.025*	.515	4.2	
505	0–5	40	.095	–	–	3.75
	28–33		.121	.761	3.9	
507	0–5	33	.099	–	–	9.52
	33–38		.078	.626	3.8	
507w	0–5		.103	.813	3.6	
	33–38		.066	.591	3.2	
509	0–5	26	.098	–	–	15.0
	33–38		.084	.817	3.2	
510c	10–15	26	.075*	.861	3.6	15.7a
	50–55		.062	.808	4.7*	
	100–105		.062	.841	6.8	
	151–156		.054*	.637	5.0	
511	0–5	22	.064*	–	–	48.0
	14–19		.061	.534	3.7	
512w	0–5	26	.072	.627	4.0	24.3a
	23–27		.055	.644	3.3	
513	0–5	29	.072	–	–	25.0
	26–31		.062	.559	3.4	
515	0–5	40	.078	–	–	6.8
	12–17		.058	.675	3.3	
515c	10–15		.059	.664	2.6	
	50–55		.065	.706	2.9	
	100–105		.066*	.898	2.5	
	140–146		.046	.487	4.0	
516w	0–5	40	.073*	.764	3.7*	8.0a
	31–36		.093	.872	0.5	
517	0	40	.095	–	–	4.45
	0		.078	–	–	
	29–34		.042	.681	3.9	
519	0–5	46	.089	–	–	4.1
	29–34		.069	.740	4.2	
521	0–5	55	.084	–	–	2.79
	17–22		.085	.848	5.1	
521w	0–5		.066	.879	3.7	
	17–22		.084	.829	3.9	
523	0–5	70	.113	–	–	1.8
	28–33		.079*	.702	4.9*	
525	0–5	105	.127	–	–	1.4
	18–23		.106	.979	6.4	
526w	0–5	120?	.115	1.091	7.1	2.6a
	32–37		.090	1.009	4.8	
527	0–5	135	.124	–	–	1.3
	30–35		.106	1.015	7.3	
529	0–5	187	.129	–	–	1.08
	28–33		.118	.940	9.6	
531	0–5	165	.116	–	–	1.21
	31–36		.082*	.796	8.5	
532c	10–15	175	.105	1.101	16.8	2.05a
	50–55		.094	1.114	9.9	
	101–106		.088	.912	13.2	
	151–156		.073	1.029	12.6*	
533	0–5	570	.135	–	–	1.03
	35–40		.107	1.049	7.3	
535	0–5	970	.117	–	–	1.10
	20–25		.096	.945	10.3	

TABLE 10 — *continued*

Station	Position of Sample in Core cm.	Depth of Water Meters	Nitrogen	Carbon Percent	$CaCO_3$	D50b Microns
536c	4–9	1065	.095*	.775	23.6	1.37a
	50–55		.088	1.017	3.8	
	100–105		.077	.944	11.8	
	148–152		.089	1.062	5.9	
	193–198		.098	1.408	6.0	
537	0–5	1175	.121*	–	–	1.35
	30–35		.102(?)	.759	21.6	
538c	8–13	1285	.057	.781	27.2	1.21a
	50–55		.051*	3.404	2.5	
	86–90		.032	.861	17.8	
538A	0–5	1230	.077	–	–	
	20–25		.083	.886	16.7	
540	0–5	1470	.096	–	–	1.23
	33–38		.072*	.754	20.1	
541c	10	1890	.072	.844	18.0	1.74a
	50		.062	.863	20.8	
	100		.056	.819	24.3	
	130		.061	.758	24.3	
	155		.061	.831	24.4	
542	0–5	2490	.174	–	–	1.08
	36–41		.112	1.045	21.1	
542c	7–11		.117	1.339	21.9	
	47–52		.093	1.060	20.7	
	96–101		.093	1.130	20.2*	
	146–150		.098*	1.011	21.1	
	198–203		.095	1.021	20.8	
	247–253		.094	1.245	19.6	
	297–301		.093	1.044	19.3	
544	0		.067	–	–	2.21
	23–28		.036	.398	36.0	
544c	10–15	3000	.053*	–	26.0	
	50–55		.075*	1.354	5.6	
	100–105		.076	1.414	11.2	
	150–155		.045	1.403	10.0	
	200–205		.084	1.474	8.3*	
	250–255		.084	1.481	8.3	
545c	10–15	3100	.036*	.504	39.5	4.75a
	51–57		.059	.620	16.0*	
	96–100		.098	1.408	9.9	
	153–158		.072	1.298	6.0	
	201–206		.077	1.152	7.8	
	256–261		.062*	1.218	12.8	
546	0–5	3150	.057	–	–	2.72
	15–20		.047	.444	31.4	
546c	10–15		.063	.491	38.5	
	35–40		.052	.915	4.3	
	60–65		.078	1.243	6.1	
	100–105		.083	1.597	8.3*	
	150–155		.073	1.143	8.5	
	200–205		.078	1.246	10.5	
	235–240		.078	1.279	13.3	
	270–275		.084*	1.357	11.5	
547c	0–4	3220	.083	.493	42.1	3.36a
	4–8		.083	.516	36.4	
	8–10		.073	.560	31.6	
	11–15		.063	.510	32.3*	

Station	Position of Sample in Core cm.	Depth of Water Meter	Nitrogen	Carbon Percent	$CaCO_3$	D50 Microns
547c	15–20		.078	.346	31.0	
	21–24		.083	.484	30.4	
	29–34		.074	.448	17.1	
	36–38		.062	.386	17.5	
	39–42		.074	.497	17.1	
	48–53		.090	.862	8.0	
	60–62		.083	.788	9.5	
	64–71		.095	.832	8.3	
	71–74		.077	–	–	
	96–99		.096	1.226	8.2	
	136–142		.090	1.164	11.0	
	150–151		.041	–	–	
	152–157		.064	1.123	11.2	
	193–199		.085	1.189	7.5	
	218–221		.080	1.229	7.1	
	230–231		.057	–	–	
	239–245		.080	1.551	2.7	
548	0–5	3350	.062	–	–	
	15–20		.073	.720	29.0	
549c	10	3430	.078	.745	32.3	3.03a
	50		.057*	.546	33.2*	
	77–82		.030	.417	85.4	
	100		.056	.908	10.6	
	137–142		.041	.483	29.0	
	200		.078	1.311	5.3	
	248		.063*	1.044	7.9	
550	0	3330	.062	–	–	6.6
	12–17		.052	.646	50.8	
550c	0–5		.067	–	–	
	5–10		.046	1.743	–	
	10–16		.057	.426	44.3	
	31–36		.063	.413	16.7	
	41–48		.036	.826	13.7	
	104–122		.063	1.176	8.2	
	156–166		.041	1.227	7.2	
	188–189		.068	1.150	7.6	
	202–203		.064	1.141	6.7	
551c	0–2	3365	.041	.471	47.6	
	2–5		.046	.386	46.3	
	5–10		.046	.344	47.7	
	20–24		.026	.496	31.0	
	32–40		.068	1.290	5.7	
	75–85		.064	1.249	7.3	
	125–135		.068	1.473	6.9	
	175–185		.047	1.274	8.2	
	200–204		.052	1.564	9.0	

Position — Depth of sample below surface of sediment.
Depth — Depth of sea bottom below sea level.
D50 — Median diameter in microns.
a — Median determined on Phleger Core (short core) sample.
b — D50 determined by H. C. Stetson.
c — Core sample.
w — Sample procured for water content.
* — Average of duplicate determinations.

TABLE II

CHEMICAL ANALYSIS OF SEDIMENTS, NORTHWEST GULF OF MEXICO, F. A. GONYER, *Analyst*

Sample	1	2	3	4	5	6	7
Core	14	145	145	168	330	336	336
Sediment	Sand	Clay	Clay	Clay	Clay	Clay	Sand
Zone	upper warm	lower warm	middle cold	middle warm	middle warm	lower warm	middle cold
Depth of water (m)	40	3630	3630	860	1120	3530	3530
Depth of burial (cm.)	43–45	32–35	171–174	44–47	30–34	36–39	170–173
D50 (microns)	103	1.5	1.1	1.9	1.17	1.4	164
				Percent by weight			
SiO_2	84.34	53.92	50.12	47.42	40.24	42.46	79.54
TiO_2	.11	.79	.88	.79	.72	.72	.28
Al_5O_3	4.78	13.46	14.30	13.44	13.64	12.84	7.52
Fe_2O_3	.83	4.03	5.84	5.06	3.96	5.70	1.66
MnO	.03	.06	.08	.08	.11	.13	.02
Mg O	.31	2.78	3.20	2.57	2.48	2.50	.26
Ca O	3.45	5.22	3.54	6.14	12.92	11.62	2.80
Na_2O	1.04	2.44	2.85	2.84	2.66	2.33	1.90
K_2O	1.46	2.51	2.59	2.55	2.28	2.12	2.24
H_2O+	1.22	6.52	8.68	10.06	8.64	8.10	1.70
CO_2	2.44	4.80	3.60	4.48	7.80	9.30	1.70
P_2O_5	.00	.15	.21	.24	.13	.22	.03
SO_3	.13	.56	.62	.39	.69	.60	.13
Cl	.22	1.49	2.38	2.49	2.26	1.90	.23
Total	100.36	98.73	98.79	98.55	98.53	100.54	100.01
Less $O:Cl_2$	.05	.34	.54	.56	.51	.43	.05
Corrected Total	100.31	98.39	98.25	97.99	98.02	100.11	99.06
Est. Residual CaO	1.50	1.56	1.72	3.96	5.80	2.83	2.04
Est. Org. C	.25	.50	.80	.75	.60	.65	.30
Probable Org. C	.24	1.14	1.24	1.06	.59	.55	.38
Probable $CaCO_3$	3	8	8	15	22	28	40
Computed $CaCO_3$	3.47	6.50	3.24	3.93	12.72	15.70	1.36
Carbon-nit. ratio	24.1	16.6	19.0	9.6	8.5	12.0	–

TABLE II — *continued*

Sample	8	9	10	11	12	13	14
Core	462	480	515	547	547	547	547
Sediment	Silt	Marl	Clay	Marl	Red clay	Clay	Clay
Zone	middle warm	middle warm	upper warm	lower warm	transition	upper cold	lower cold
Depth of water (m)	127	1865	40	3220	3220	3220	3220
Depth of burial (cm.)	41–44	30–33	47–50	20–23	33–36	92	185–188
D50 (microns)	6.9	1.4	1.8	2.4	2.1a	1.3a	1.5
				Percent			
SiO_2	53.22	36.94	57.50	41.86	45.24	49.48	49.80
TiO_2	.72	.46	.61	.51	.55	.55	.53
Al_2O_3	11.76	12.72	14.56	12.90	13.94	16.04	16.04
Fe_2O_3	3.80	4.42	5.21	6.32	9.16	4.11	4.90
MnO	.11	.09	.07	.11	.04	.06	.09
MgO	2.58	2.34	2.66	3.35	4.24	3.09	3.14
CaO	8.42	16.24	1.30	10.58	5.12	3.26	3.56
Na_2O	2.18	2.35	2.78	2.31	2.43	2.79	2.81
K_2O	2.20	2.17	2.50	2.09	2.17	2.51	2.56
H_2O+	6.14	6.43	8.22	8.21	10.17	9.32	8.96
CO_2	6.72	12.46	1.13	8.38	4.13	3.22	3.41
P_2O_5	.23	.09	.19	.19	.21	.20	.17
SO_3	.47	.61	.57	.63	.46	.65	.57
Cl	1.33	1.67	1.96	1.96	2.53	2.46	2.48
Total	99.88	98.99	99.26	99.40	100.39	97.74	99.02
Less $O:Cl_2$	.30	.38	.44	.44	.57	.55	.55
Corrected Total	99.58	98.61	98.82	98.96	99.82	97.19	98.47
Est. Residual CaO	2.44	2.75	1.19	1.84	1.74	1.49	1.55
Est. Org. C	.55	.50	.28	.40	.40	.50	.50
Probable Org. C	.58	.60	.70	.48	.39	1.22	1.19
Probable $CaCO_3$	17	27	3	30	18	8	8
Computed $CaCO_3$	10.64	24.13	.20	15.60	6.04	3.16	3.59
Carbon-nit. ratio	16.8	7.3	10.9	5.8	6.2	12.7	14.0

TABLE 12

MOLECULAR RATIOS OF SEDIMENTS, GULF OF MEXICO

Core	Depth of burial (cm.)	Analysis number	Sediment zone	SiO_2/R_2O_3[a]	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Na_2O+K_2O[b]$/Al_2O_3$	B[c]$/Al_2O_3$	Na_2O/K_2O	CaO/MgO	$CaO+MgO/Na_2O+K_2O$	$CaCO_3$[d]
44	43	1	Sand warm	27.0	30.0	.11	.63	1.20	.90	3.70	1.1	3.5
145	32	2	Clay warm	5.7	6.8	.19	.36	.56	.81	.41	1.9	6.5
145	171	3	Clay cold	4.7	6.0	.26	.32	.53	.64	.40	2.3	3.2
168	44	4	Clay warm	4.8	6.0	.24	.32	.85	.59	1.20	3.0	3.9
330	30	5	Clay warm	4.2	5.0	.19	.29	1.06	.65	1.82	4.0	12.7
336	36	6	Clay warm	4.4	5.6	.28	.29	.68	.64	.87	2.9	15.7
336	170	7	Sand cold	15.7	18.0	.14	.70	1.09	1.28	.63	1.8	1.4
462	41	8	Silt warm	6.4	7.7	.21	.37	.73	.82	.70	2.5	10.6
480	30	9	Marl warm	4.0	4.9	.22	.32	.71	.78	.90	2.5	24.1
515	47	10	Clay warm	5.5	6.7	.23	.33	.44	.81	.33	1.7	0.2
547	20	11	Marl warm	4.2	5.5	.31	.28	.53	.64	.41	3.1	15.6
547	33	12	Red clay	3.9	5.5	.42	.23	.45	.41	.30	4.1	6.0
547	92	13	Clay cold	4.5	5.3	.16	.26	.43	.59	.36	2.3	3.2
547	185	14	Clay cold	4.4	5.3	.19	.26	.43	.59	.37	2.3	3.6

a. $R_2O_3 = Al_2O_3 + Fe_2O_3$

b. $Na_2O + K_2O$ is ba_1 value of soil physicists.

c. $B = CaO + Na_2O + K_2O = ba$ value of soil physicists.

d. $CaCO_3$ is computed percent by weight as reported in Table 11.

Molecular ratios are based on rounded molecular weights advocated by Washington (1917, p. 1163) and Jenny 1941, p. 26)

The weight percentages reported in Table 11 have been corrected for sea salt content in computing molecular ratios as follows: Correction for Na_2O is 0.75 Cl; MgO is 0.11 Cl; CaO is 0.03 Cl; K_2O is 0.024 Cl (See Revelle 1944, p. 61).

TABLE 13

MECHANICAL ANALYSES OF GULF OF MEXICO SEDIMENTS ON WHICH CHEMICAL ANALYSES WERE MADE

(CONSTANCE F. KLEBBA and SALLY M. MACAUSLAN, *Analysts*)

Core	Depth of burial (cm.)	Number	Q_1	Median Microns	Q_3	So	$\log_{10}Sk$
14	43–45	1	116	103	87	1.15	−.022
145	32–35	2	6.4	1.5	0.3	4.34	+.009
145	171–174	3	2.6	1.1	0.4	2.54	−.049
168	44–47	4	6.0	1.9	0.6	3.25	−.025
336	35–41	6	4.2	1.4	0.5	2.84	+.019
336	170–173	7	203	164	115	1.33	−.062
462	41–44	8	30.3	6.9	1.1	5.30	−.163
480	30–35	9	4.2	1.4	0.6	2.69	+.065
515	47–51	10	6.1	1.8	0.5	3.42	+.013
547	17–20	11	11.4	2.4	0.6	4.20	+.117
547	37–40	12	6.5	2.1	0.9	2.69	+.107
547	87–92	13	3.3	1.3	0.5	2.46	+.019
547	183–188	14	3.5	1.5	0.6	2.34	−.026

Q_1 and Q_3 are first and third quartiles,

$So = \sqrt{Q_1/Q_3}$, $Sk = \frac{\sqrt{Q_1 \times Q_3}}{M^2}$ (calculated on basis of 3 significant figures)

Note that some of the samples are at slightly different depth intervals than the samples analyzed chemically.

Table 14

Chemical Analyses of Sediments and Rocks Related to Gulf of Mexico Sediments

Sample	15	16	17	18	19	20	21	22	23	24	25	26
Sediment ...	Glob. ooze	Glob. ooze	Fleist. clay	Red mud	Red clay	Marine mud	Silt	Silt	Shale	Sand-stone	Lime-stone	Litho-sphere
Location.....	Carib. Sea	off N.Fnld.	off N.Fnld.	off Amazon	Composite sample		Miss. delta	off Md.		General average		
Depth of water(m.)..	4880	4820	4820	1220		various		338		rocks		
Analyst......		Edgington		Brazier		Steiger		Edgington		after Clarke		
SiO_2........	20.72	29.52	46.01	31.66	54.48	57.05	69.96	61.12	58.10	78.33	5.19	59.08
TiO_2........	.37	.46	.57	–	.98	1.27	.54	.61	.65	.25	.06	1.03
Al_2O_3........	7.98	7.53	11.53	9.21	15.94	17.22	10.52	9.62	15.40	4.77	.81	15.23
Fe_2O_3........	3.91	3.26	4.57	4.52	9.59	7.62	3.47	3.22	6.74[n]	1.40[n]	.54	7.23
MnO........	.17	.12	.09	–	.99[i]	.12	.06	.05	–	–	.05	.12[n]
MgO........	2.17	2.28	2.44	2.07	3.31	2.17	1.41	1.63	2.44	1.16	7.89	3.45
CaO........	32.29	28.04	14.96	25.68	1.96	2.04	2.17	7.29	3.11	5.50	42.57	5.10
Na_2O........	1.93	2.07	2.45	1.53[f]	2.05	1.05	1.51	2.34	1.30	.45	.05	3.71
K_2O........	.71	1.37	2.12	1.33	2.85	2.25	2.30	1.88	3.24	1.31	.33	3.11
H_2O........	2.33[d]	1.31[d]	1.63[d]	–	7.04	7.17	3.78	1.50[d]	5.00	1.63	.77	1.30
CO_2........	23.85	21.63	11.37	17.13	–	–	1.40	5.50	2.63	5.03	41.54	.35
P_2O_5........	.10	.08	.13	–	.30	.21	.18	.13	.17	.08	.04	.29
SO_3........	.29	.23	.25	.27	–	–	.03	1.00	.64	.07	.05	.03
Cl..........	1.42	1.48	1.39	2.46	.00	.00	.50	–	–	–	.02	.05
Total.......	98.24	99.38	99.50	95.96	99.49	98.17	97.83	95.89	99.42	99.98	99.91	100.08
Ign. Loss	29.40	25.19	14.97	6.02	–	–	1.96[j]	10.86	–	–	–	–
Meas. Org. C.	.74[e]	.16[e]	.36[e]	–	–	1.69	.66[e]	.56[e]	.80	–	–	.04
Est. Org. C...	.30	.30	.30	.20	–	–	.25	.30	.55	.40	–	.06
Residual CaO[b]	3.36	1.89	1.91	4.68	1.96	2.04	1.55	1.69	2.33	.98	–	4.93
$CaCo_3$[c]	51.65	46.68	23.32	37.30[g]	–[e]	–[e]	1.10	10.00	1.39	8.08	76.0[k]	.30

Description of Analyses Given in Table 14

Sample

(15) Edgington and Byers (1942, p. 153) — Globigerina ooze, Bartlett deep, Caribbean sea, Lat. 19° 14′N, 76° 48′W. Sample 137 A-1 from surface of deposit.

(16) Edgington and Byers (1942, p. 153) — Globigerina ooze, off Newfoundland, Lat. 48° 38′N, Long. 36° 01′W. Sample 5A-19 from surface of deposit.

(17) Edgington and Byers (1942, p. 153) — Clay from late glacial warm zone at depth of 110 cm. below surface of core at same locality as (16). Sample 5A-11.

(18) Murray and Renard (1891, p. 235) — Red mud off Amazon River, Challenger Station 120, Lat. 8° 37′S, Long. 34° 28′W.

(19) Clarke (1924, p. 518) — Single analysis of composite sample of 51 samples of red clay collected by Challenger and other expeditions from many parts of the ocean; analyses corrected for sea salt, $CaCO_3$ and hygroscopic water.

(20) Clarke (1924, p. 518) — Single analysis of composite sample of 52 terrigenous muds from many parts of the sea — analyses corrected for sea salt, $CaCO_3$ and hygroscopic water.

(21) Clarke and Steiger (1914, p. 59) see also Clarke (1924, p. 509) — Single analysis of composite of 235 samples of silt from the Mississippi delta.

(22) Edgington and Byers (1942, p. 153) — Surface mud from continental slope on Atlantic coast off Ocean City, Maryland. Sample 1, Lat. 37° 26′N, Long. 74° 28′W.

(23–26) Clarke (1924, p. 34) — Table showing average composition of lithosphere and major rock types.

Explanation Table 14

a. Ignition loss represents water above 105° + CO_2 + chlorine.

b. Difference between total CaO and CaO in carbonate as reported under (*c*).

c. $CaCO_3$ as determined from CO_2 in form of carbonate. This carbonate CO_2 is total CO_2 derived from organic matter, using estimated organic content as basis of computation.

d. Water 105° to 110°C.

e. Organic matter as reported in the analysis; presumably organic carbon is 56 percent of this quantity.

f. This sample when leached with water to remove chlorides yielded 0.70 percent Na_2O and 1.38 percent K_2O. (Murray and Renard, 1891, p. 236). These quantities have been used in computing molecular ratios. The chlorine content on this basis would be 1.24 percent.

g. $CaCO_3$ as reported in the analysis is 38.93 percent.

h. Includes FeO computed as Fe_2O_3.

i. MnO as computed from MnO_2.

j. H_2O.

k. As reported by Clarke (1924, p. 33).

l. Analyses presented on carbonate-free, sea-salt-free basis.

TABLE 15

COMPARISON OF MOLECULAR RATIOS OF GULF OF MEXICO SEDIMENTS WITH ANALOGOUS SEDIMENTS

	Analysis	SiO_2/R_2O_3[b]	SiO_2/Al_2O_3	Fe_2O_3/Al_2O_3	Na_2+K_2O/Al_2O_3	B[c]$/Al_2O_3$	Na_2O/K_2O	CaO/MgO	$CaO+MgO/Na_2O+K_2O$	$CaCO_3$
				Sands						
Sand — C. shelf, Gulf Mex....	(1)[a]	27.0	30.0	.11	.63	1.20	.90	3.70	1.1	3.5
Sand — Deep water, Gulf Mex.	(7)	15.7	18.0	.14	.70	1.09	1.28	.63	1.8	1.4
Sandstone — World Ave......	(24)	23.5	27.8	.19	.45	.83	.52	.61	2.2	8.1
				Silts						
Silt — Gulf Mex............	(8)	6.4	7.7	.21	.37	.73	.82	.70	2.5	10.6
Silt — Miss. Delta...........	(21)	9.3	11.3	.21	.41	.68	.76	.82	1.4	1.1
Silt — Ocean City, Md.......	(22)	9.0	10.8	.21	.61	.94	1.88	.75	1.2	10.0
				Clays						
Clay — C. shelf, Gulf Mex....	(10)	5.5	6.7	.23	.33	.44	.81	.33*	1.7	0.2
Clay — C. slope G.M........	(4, 5)	4.5	5.5	.22	.31	.96	.62	1.51*	3.5	8.3
Clay — Deep W., Gulf Mex...	(2, 6)	5.0	6.2	.24*	.33	.62	.72	.64*	2.4	11.1*
Marine muds...............	(20)	4.3	5.6	.28	.24	.46	.71	.67	2.2	–
Shale — World Ave..........	(23)	5.0	6.4	.28	.37	.64	.61	.68	1.9	1.4
Ave. Lithosphere............	(26)	5.1	6.6	.30	.62	1.21	1.80	1.02	1.9	0.3
				Pleistocene clay deposits						
Cold Zone, Gulf Mex.........	(3, 13, 14)	4.5	5.5	.20	.28	.46	.61	.38	2.3	3.2
Warm Zone, N. Atlan.........	(17)	5.4	6.8	.25	.41	.71	1.09	.59	2.0	23.3
				Calcareous deposits						
Marls — Gulf Mex...........	(9, 11)	4.1	5.2	.26	.30	.62	.71	.65*	2.8	19.9
Glob. ooze Carib. Sea........	(15)	3.4	4.4	.31	.27	1.01	1.97	1.14	5.1	51.6
Glob. ooze N. Atlantic........	(16)	5.2	6.6	.27	.40	.84	1.08	.63	3.0	46.7
Limestone — World Ave......	(25)	7.7	10.9	.43	.54	–	.23	–	–	76.0
				Red clay						
Red clay — Gulf Mex........	(12)	3.9	5.5	.42	.23	.45	.41	.30	4.1	6.0
Red clay — World Ave.......	(19)	4.2	5.8	.39	.41	.63	1.09	.42	1.9	8±
Red Mud (Amazon R.).......	(18)	4.5	5.9	.31	.29	1.21	.77	1.71	5.0	37.3

See Table 2 for explanation.

a. Numbers refer to columns in Tables 1 and 4. *b.* $R_2O_3 = Fe_2O_3 + Al_2O_3$. *c.* $B = Na_2O + K_2O + CaO$.

* Based on variable data.

TABLE 16

WATER CONTENT OF GULF OF MEXICO SEDIMENT ANALYSES BY MRS. CONSTANCE KLEBBA

Sample	Depth Fathoms	Length cm.	Water Content Top	Water Content Middle Percent	Water Content Bottom	Texture Top Microns	Texture Bottom[a]
14	22	18.1	41.3	27.7	25.7	84	S
36	400	24.5	151.3	141.0	121.9	1.07	S
48	510	27.3	134.0	–	45.4	1.68	C
53	720	37.0	167.5	143.4	72.0	1.34	F
58	483	42.0	139.2	132.0	92.4	1.82	S
59	385	31.0	221.1	–	145.9	1.31	S
62	185	38.4	150.3	–	135.9	1.06	S
64	187	25.9	142.2	138.6	114.8	1.48	F
67	175	31.0	220.8	–	156.1	1.10	S
72	50	29.0	102.0	–	62.8	10.8	S
77	26	17.6	26.9	–	28.6	190	F
82	20	17.6	43.4	–	28.6	104	S
87	17	21.6	43.7	–	43.4	36	S
92	14	25.4	53.6	–	50.5	53	S
101	15	21.4	81.9	–	62.1	26	F
106	19	20.7	47.3	–	35.7	72	C
125	725	33.3	103.0	139.0	110.6	1.35	F
140	1790	40.5	143.1	110.0	129.8	17.2	F
145	1985	–	117.9	161.3	118.0	1.95	F
146	1985	–	101.5	151.3	96.0	1.17	C
147	1853	–	122.6	144.7	87.5	1.64	S
149	1650	–	61.5	–	41.8	1.91	S
153	820	–	129.0	109.5	94.4	11.5	F
168	470	30.0	157.8	144.1	106.8	1.08	F
175	50	19.5	70.2	–	56.4	35	S
199	8	13.1	57.4	–	50.6	78	F
204	14	26.6	49.5	–	47.4	66	F
209	20	16.2	67.8	–	50.2	27	S
214	33	31.5	109.0	–	95.5	12.7	F
219	50	34.9	137.9	–	64.7	14.4	S
224	84	28.4	140.0	–	102.7	2.01	C
246	23	30.0	99.5	–	79.9	6.1	S
251	31	33.4	133.2	–	103.1	1.55	C
256	48	39.0	165.8	–	97.2	2.36	S
261	78	39.6	200.1	–	124.4	1.49	S
263	125	30.5	199.2	–	115.0	1.67	S
275	403	25.7	136.7	133.0	126.8	1.05	S
280	150	29.9	153.8	136.7	110.6	1.00	S
282	72	25.3	184.0	–	119.8	2.83	S
287	39	46.4	134.2	–	110.3	1.32	S
292	22	25.0	51.7	–	36.6	165	C
297	19	37.3	124.5	–	76.3	1.65	F
302	12	9.6	42.4	–	20.9	165	S
307	21	28.1	168.2	–	37.3	2.50	C
312	29	30.0	143.5	–	60.0	18	S
317	66	29.0	175.9	–	123.8	1.56	S
321	200	44.3	192.0	–	145.1	0.95	F
330	610	47.0	128.4	109.1	92.7	1.10	S
335	1880	–	143.9	119.5	94.2	2.01	S
336	1930	–	118.0	–	26.4	2.43	F
337	1950	–	146.8	105.2	90.9	1.70	C
339	1940	26.8	123.0	162.8	63.0	0.94	F
343	1056	25.8	107.0	114.9	85.4	2.50	S
348	710	28.8	137.0	161.2	95.4	1.18	S
362	48	17.3	71.9	–	55.6	26.1	S
407	12	14.6	52.0	–	40.5	27	C
412	13	16.7	27.5	–	25.2	154	F
417	15	11.9	24.6	–	36.5	152	S
421	20	24.8	46.1	–	35.2	67.5	S
426	26	32.5	60.0	–	42.5	17.0	S
432	46	33.7	135.1	–	91.5	6.2	S
437	67	34.0	143.1	–	66.5	52.0	C
443	109	33.8	144.1	–	103.8	2.21	S
448	235	27.0	166.4	–	112.9	1.91	S
485	402	35.8	172.0	121.8	109.6	1.32	S
486	70	12.0	62.5	–	41.8	10.5	S
487	104	26.3	92.9	–	71.4	26.2	F
489	80	29.5	158.8	112.2	46.2	2.12	F
492	55	30.0	123.7	–	92.2	1.53	C
497	37	44.4	180.9	–	95.9	5.25	S
498	36	42.6	118.9	82.8	74.5	4.39	S
502	32	35.9	165.5	–	88.5	2.70	S
504	27	38.4	25.3	71.2	20.1	11.20	S
507	18	37.6	151.2	–	67.8	9.52	S
510	14	33.4	64.4	71.8	75.6	15.7	S
512	12	27.4	92.2	–	53.3	24.3	S
515	22	17.3	76.1	88.0	68.6	6.8	C
516	22	35.8	112.9	–	91.5	8.0	F
521	30	21.9	92.1	–	95.5	2.79	F
526	65	37.2	140.7	–	88.5	2.6	S
532	150	–	143.1	112.9	104.2	2.05	S
536	580	25.4	138.2	127.3	121.0	1.37	F
538	700	33.7	132.0	–	157.5	1.21	F

See text for explanation.

a—Texture symbol for bottom of core.
S—Same as top.
C—Coarser than top.
F—Finer than top.