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THE SEDIMENTS OF THE CONTINENTAL SHELF OFF THE EASTERN COAST OF THE UNITED STATES

BY

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INTRODUCTION

Our knowledge of clastic, shallow-water sediments over any considerable area of ocean floor is very generalized and leaves much to be desired. The notations concerning the character of the bottom found on all charts are necessarily limited to a descriptive word or two, and although sufficient for navigational purposes, are of little use to the stratigrapher. Of all the marine sediments in the geologic column, those laid down in the neritic zone bulk the largest. They grade slowly into the sediments of the bathyal zone with no sharp line of demarcation. The early oceanographers were more interested in the clays and organic oozes of the deep sea and they added but little information concerning those materials which to the geologist are the most important. From the charts one is apt to obtain the impression that bottom deposits, excepting those of the deep sea, are very patchy in their distribution, and that there is little rhyme or reason in their arrangement. On the other hand the geological text books are apt to make it appear that there is an orderly gradation of sediments from coarse to fine in an offshore direction, and that a sandstone is always an indication of shallow water deposition, with a shale the reverse.

Twenhofel (1) has called attention to the role of environment in sedimentation. Like organisms, sediments are the resultants of a long sequence of environmental factors to which they have been exposed: action by currents, wave generated and otherwise, availability of supply and its type, distance from shore, and depth of water, plus their combined effect during times of changing sea level in the past. These factors have operated in the regions of production, during the period of transportation, and at the place of deposition, and the retention of older characteristics further complicates the record. The following study was undertaken with the hope that through a detailed and systematic series of samples not only might something be learned about the characteristics and distribution of the sediments of a particular area, but something also of the environmental factors which govern conditions of sedimentation in a major ocean.

The continental shelf off the eastern coast of the United States was chosen for two reasons; it is readily available, and it happens to be one of the best developed. The coastal deposits are unconsolidated, insuring an abundant supply of sediment for the sea to work upon. Wave action is vigorous. Theoretically a profile of equilibrium should have been developed at least on the near-shore bottoms. Glaciation of the northern section, which has furnished the sea with new material to work on, offers a contrast to the southern section where the sea is reworking old marine and fluviatile deposits. All in all, conditions here seem most favorable for the unhindered operation of those factors which govern transportation and deposition under marine conditions.

Accordingly eight long traverses were run across the shelf, beginning as near the beaches as possible, and in most cases carrying over the break in slope. South of New England two short lines were added which begin at the break in slope and continue downwards. Three traverses from the Gulf of Maine are included for the purpose of comparing conditions in which the water deepens rapidly with conditions on the shelf proper where the gradient is less steep. Stations were made one half to two miles apart.

The writer wishes to acknowledge his chief indebtedness to Mr. William S. Warner who not only took most of the samples but also had to solve many of the difficulties encountered in the operation of a new boat and new gear. Profs. P. E. Raymond, R. A. Daly, and Kirk Bryan have been most helpful with advice and criticism.

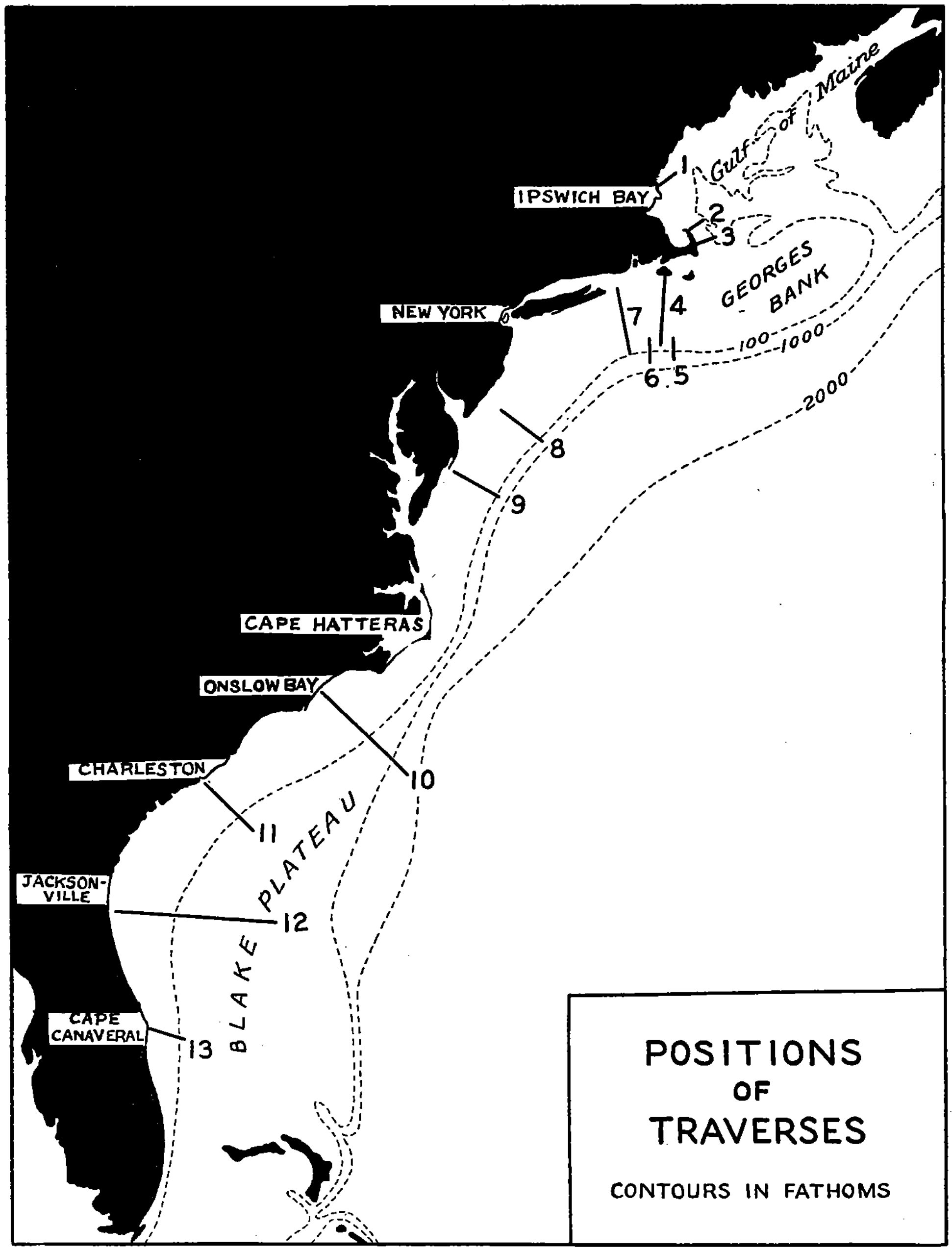
Gulf of Maine
IPSWICH BAY
1
2
3
4
5
6
7
GEORGES BANK
100
1000
2000
NEW YORK
8
9
CAPE HATTERAS
ONSLOW BAY
10
CHARLESTON
11
JACKSON-VILLE
12
BLAKE PLATEAU
CAPE CANAVERAL
13
POSITIONS OF TRAVERSES
CONTOURS IN FATHOMS

FIG. 1.

THE DREDGE

It is obvious that the problem of obtaining a fair and representative sample for mechanical analysis from the sea bottom represents difficulties not encountered on land. Krumbein (2) has shown, using beach sands as an illustration, that the sampling error may run as high as 4.51 percent, but that this error may be reduced to any desired order of magnitude by a composite made up of several closely spaced samples. Such a procedure is out of the question at sea, and therefore the only solution lies in using a dredge which will secure as representative a sample as possible under existing conditions. Roughly, dredges fall into three groups and all have drawbacks. There is the coring tube, the snapper or grab variety, and various forms of scraper dredges. The coring tube, although excellent for soft bottoms, will not take a sample in hard-packed sand or gravel. Scrapers and snappers have two major faults in common, which render them unsatisfactory except in shallow water. First, the sample is never uniform, i.e., the dredge digs to varying depths below the surface depending upon the character of the bottom, and, secondly, the container is not water tight and selective washing of the material occurs on the trip to the surface. This is particularly true of the snapper variety in which the jaws are always held apart to a varying degree by sand and pebbles. If one goes to the trouble of making a mechanical analysis, it seems worth while to use a dredge which will eliminate these faults, so that additional errors may not be superimposed on the already existing sampling error.

Accordingly, with C. O'D. Iselin the machine was designed which appears in Fig. 2. When the apparatus is first lowered over the side the whole weight is carried by the bail (a) into which the release (b) is hooked. The wire from the winch is made fast to a shackle in the upper end of the release, and the wire from the drum (c) is made fast to the lower end. When the dredge reaches the bottom the hoisting wire goes slack and the release is tripped. It was found advisable to solder a rectangle of sheet zinc (d) at right angles to the release arm, for when any considerable length of wire was out, a sharp roll of the vessel was often enough to slacken the wire sufficiently to allow the release to operate prematurely. The resistance offered by the water to this plate while the dredge was sinking was sufficient to keep the release in place until bottom was reached.

When hoisting, after the release has tripped, the strain comes on the wire which has been wound on the drum, and the dredge, which weighs 125 pounds, cannot be lifted from the bottom until all the wire (about 25 feet) has been unreeled. This turns the worm gear (e) which drives the cutter (f) by means of a segment of a beveled gear (g). The cutter, which is a hollow bronze casting, 2 inches in diameter, rotates through a semicircle. The last turn of wire on the drum drives the mouth of the cutter against the soft rubber pad, (h) which completely seals it. Considerable mechanical advantage is secured by this system of gearing. As the sediment is scooped in, the water is allowed to escape through a stop cock (i) fitted to the cap which closes the back end of the cutter. The cap is held on by wing nuts. The stop cock is closed by its lever (j) coming in contact with an arm (k) which is fixed to the frame. For dumping the contents the whole cutter is removed from the dredge by pulling out the axle (l), the cap is taken off and the sediment washed out. It was found that a rectangle of brass pipe bolted to the frame of the dredge afforded the best sort of a base for keeping the machine upright on the bottom. Cross pieces of wood were first tried because it was thought that the apparatus would sink too deeply in soft bottoms, but the resistance offered to the water by these flat surfaces while lowering was very considerable, and the time consumed in making a station was too great. The pipe offers much less resistance and does not sink in appreciably on a muddy bottom.

Experience has shown that when a station has been properly made the samples have approximately the same volume, showing that each scoop is much like the previous one. The cutter digs to a depth of about three inches, and is as effective on hard packed sand and gravel as on soft mud. The surface layer is of course cut through twice, but

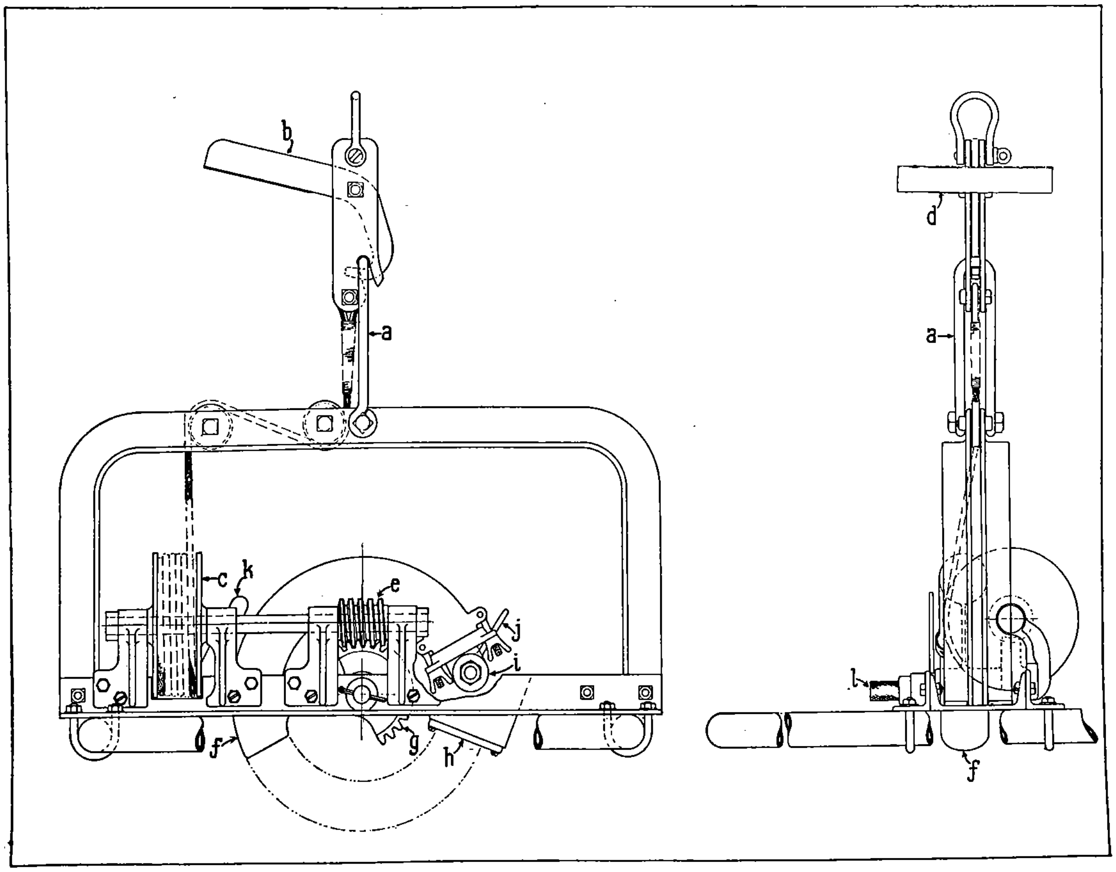

FIG. 2.—The dredge. About one twelfth natural size.

a coring tube will not work on a hard bottom, and the disadvantages of other types of dredges far outweigh this fault. Sand and pebbles do not jam the moving parts nor do they keep the cutter from sealing itself. Thus each sample is brought up in a water-tight container, and arrives at the surface in its original condition. It is of course essential that the bottom contain no pebbles greater than the diameter of the tube. This can be occasionally checked with a drag dredge. It so happened that none were encountered on the parts of the shelf where lines were run. All in all this new sampler has proved itself well adapted to the purpose in hand.

MECHANICAL ANALYSIS

The coagulating effect of the electrolytes in sea water has been a matter of common observation for a number of years. It is only recently however, that any considerable experimental attack has been made on the problem. This has been well summarized by Gripenberg (3, pp. 54–85), who also carried out various experiments of her own on the settling velocities of coagulating solids. In a coagulating suspension the size of the flocs is not well defined because of the variable amount of water contained in them. It is extremely unlikely therefore that their settling velocities obey Stokes law. Furthermore coagulation is influenced by the concentration of the electrolytes, and the density, as well as the nature, of the material in suspension. In addition, it is doubtful if the natural conditions of the original suspension, from which a given sediment was deposited, could ever be reproduced in the laboratory once the hydrated aggregates had settled to the bottom and become somewhat compacted. As dispersion into definite particle sizes is impossible in sea water, and as our knowledge is at present insufficient to reproduce conditions existing in the sea itself, the only way of obtaining data for comparative purposes is to break up the sample into its ultimate size distribution by dispersion in distilled water. This is a somewhat artificial procedure and not particularly desirable from the point of view of an environmental study, but it is the lesser of two evils.

The removal of electrolytes in this case was accomplished by prolonged washing. Pasteur-Chamberland porcelain filters, operated by a vacuum pump were used. Fresh water was added, and during repeated washings the sample was stirred until all trace of the chlorides was gone. As chlorides are the commonest electrolytes in sea water, it was assumed that when they had been removed no others were present in sufficient quantities to cause flocculation. Minute amounts of chlorides can easily be detected with silver nitrate. For the last washing distilled water was used. The porcelain filter tube effectually prevents the loss of even the finest grade sizes, and the coating of silt and clay can easily be removed by back pressure applied with a syringe bulb when the operation is over. The sample was never dried out until the final weighing, which made dispersion easy and thorough by means of an electric egg beater. Sodium silicate, or ammonium hydroxide were the reagents used to prevent flocculation and facilitate dispersion. Sodium silicate proved to be the more effective.

There is considerable difference of opinion concerning the advisability of removing the organic matter from the samples before mechanical analysis. The U. S. Bureau of Soils (Olmstead, L. B. and others, 4) considers it a necessary part of the procedure, and recommends hydrogen peroxide as an oxidizing agent. On the other hand Vageler (5, pp. 308–309) questions its use or that of any other oxidizing agent, as well as that of alkalies. He considers that unless the organic content is very high it is not disturbing to the mechanical analysis, and the destruction of some proportion of the inorganic colloids, which must inevitably result from such a procedure, is thereby avoided. Gripenberg (3, p. 60) has noted another unfavorable effect of the hydrogen peroxide treatment in samples high in iron compounds. When ferrous sulphide is present in considerable quantities, as is apt to be the case with marine muds, its oxidation causes loss of weight of the solid matter in the suspension. In the case of the oxides some of the iron goes into solution, "but part of it probably remains in colloid form causing slow coagulation during mechanical analysis." In a personal communication, Dr. Arthur Casagrande of the Harvard Engineering School, states that he has been unable to detect any deleterious effects on mechanical analysis due to the organic content of a sediment, provided this content, as determined by the organic carbon, does not run over 2% by weight. Below this amount he considers its removal unnecessary. As the organic matter in the marine sediments dealt with in this report remained within this limit, it was not removed.

The procedure of analysis adopted was the combined sieve and hydrometer method developed by Casagrande (6). The principal errors of the older hydrometer technique, such as the influence of the diameter of the sedimentation cylinder on the computation of grain size, the temperature factor, and accumulation of sediment on the bulb, have been compensated for by various corrections resulting from much experimental work, and by a hydrometer of very slender shape, accurately calibrated. Since the determination of grain size and percentage distribution requires the solution of equations for every hydrometer reading, Casagrande has devised a nomographic chart which greatly accelerates this process. For separating the coarse fraction, the Tyler Standard Screen Scale sieves were used.

In a combined sieve and hydrometer analysis, the fine fraction for the hydrometer is separated from the coarse fraction by simple panning. Since the results of both analyses are combined in one cumulative curve, separation at an exact grade size is of no importance, but it is essential that the total weight of the sample be known and that no material be lost. The overlap in grade sizes of the two parts of the curve, caused by the panning, is eliminated by smoothing the curve, and when the washing is carried out with reasonable care this overlap is small.

Many writers have recognized the undesirability of presenting the size distribution of clays and silts in terms of actual diameters. Rather, settling velocities should be used. Rubey (7) is one of the most recent writers to comment on this procedure. Although this is theoretically correct, it causes difficulty when the sample is partly sand, as Trask (8, p. 69) has pointed out. When this condition is found, as is the case with most marine sediments, except abyssal deposits, presentation of data in terms of actual diameters is essential if a reasonable picture of the sediment as a whole is to be secured. Furthermore, such procedure is necessary if we are to compare by means of statistical constants the sandy samples at the inshore end of a long traverse across the continental shelf with the finer ones from the slope.

The data from the mechanical analyses were plotted in cumulative curves rather than histograms. A histogram, though apparently easy to interpret, is misleading in that the particular grade size intervals which happen to be used determine its shape, and for the same sediment two unlike histograms can be constructed if different intervals are used (Galliher, E. Wayne, 9). The size intervals into which a sample happens to be divided have no effect on a cumulative curve as only one such curve can be constructed in each individual case. The only consideration is that the points be closely enough spaced so that the error introduced in smoothing the curve may be as small as possible. For instance, in the procedure followed in this study if a sample contained material as coarse as the 14 mesh sieve (1.168 mm.), the curve would be constructed with 19 points between that figure and the 0.0016 mm. grade size which is approximately the twenty four hour hydrometer reading.

STATISTICAL CONSTANTS

For purposes of comparison in a long series of samples it is convenient to employ statistical constants for expressing the important characteristics of size distribution.

Such constants are not altogether satisfactory as the data tend to become generalized and the samples to lose their individuality. However, in a survey of this sort it is the relative differences which are important, and the use of curves alone in presenting the data would be cumbersome, and their evaluation in a large suite of samples exceedingly difficult. Some synthesis, therefore, is unavoidable. Many such methods have been put forward, but that devised by Trask (8) seems well suited to the purpose at hand. The following is a brief summary.

Three constants are employed: the median diameter, the coefficient of sorting, and the coefficient of skewness or its logarithm. All of them are derived from cumulative curves. The median diameter indicates the mid-point of size distribution. One half of the total weight of a sample is composed of particles larger than this diameter and one half, smaller. It is probably the most important single constant.

The coefficient of sorting expresses the degree of sorting. It is based on the relationship of the first and third quartile diameters. Twenty five percent by weight of the sample is composed of grains of larger diameter than the first quartile, and seventy five percent of larger diameter than the third quartile. It is derived from the formula, $So = \mathcal{Q}_1/\mathcal{Q}_3$. Thus perfect sorting equals unity. Analysis of many samples by the present author gives an average value of 1.45 as indicative of good sorting for samples from the neritic zone, and 1.25 for beach sands.

The coefficient of skewness measures the dissymmetry of the size distribution curve. It shows on which side of the median diameter, and how far from it, the mode or point of maximum sorting lies. It is derived from the formula $Sk = (\mathcal{Q}_1 \times \mathcal{Q}_3)/M_2$. For ease in interpretation, i.e. to show readily on which side of the median the mode lies, and its relative divergence, the logarithm of the skewness is given. Thus a log of 0.0 ($Sk = 1$) indicates a symmetrical size distribution curve, the mode coinciding exactly with the median; a plus log (Sk greater than one) that the mode is on the fine side of the median; a minus log Sk the opposite.

The constants for each sample may be found in Table I, from which exact data as to position, depth of water, and distance from shore, or between stations, may be obtained. Table II gives each sample split up into the arbitrary divisions of gravel, sand, silt, clay, and colloid. Although such divisions possess all the disadvantages of histograms, nevertheless they are useful, for a quick, general appraisal of the texture of a sample. The graphs (Figs. 3 to 15) are all plotted to the same scale of miles as the topographic profile at the top, so that the statistical constants for any given station on a traverse, the distance from shore, and percentage of silt, clay, and colloid (particles smaller than .05 mm.) all fall on the same ordinate.

INTERPRETATION OF STATISTICAL CONSTANTS

It is obvious that the higher the curve for the median diameter climbs the coarser is the sample; the higher the curve for So climbs, the poorer is the sorting; and the more the curve for log Sk diverges from zero the more unsymmetrical is the frequency curve for that sample. Log Sk plus or minus depends on the dominant grade sizes which are being supplied, which in turn depend on transporting power.

Small values for both So and log Sk indicate a well sorted sediment in which the peak of the size distribution lies near the median diameter, one which is in adjustment with its environment, and is therefore transported, deposited, and maintained by a narrow range of conditioning factors. If we have a coarse, well sorted sediment, with a symmetrical curve, we may assume that the bottom is directly agitated, for if the bottom waters were still, and the coarse particles supplied from a current flowing higher up, enough of the finer grades would be allowed to accumulate to completely change the characteristics of the whole. Conversely a well sorted, fine-grained sediment requires quiet water at its place of deposition, with the possibility that the initial sorting has been effected by currents which are far removed.

A symmetrical frequency curve does not necessarily indicate a well adjusted sediment. It is possible to have a large value for *So* accompanying a small *Sk*. This indicates that though the peak of the size distribution nearly concides with the median, it is not well developed, and the material is spread evenly through many grade sizes. Glacial till would fall into this category. Under marine conditions it indicates that the deposit is being equally affected by a variety of factors.

A small value for *So* and a large log *Sk* likewise indicate that a given sample ranges through many grade sizes, but with the important difference that the frequency curve would show a well developed peak, and relative to it the proportion of more poorly sorted material would be smaller. It indicates that one set of environmental factors is dominant, though traces of others are still retained. For instance, a change of sea level would produce a sediment of this type in which the characteristics imposed by the new set of environmental conditions would gradually mask the old.

Large values for *So* and log *Sk* indicate that the sediment is completely out of adjustment with the environment in which it is found. As in the two other cases cited, in which one or more of the constants are abnormally large, it likewise is produced by the adventitious mixture of material derived from several sources. It is only a matter of degree. Variations in the velocities of the transporting currents, and ice rafting would produce this effect. In addition, a sediment on any given part of the sea floor may have its characteristics affected by a current not in contact with the bottom as well as by conditions on the bottom itself. Trask has pointed out, from the analysis of many sediments, that it is normal to have poorly sorted deposits bordering on a region of agitation. The sediments in such depositional areas are derived from the normal load of detritus in the water, plus the particles carried out of the local region of agitation.

With these main points in mind let us now turn to the examination of the sediments themselves.

DESCRIPTIVE DATA

It is logical, on the basis of the sediments, to divide the continental shelf into three parts. The traverses which lie in regions affected by the Pleistocene ice sheets make up one natural unit. This comprises Series 1 to 7, from the Gulf of Maine to Block Island. Series 8 and 9 off New Jersey and Maryland constitute the second division, lying between the southern limit of glaciation and Cape Hatteras, which marks the point at which the Gulf Stream is deflected away from the continental slope. Series 10 to 13, Onslow Bay, North Carolina to Cape Canaveral make up the third. The seaward ends of the last group are strongly affected by the current of the Gulf Stream. Organic remains are much more abundant, and calcareous sediments of all grade sizes play an important part.

Northern Section

Series 4. Marthas Vineyard: Figure 3

The sediments encountered on this line fall into four main divisions. First there is a near-shore zone of well sorted sands, second, a zone of coarse, well sorted sands and gravels, third a zone of finer material, usually poorly sorted silts and clays, and lastly the sands at the break in slope. This zoning of sediments parallel to the shore is characteristic of all the northern traverses. It is best exemplified on the Marthas Vineyard traverse, and consequently it will be described in greater detail here than in the other instances. The lines within the Gulf of Maine do not, of course, cross the break in slope; except for this, they exhibit the same characteristics at comparable depths as do those from the ocean proper. The zones will be described starting at the inshore end of the traverses and proceeding seaward.

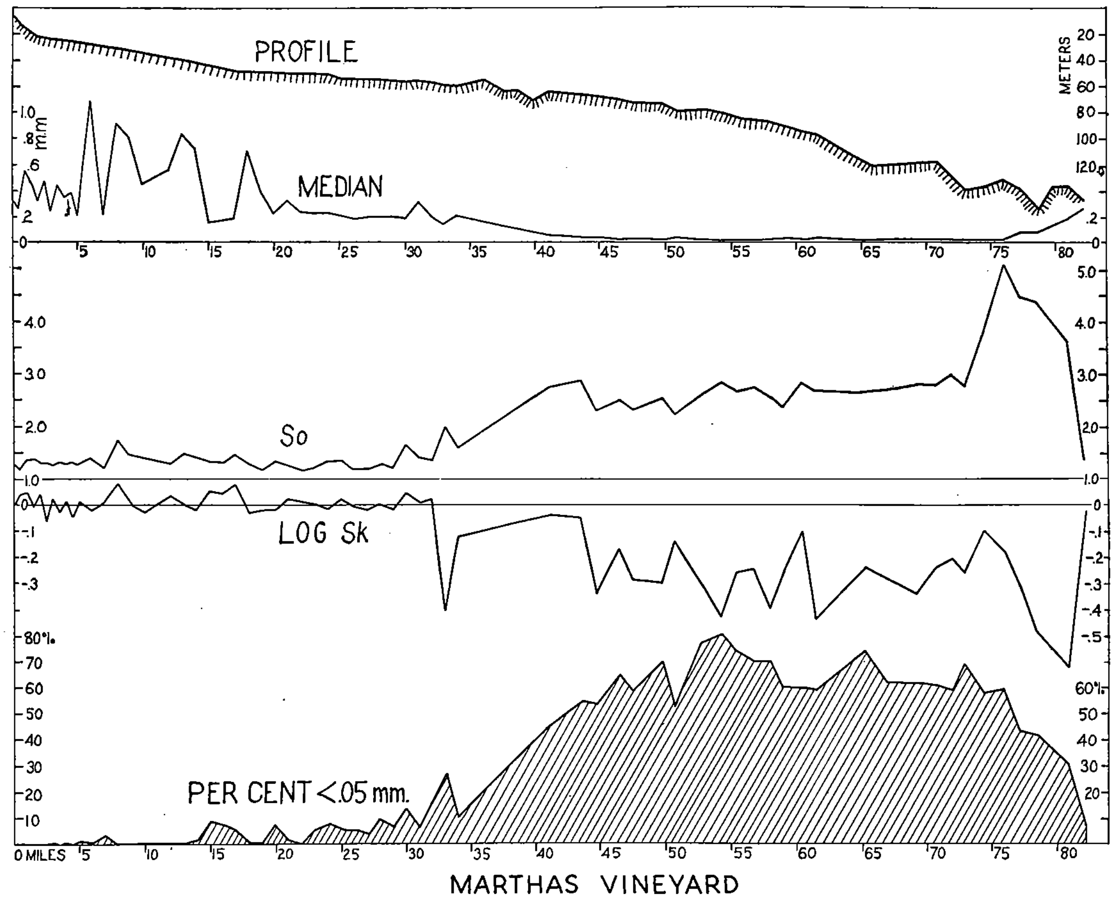

Fig. 3.—Series 4, see Fig. 1.

The inshore zone of sands, on this traverse, extends seaward about 34 miles to a depth of 59 meters. It is characterized by remarkably small values for *So* and log *Sk*, which indicate that the sorting is good and that the curves for the size distribution are symmetrical. The curve for the median diameter, on the other hand, fluctuates rapidly, indicating great variations in texture. The sediments of this zone, therefore, may be considered well adjusted to their environment.

From the shore to a point five miles off, in 26 meters of water, median values are small, ranging from .20 – .56 mm. At the six mile mark, in 27.5 meters of water, the curve takes its first major upward swing, reaching 1.5 mm. Relatively coarse sands are encountered, interspersed with finer, from this point seaward until 48 meters of water is reached 18 miles from shore. This belt of coarse material, flanked on either side by finer sediment, occurs in the other traverses in the same relative position. Its width is not always uniform, but the depth of water is of the same order of magnitude in each instance, and in some cases the correspondence is exact. The sand is heavily stained with limonite, and is much redder than the beach material. Here Alexander (10) obtained limonite pellets. From the sixteen mile point onward the red stain disappears. In spite of the fluctuations in grade size throughout this stretch the sorting is not affected to any extent. The coarser samples as a whole tend to have slightly larger values but relatively the sorting is always good. Log *Sk* fluctuates slightly about zero with no marked tendency for the mode to lie on either side of the median. In general, skewness and sorting correspond, the poorer the sorting the more unsymmetrical is the curve of the size distribution, although the total ranges involved are small.

The percentage of material below .05 is low, with a slight tendency to increase as the 34 mile mark is approached, but the total amounts are so small that they have no appreciable effect on sorting and skewness. The sand percentage is high throughout, with occasional large values for gravel which are reflected in the irregularities of the median diameter curve.

According to the interpretation of the constants previously outlined it seems probable that the sediments throughout this zone are being strongly worked upon by bottom currents which vary greatly in velocity from place to place. As the texture has no effect upon sorting or skewness, the sediments may be considered to be products of factors in operation at the present time, and to be in adjustment with their environment.

Proceeding seaward from the outer boundary of the near shore sand zone ($33\frac{3}{4}$ mile mark, 59 meters), an abrupt change in the type of sediment takes place. The median diameter curve drops from .21 mm. to .06 mm. and continues at about that level for about 40 miles until 135 meters of water is reached. The percentage for gravel drops to zero, and for much of the distance that for sand is greatly diminished, silt increases greatly, as do clay and colloid to a lesser degree. Simultaneously large fluctuations occur in the sorting and log *Sk* curves, the former, in one instance, reaching 5.1, whereas the latter varies from –.04 to –.48. The position of the mode remains on the coarse side of the median throughout. The percentage of particles below .05 mm. gradually increases to about 80% in 78 meters of water and then declines as the break in slope is approached. The poor sorting and unsymmetrical distribution of the grade sizes indicate that the sediment is the product of two or more sets of environmental conditions, and inspection of the sediment verifies the assumption in this particular case in a rather striking manner. Mixed with the silt and clay are considerable quantities of very highly rounded and frosted grains of quartz. It is obvious that two such very different types of material can neither be produced nor deposited under the same environmental conditions. The origin and distribution of this material will be discussed later.

The conditions found at the break in slope are, perhaps, the most significant of the whole traverse. In the outer parts of the so-called silt and clay zone the percentage of particles below .05 mm. steadily decreases, although the depth of water is steadily increasing. At the same time the sorting remains poor and the distribution of the grade sizes unsymmetrical. At the break in slope, the percentage of material below .05 mm. has declined to 7.7% and the curve for the median diameter has gradually climbed from .02 to .27 mm. Table II shows for this area (samples 63–66) a marked increase in the sand fraction, the reappearance of gravel and diminution of the silt and clay grades. In addition, these samples contain numerous fragments of broken shell.

Series 5 and 6. Figures 4 and 5

These two short traverses were run as a check on the curious occurrence of coarse material at the break in slope which was first discovered on the Marthas Vineyard traverse. They begin just at the outer edge of the zone of poorly sorted silts, in 128 and 122 meters, respectively, and run over the edge of the continent to 410 and 580 meters. Series 5 lies six miles to the eastward of the end of the Marthas Vineyard traverse, and Series 6, eight miles to the westward. The median diameter of the first sample in Series 5, is .05 mm. The curve rises to a peak of .34 mm. at a depth of 134 meters, about two miles from the break in slope, and from then on, as might be expected, the values grow smaller as the samples are taken progressively deeper down the continental slope. The curve for sorting bears the same relationship to that for the median as occurred in the Marthas Vineyard traverse. The inner sample with the smallest median shows the very poor sorting characteristic of the silt zone but as soon as the sand at the break in slope is encountered, the sorting immediately improves. The value for *So* drops from 5.04 to 1.5 and continues at about that level until the water is about 300 meters deep, when the curve gradually starts to climb again, as the sediments grow finer with increasing depth. Values for log *Sk* indicate, in general, symmetrical frequency curves for each sample. The graph for the percentage of material below .05 gives about 10% in this division from a point just inside the break in slope down to 300 meters. In other words we have a belt of sand at the break in slope, sharply marked off from finer material inshore in shallower water and from that offshore in deeper water.

Series 6 shows the same sedimentary sequence, as does Series 5. The first two samples lie in the inshore zone of poorly sorted silt having medians of .02 and .03 mm., with characteristically large values for *So* and large negative values for log *Sk*. The percentage of material below .05 lies between 74 and 88%. The coarsest sample is actually at the break in slope with a median value of .20 mm. From this point seaward values for the median gradually grow smaller as the water deepens. Throughout the coarsest part of this traverse, a distance of five miles, sorting is good and the percentage of material below .05 never climbs above 14%. The deepest sample is a little coarser than the one immediately preceding, and the sorting is a little better, but, as we have seen in the Marthas Vineyard series, small fluctuations which do not obscure the major trends may occur in a traverse and have no particular significance. The inner part of the series has a negative log *Sk*, indicating that the mode lies on the coarse side of the median; the deeper samples show the reverse.

Series 1. Ipswich Bay, Massachusetts: Figure 6

The Gulf of Maine is a deep basin lying on the continental shelf. Three traverses from it are included here for the purpose of comparing the sedimentary sequence on a rapidly deepening topographic profile, and one with a more gradual grade such as the continental shelf. In addition, they furnish valuable data on the problem of the profile of equilibrium and on the depth of the wave action.

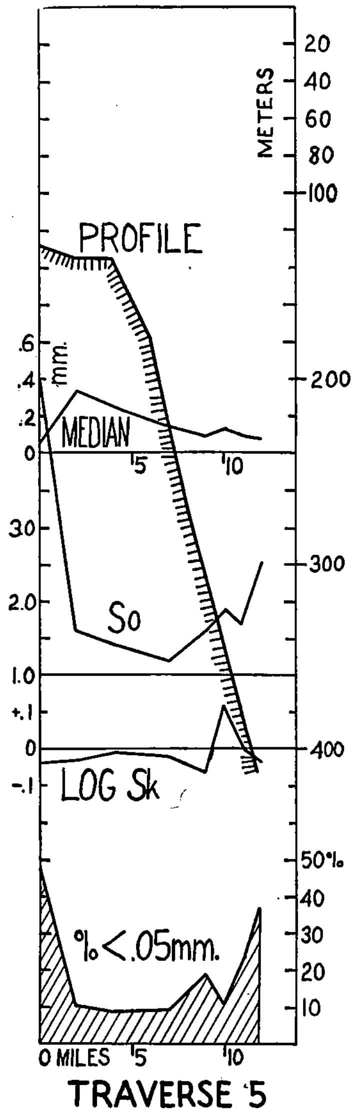

FIG. 4.—Series 5, see Fig. 1.

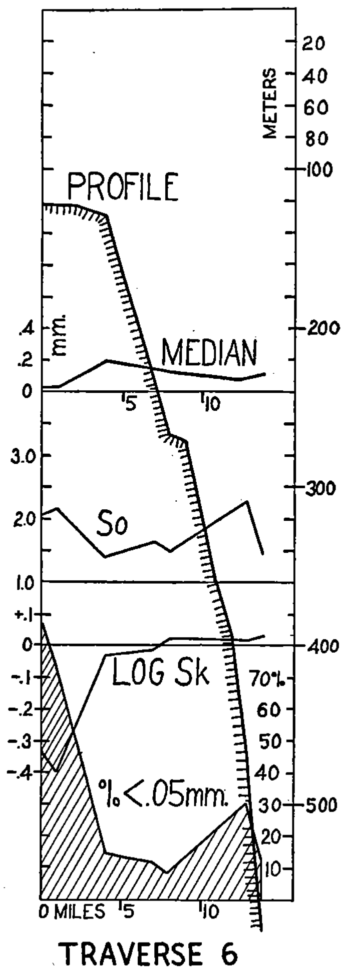

FIG. 5.—Series 6, see Fig. 1.

The beach sands at the head of Ipswich Bay are unusually fine grained probably due to the fact that the shore is bordered by extensive tracts of dunes. During exceptional storms these dunes are cliffed by the sea and the sand spread out over the beach and foreshore. Much of this doubtless finds its way offshore, which accounts for the small values of the median diameters. The most important point to be considered in this traverse is the position of the zone of coarsest material. It is found in depths of from 28 to 47 meters which is almost identical with the depth of the coarse zone off Marthas Vineyard, although in the latter case it is many miles farther from shore, due to a gentler bottom gradient. As soon as the silt zone is reached at about 70 to 80 meters depth, the sorting immediately becomes very poor with a large negative skewness. Here again there is close correspondence with the Marthas Vineyard traverse.

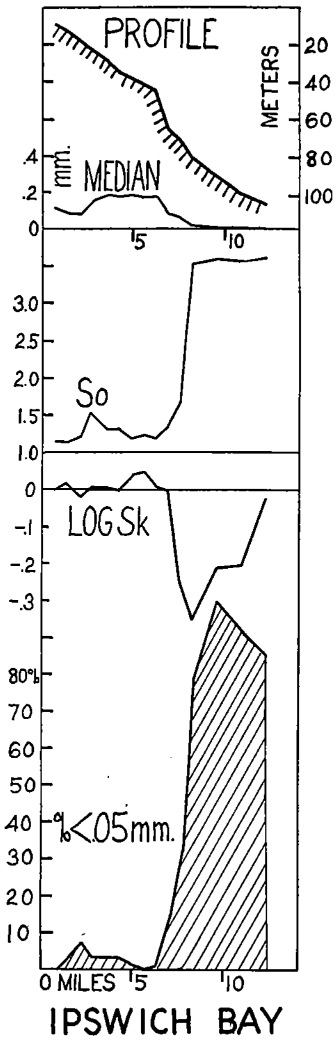

FIG. 6.—Series 1, see Fig. 1.

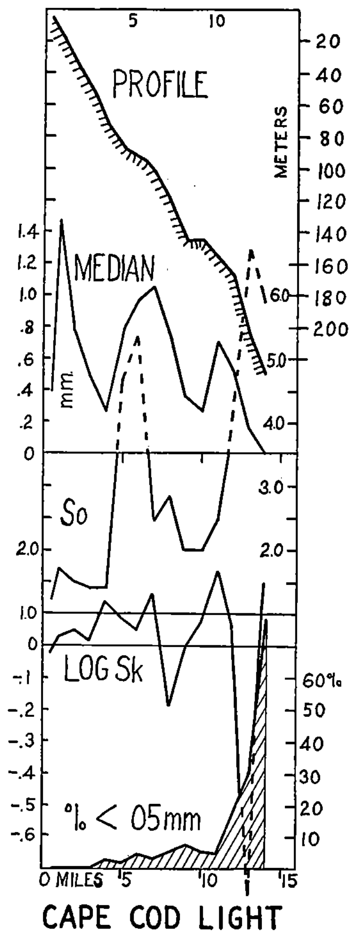

FIG. 7.—Series 2, see Fig. 1.

SERIES 2. CAPE COD LIGHT: FIGURE 7

This line is something of an anomaly. There is no apparent order in the sedimentary sequence, nor is there correspondence with any other line. The coarsest part of the whole traverse occurs one mile from shore in 12 meters of water. The curve of the median diameter reaches 1.5 but the sorting is good with a value of 1.7. It remains good throughout the fluctuations of the median diameter until the 4 mile mark has been passed in 70 meters of water. It is probable, therefore, that this section of bottom is strongly scoured. The absence of silt, clay, and colloid supports this view. From this depth to the end of the line the median diameter is subject to abrupt and rapid fluctuations. Unlike the Marthas Vineyard traverse, in which the sorting remains uniformly good throughout the whole stretch of sandy bottom, once outside the nearshore zone noted above, it here becomes very poor which is unusual for a marine sand. It is probably due to the fact that glacial conditions have not yet been obliterated, and that debris is being cut from the cliffs at High Head faster than the sea can dispose of it. Except for the last sample, which was taken in 230 meters from the silts which occupy the deeper parts of the Gulf of Maine, the percentage of material below .05 mm. remains low. There is some tendency for the coarsest samples to have the largest values for *So*. Log *Sk*, on the other hand, with two exceptions, does not show as large values as one might expect. The two constants taken together indicate that although the samples run through a large range of grade sizes, the material is relatively evenly distributed with no very marked concentration in any one size. The silt zone proper in this series begins in deeper water than in any of the other northern traverses which adds one more point of dissimilarity.

Series 3. Nauset Light: Figure 8

The sedimentary sequence here, is a repetition of the Marthas Vineyard series, compressed into 14 miles. The maximum concentration of coarse material occurs two to four miles from shore in 28 to 67 meters of water. The curve for the median diameter reaches 1.4 mm., then drops rapidly to about .10 mm. The material changes from a sand stained with limonite to a fine-grained, gray sand which continues to 133 meters of water, 8 1/5 miles offshore. The sorting up to this point is good and the frequency curves symmetrical, which is usually the case with inshore sands. Next comes a narrow belt of silts in 141 to 180 meters, with the usual poor sorting and large skewness values. Thirteen and one-fifth miles from shore in 172 meters of water a ridge is encountered, the median jumps to .46, the sorting improves somewhat, and the frequency curves become more symmetrical. In 183 meters, beyond this ridge of sand, are found the very fine, poorly sorted silts characteristic of the deeper parts of the Gulf of Maine, which were also reached on the outer end of the Highland Light series. Here, however, the depth is shallower by 50 meters.

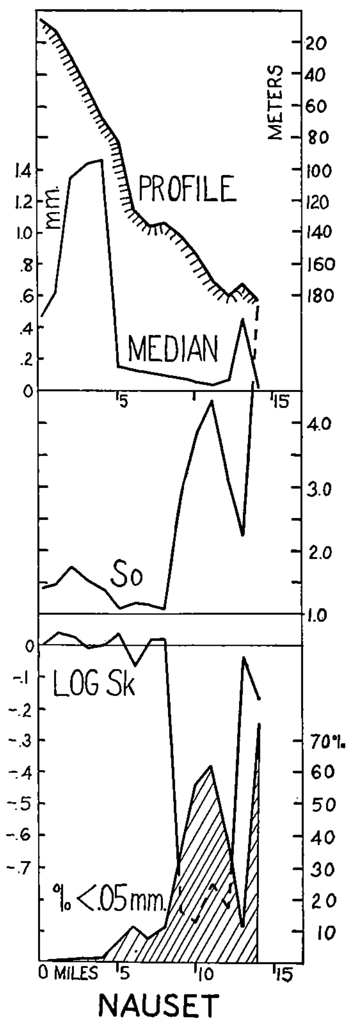

FIG. 8.—Series 3, see Fig. 1.

SERIES 7. BLOCK ISLAND: FIGURE 9

Taken as a whole, the general trends of the constants resemble those for Marthas Vineyard, although certain differences are at once apparent. The distribution of sediments by zones which was found in the latter series is, in general, still recognizable, although the boundaries are not as sharply defined. Furthermore, it must be remembered that the traverse does not start at the coastline but 1 1/4 miles from an island which is itself some twelve miles offshore. Since the line begins in 18 meters of water the usual zone of relatively fine, well sorted sands, which in other cases is encountered nearest the

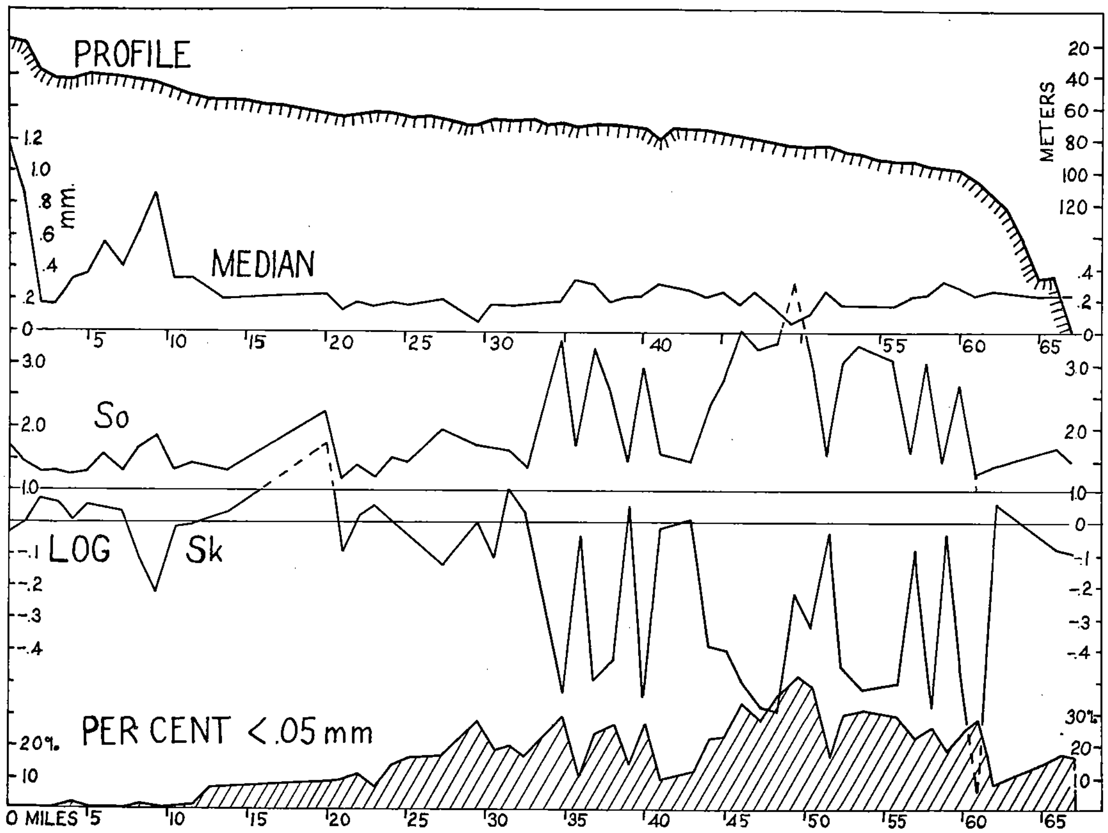

FIG. 9.—Series 7, see Fig. 1.

beach, is not present. The first samples apparently came from the next zone of coarse sands which are found at comparable depths on the other traverses. This well sorted sand, with fluctuating medians continues to a depth of 53 meters. Here the grains are heavily stained with limonite, and limonitic pellets are found. In the next sample, at 55 meters, about 13 miles from shore, the median diameter drops to .19 mm., and continues at about this figure to the continental slope, although in places rising as high as .34 mm. and dropping as low as .16 mm. The curve for the grades below .05 mm. is more instructive and shows the zoning more clearly. As the sediments of the middle portions of the shelf contain more fine material than that portion immediately shorewards or seawards, the curve for the percentage of material smaller than .05 mm. gradually trends upward with many fluctuations, until at 84 meters these grades constitute 42%. It then declines, in the same irregular manner, to 15–20% at the break in slope. We do not find here the marked transition in the type of sediment that occurred on the Marthas Vineyard traverse, but the proportion of the finer grades is definitely smaller. Throughout this distance, the sand grade, in general, maintains a fairly high percentage and gravel is found practically throughout.

As might be expected, the curves for *So* and log *Sk* are extremely irregular across the entire shelf and some high values are found. Those samples which contain the least material below .05 mm. are the best sorted, and have the most symmetrical frequency curves.

Central Section

Series 8. New Jersey: Figure 10

Due to weather conditions this traverse, which was begun at the seaward end, terminates 23 3/4 miles from shore. We have enough of it, however, to show that the zone of poorly sorted silts intermediate between the near-shore sands and the break in slope is

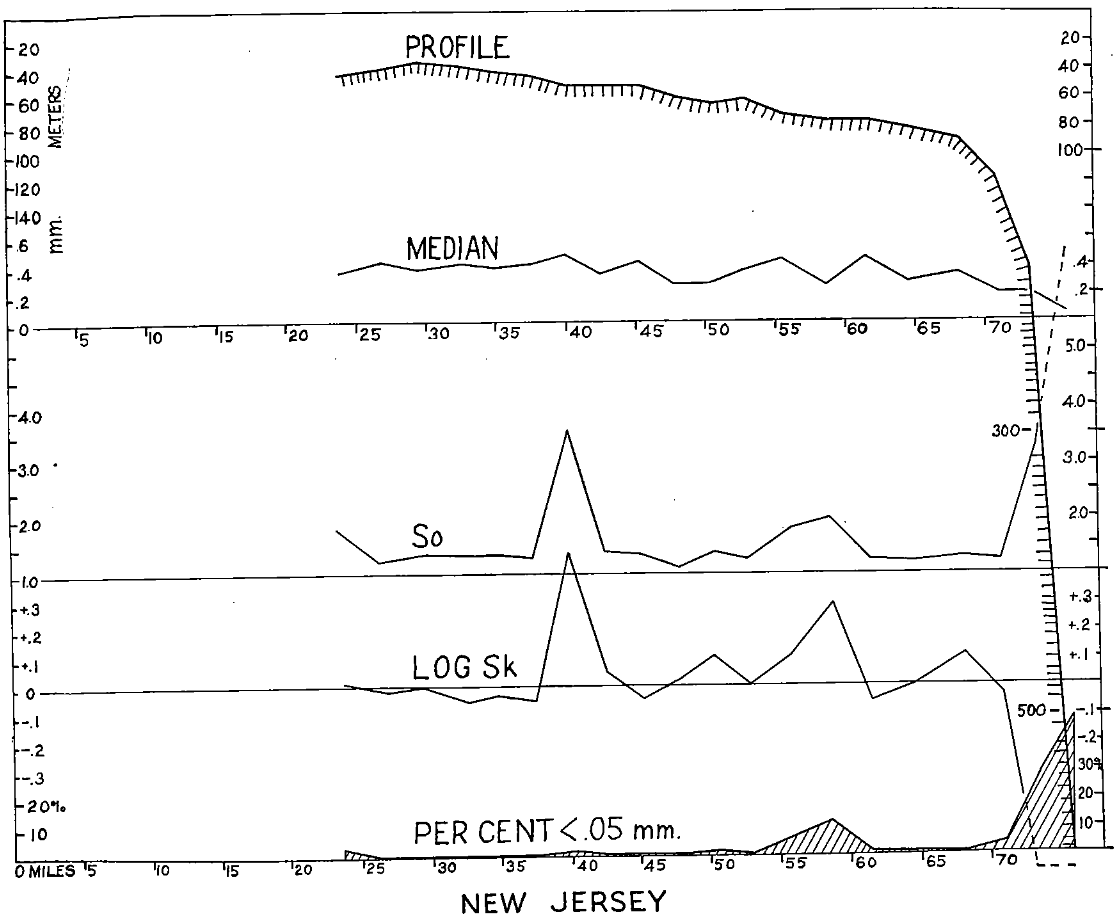

Fig. 10.—Series 8, see Fig. 1.

not present. Sediments which here are sands, off New England in the same depth of water are silts. In the case of the Maryland traverse, and of the four south of Cape Hatteras, the water is shallower over the shelf proper and the break in slope is likewise found at lesser depths. However, the continental shelf off New Jersey has about the same depth of water as farther north. Shallowing alone, therefore, is not a sufficient reason for the absence of fine material. The explanation probably lies in the fact that from this point south the sea is not cliffing the shore but is reworking old marine deposits from which the finer grades have been previously removed.

The values for the median diameters lie for the most part between about .25 and .45 mm., and the large percentage in the sand grade is consistent and uniform. Because there is no silt and clay zone, there is no increase in the median diameters at the break in slope; the texture remains the same here as further inshore. Once past this point however, the sediment is finer, and the last sample from 610 meters is a silt which is characteristic for that depth on the continental slope. The sorting is, in general, good and there is a close relationship between sorting and skewness. Those samples which are the more poorly sorted also have the largest skewness values. The statistics for this traverse indicate that on the outer portions of the shelf, in this section, the relatively coarse sands are being actively worked on by bottom currents and are in adjustment to their environment.

Series 9. Maryland: Figure 11

This line, which begins five miles offshore, presents an unbroken series of sands to the last sample in 386 meters of water, which is well down the continental slope. In almost

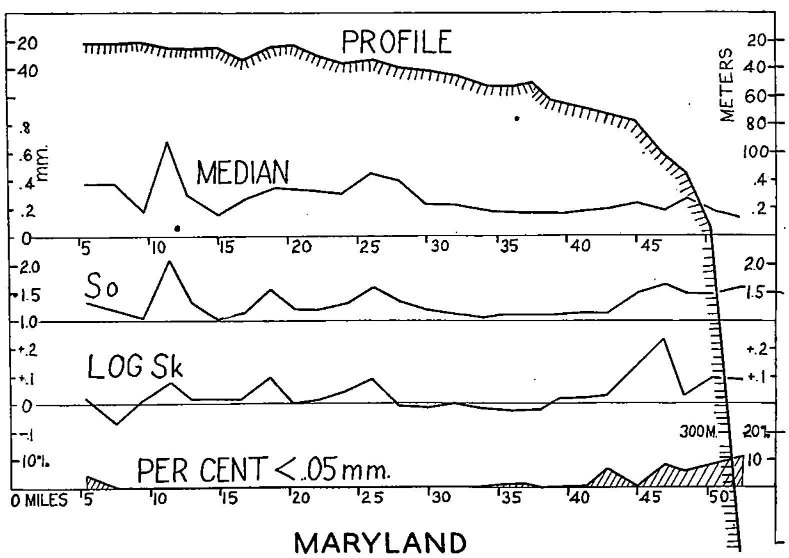

FIG. 11.—Series 9, see Fig. 1.

every sample this grade runs over 90%, and silt, clay, and colloid are either entirely absent or occur in very small amounts. Out to the 32 mile mark (sample 1238c), the curve for the median diameter ranges for the most part from about .25 to a little over .4 mm. In only one case does it rise as high as .68 mm. The sorting is, in general, good with a distinct tendency for the coarser samples to be the more poorly sorted and have large skewness values. In this part of the traverse the mode is on the fine side of the median with one exception.

Proceeding seaward from the 32 mile mark we come to a stretch of fine, grey sand containing very small amounts of material below .05 mm., which continues for about 17 miles to the break in slope. The sorting is excellent and the values for log *Sk* small. From its position between two coarser textured zones, this area might correspond to the silts which are found on the New England traverses. As we approach the break in slope we still find the same fine, grey sand, but added to it is an increasing amount of gravel. This is only slightly reflected in the curve for the median diameter, but the curve for sorting takes an upward swing as does that for log *Sk*. The last sample which shows any appreciable increase in the gravel grade is found in 114 meters of water below the break in slope. The percentage of the material below .05 mm. is definitely on the increase at the end of the traverse. There is marked similarity between the coarsening at the break in slope found here and that off southern New England.

Southern Section

There are three factors affecting the lines south of Cape Hatteras which serve to mark them off from the traverses which have been described so far. They are: shallowness of the water over the shelf proper; large amounts of calcareous material in the sediments; and the erosive effect of the Gulf Stream where it impinges against the continental slope. These topics will be taken up further in the discussion, but they must be kept in mind during this description of physical characteristics.

Series 10. Onslow Bay: Figure 12

From the shore to a position 16 1/2 miles seaward in 27 meters of water (sample 1634a), the bottom is a well-sorted quartz sand with values for the median diameter ranging from .18 to .26 mm. The curve for log *Sk* is fairly regular as would be expected in a shoal water sand subject to wave action. Small amounts of broken shell are present.

The next sample, 1634b, 27 meters depth, at the 18 1/2 mile mark shows the beginning of an abrupt change in the characteristics of the sediments, due to the addition of large amounts of ground up shell. The shell was included in the mechanical analysis as it is considered to be as much a part of the sediment as the inorganic detritus. The amount varies greatly from sample to sample. The texture of this zone is, on the whole, somewhat coarser than the belt of quartz sand near shore, and the sediments are not quite so well sorted, but in no case can the sorting be considered really poor. The curve for sorting follows that for the median, showing higher values as the median increases. Values for log *Sk* remain small throughout. Increasing depth of water has no apparent effect on the constants. They exhibit the same characteristics out to the break in slope, a distance of about 39 miles, although the actual material composing the samples has completely changed. The molluscs which furnish the fragmental shell at the inner end of the zone are chiefly Spisula, Anomia, Cardium, and Ostrea. Whole valves, when present, are almost exclusively those of young individuals. They are somewhat waterworn, which probably indicate that these small shells have been concentrated by the selective action of bottom currents.

On this traverse oölites make their first appearance in the zone containing the shell fragments, and gradually increase in numbers in a seaward direction, reaching their greatest concentration in 39 meters of water, 43 miles from shore. They range in size, for the most part, between 1.16–.208 mm. although occasional grains are found outside both limits. In color they vary from black to pearly white, and almost all of them have a nucleus consisting of a grain of quartz. The typical concentric structure is usually visible, though in the case of the black oölites considerable recrystallization appears to have taken place. They all have a polished and somewhat waterworn appearance, and are associated with shell fragments likewise polished and much rounded. It seems more likely that these oölites have been derived from some older formation rather than that

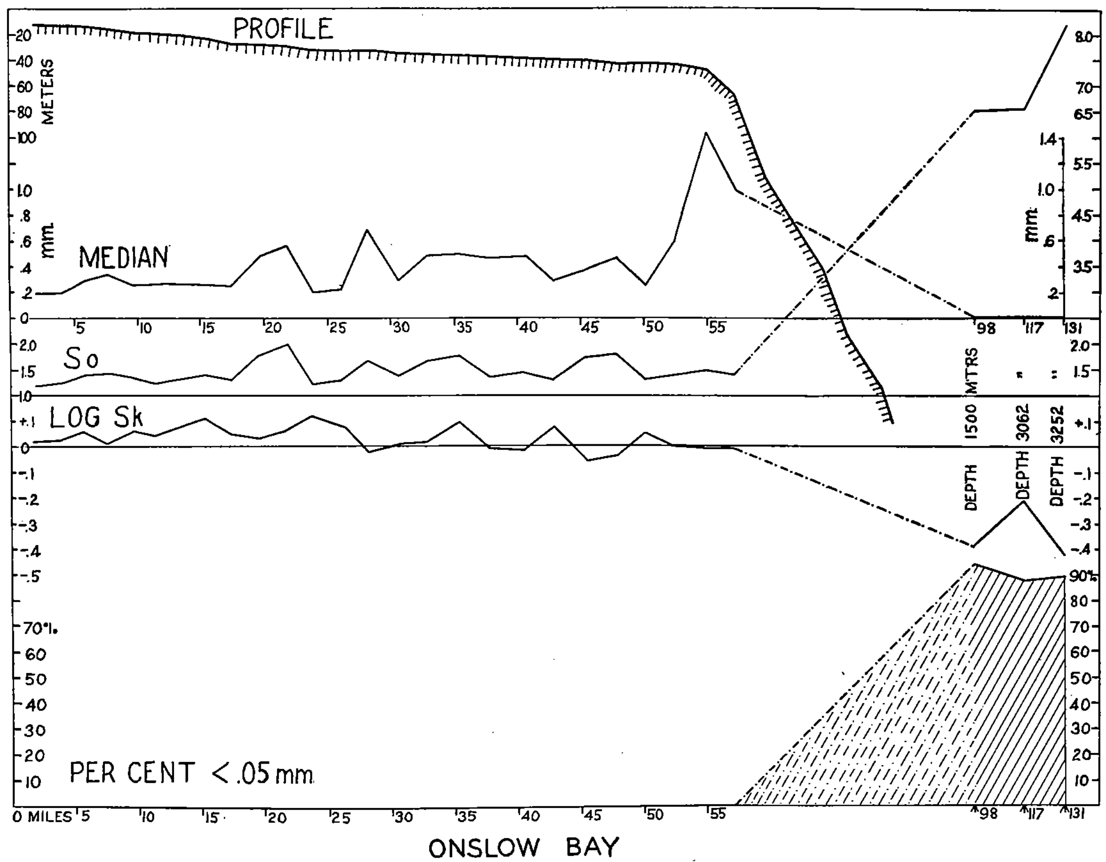

FIG. 12.—Series 10, see Fig. 1.

they are being produced under present marine conditions. This will be further discussed under the heading of calcium carbonate.

At a depth of 42 meters, 52 1/2 miles from shore, the molluscan fragments have largely disappeared, and their place is taken by detritus derived from bryozoans, calcareous algae and barnacles, all too badly waterworn to be specifically identified. At the break in slope, and beyond it to a depth of 67 meters, the fragments of these organisms are so numerous that they make up most of the deposit. Once again the break in slope is the place for a large jump in the median diameter accompanied by good sorting and symmetrical frequency curves. Here, however, the coarsening of the texture is due to an organic gravel consisting of the broken down skeletons of calcareous algae. This sediment must be considered as much a product of its environment as were the sands at the continental margin further north.

The last sample was obtained in 67 meters of water, and between this point and 1500 meters, a distance of 40.4 miles, the bottom is hard. Repeated attempts were made to obtain samples, but the net results were a few fragments of living bryozoa. It should be remembered that in all the southern traverses the figures which are given for the depth at which the zone of hard bottom begins are probably not exact, but are dependent on the chance spacing of the samples. The latest hydrographic information, also obtained on this cruise, indicates that this stretch of bare bottom is the section where the Gulf Stream impinges most strongly against the slope, and is keeping it swept bare of sediment. This point will again be referred to in the general discussion. It is not until deep water is reached at 1500 meters, about 100 miles from shore, that unconsolidated sediment is found once more. This is a calcareous clay with a median diameter of .006 mm., a very poor sorting. At depths of over 3000 meters on stations 1640 and 1641, the median diameter remained the same and the sorting poor.

Except for these last three samples, there is no median below .18 mm. in the whole traverse. It is characteristic of these southern lines that no material finer than the sand grade is found on the shelf proper, in contrast to the situation farther north.

SERIES 11. CHARLESTON: FIGURE 13

The curve for the median diameter shows that, as in the case of Onslow Bay, the sand near the shore is somewhat finer than that farther out. It consists of quartz with

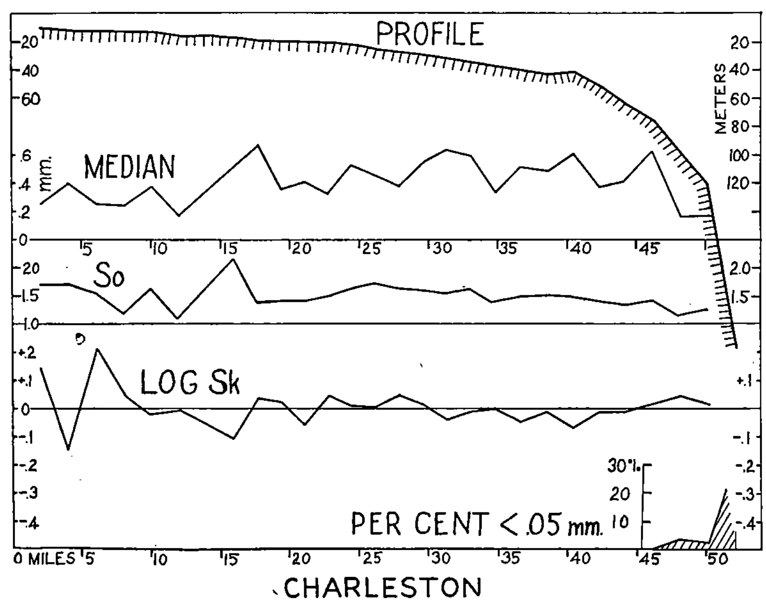

FIG. 13.—Series 11, see Fig. 1.

almost no organic material. In 18 meters of water, 16 miles from shore, the curve for the median rises, and continues at that general level, fluctuating within fairly narrow limits, throughout the rest of the distance. The sediment at the break in slope is a coarse sand, but no coarser than some others on the traverse. Out to the 16 mile mark sorting is somewhat variable, and the coarsest samples tend to have the poorest. Beyond this point it is remarkably uniform, and changes in the median have little influence upon it. Values for log *Sk* are small throughout. Many of the samples contain large amounts of shell fragments but the replacement of siliceous by calcareous sand is not as regular as it is on the Onslow Bay traverse. The samples from the outer parts of the shelf show, in general, the higher percentages of the latter.

Anomia, Cardium, Spisula, Ostrea, Nassarius, and Pecten are the genera which furnish most of the shell fragments. Wherever whole shells are present they are valves of small individuals, a fact which suggests that they have been transported and sorted by selective current action. In samples 1629 and 1628d, 120 and 235 meters respectively, molluscan fragments are largely displaced by foraminifera, bryozoa, and barnacles, as was the case with the offshore samples in the Onslow Bay traverse. Oölites are very scarce though a few may be found in samples 1630–1629a (37–99 meters).

The last unconsolidated sample was obtained in 235 meters of water and consists entirely of foraminifera. Two miles seaward in 419 meters hard bottom was reached, and repeated attempts with different kinds of dredges failed to bring up more than a few fragments of living corals and bryozoans.

Series 12. Jacksonville: Figure 14

This traverse is very similar to that of Onslow Bay. It starts with the near-shore belt of fine sand characteristic of all four southern lines. There are few shell fragments present. At about 28 miles from shore, in 29 meters of water the curve for the median climbs to .41 mm. and steadily maintains this level to the break in slope, rising above it only once to .50 mm. The sorting throughout this stretch is excellent, with 1.66 as the highest value. Skewness values are small. Silt, clay, and colloid are entirely lacking from the surface of the shelf. Shell fragments and oölites are found in increasing numbers as one progresses seaward across this zone. Here again, it is significant that despite the heterogeneous nature of the bottom sediments, which include shell fragments, oölites, and inorganic clastics, the statistical constants show that the material is controlled by the environment in which we find it.

The principal genera which furnish the calcium carbonate are Terebra, Spisula, Arca, Pecten, Cardium, Olivella, and Ostrea. Oölites are particularly numerous on this traverse and are present in every sample out to the break in slope. As on the Onslow Bay traverse there is a tendency on the outer parts of the shelf for bryozoan and echinoid fragments to replace those derived from the shells of molluscs. The maximum concentration of the former occurs in 33 to 39 meters of water, and in many cases they make up more than half the sediment. The oölites from the offshore samples are largely white or ivory colored, whereas those from shallower water are usually black. Both varieties have a concentric structure around a quartz nucleus and show a high polish similar in every respect to those obtained from the Onslow Bay and Charleston traverses.

The last unconsolidated sample was obtained at 246 meters and consists entirely of foraminifera while the sands of the shelf proper are last found at 52 meters depth. This compares with a lower limit of 235 meters off Charleston for an unconsolidated deposit, again composed entirely of foraminifera, and 120 meters for the sands of the shelf. On the next station, at a depth of 418 meters the bottom was found to be hard. Again, this is due to the sweep of the Gulf Stream against the continental slope. This line continued for a considerable distance across the Blake Plateau. The surface of this curious submarine plain is either hard or covered with deposits of foraminifera mixed with pteropods, the latter becoming more abundant towards the outer end of the line.

Series 13. Cape Canaveral: Figure 15

This traverse much resembles that for Charleston compressed into 50 odd miles. The first sample is a fine-grained, well sorted, quartz sand such as occurs on the inshore ends of all the southern lines. Abruptly, with sample 1616c, in 24 meters of water, fragments of mollusc shells are found abundantly with large quantities of black oölites.

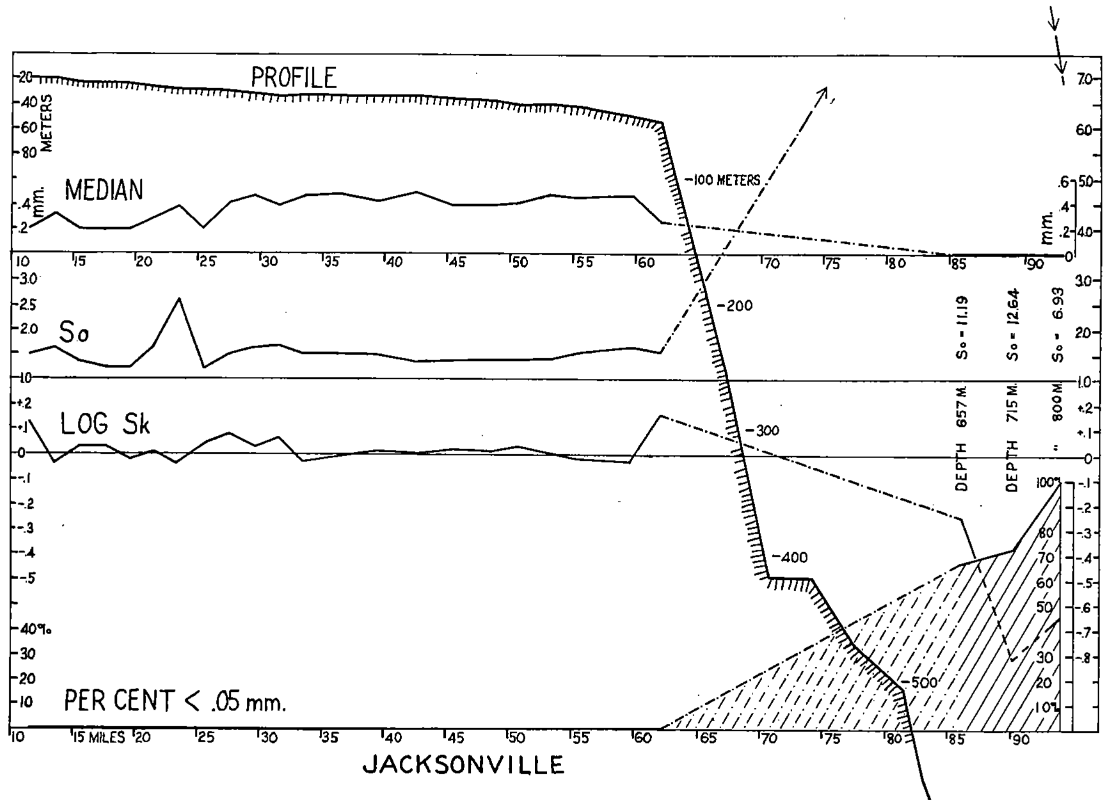

Fig. 14.—Series 12, see Fig. 1.

The principal genera represented are Pecten, Arca, Marginella, Crepidula, Cardium, and Glycimeris. 1616c, b, and a, from 24, 26, and 29 meters of water, are all of this type with the oölites particularly numerous in 1616a. The median diameters are somewhat larger than for similar material on the other southern lines, and the shell fragments appear less water worn. At station 1616, in 38 meters of water, inorganic sand is again the most important constituent, although there is a considerable quantity of shell fragments. Silt, clay, and colloid are entirely lacking throughout the sand zone, except in the first sample. The percentage of gravel is high, and is entirely calcareous, consisting of shell fragments. The sand zone continues to station 1615, where hard bottom was found in 72 meters. In this particular case, it is probable that the dredge encountered a piece of coral or bryozoan, as the clean swept bottom due to the Gulf Stream is not reached so near shore. Unconsolidated material is again picked up in 142 meters, but the sample contained so large a proportion of whole foraminifera (45.3% by weight) that a mechanical analysis would be worthless. The proportion of foraminifera continues to increase until hard bottom is encountered at 566 meters, 10 miles further seaward. From this point to the end of the traverse, 15 miles beyond in 731 meters of water, the bottom

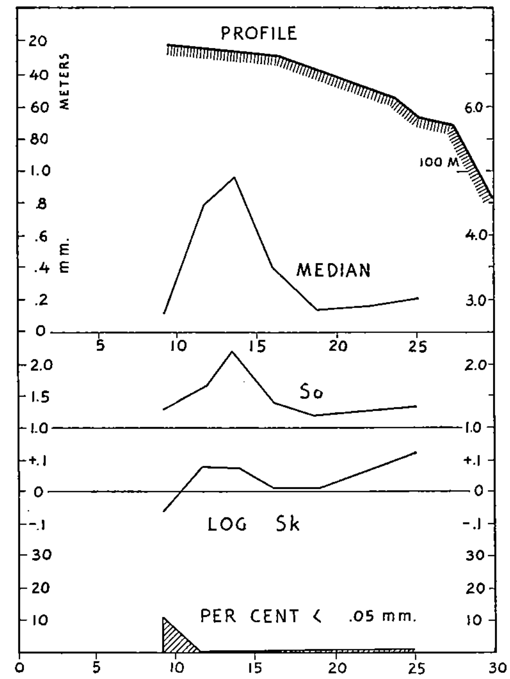

FIG. 15.—Series 13, see Fig, 1.

remains bare of any unconsolidated sediment. This section, comprising the inner margin of the Blake Plateau, lies beneath the axis of the Gulf Stream just after it has left the Straits of Florida.

CALCIUM CARBONATE

North of Cape Hatteras calcium carbonate is derived entirely from shell detritus. The amount is small, rarely more than 3%, and in most places 1% or less. The deeper samples on the whole show higher percentages because in them foraminifera are relatively more abundant than in the ones nearer shore. Such small quantities are of little importance from the point of view of rock formation. A detailed account of the northern samples is therefore of no value.

South of Hatteras the situation is altogether different. Here calcium carbonate is present in sufficient quantities to form an important constituent of the resulting rock, should this sediment ever become consolidated. In fact much of it would be classed as impure limestone. It is derived from two sources, the skeletal remains of organisms, and the oölites described above. The calcareous material is distributed in definite zones on the shelf, and the percentages will be given for a few samples from each of these zones which may be considered as characteristic of the whole. Samples from the inshore ends of the southern traverses, taken in the longshore zone of quartz sand described above, are almost as poor in calcium carbonate as those from the northern lines. The shell fragments are chiefly derived from molluscs. Sample 1618b, 23.5 meters depth, from the Jacksonville line, runs as high as 12.10% but this is an exception, as all the others are in the neighborhood of 3% or less.

Seaward from the quartz sand zone, the shell fragments become very abundant. On the Onslow Bay traverse, sample 1634b, 27 meters depth, contains 55.16% of calcium carbonate, and 1618e, 27 meters depth, from the Jacksonville traverse, 89.56%. The median diameters for this area are high, but the sorting is good and the values for log *Sk* are small. This part of the bottom is evidently under the influence of vigorous wave and current action.

From 35–45 miles off shore on the Onslow Bay and Charleston lines, the numbers of shell fragments begin to decline. Sample 1634e, from the former line, 33 meters depth, has only 15.37% $CaCO_3$, and sample 1629g, 40 meters from the latter, has only 10.78%. On the Jacksonville and Canaveral traverses, in comparable depths, the same decrease in the number of shell fragments takes place, but there is no corresponding decrease in the lime content because the supply is maintained by increasing numbers of oölites. They are found on all four of the southern traverses, but only occur in abundance in these two lines. Samples 1619g, 33 meters depth, and 1620, 37 meters depth, from the Jacksonville line, contain 48.50% and 42.20% respectively, and samples 1616a, 29 meters depth, and 1615c, 45 meters depth, from the Canaveral traverse, contain 62.40% and 63.00%. The oölites from 1619g may be regarded as typical. Several were analyzed and the results averaged. Exclusive of the quartz nucleus, these specimens were found to contain 98.27% calcium carbonate and 1.27% calcium phosphate. Magnesium, iron, and aluminum were not present.

On the outer parts of the shelf the calcium carbonate is derived from fragments of calcareous algae and bryozoans, plus a small amount from corals and barnacles, in contrast to the inshore samples where molluscs are the chief source of supply. Oölites are present, though not in large quantities. Samples 1635d, 39 meters depth, and 1636b, 44 meters depth, from this zone on the Onslow Bay traverse, have 64.50% and 55.70% respectively. Sample 1629a, 99 meters depth from Charleston, has 57.50%, 1620e, 50 meters depth, from Jacksonville, has 68.80%, and 1615c, 45 meters, from Canaveral has 63.00%. Below the break in slope, foraminifera and pteropods are the chief source of calcium carbonate. Sample 1628d, 235 meters depth, from the Charleston line, has 62.23% and sample 1613a, 460 meters depth, from Cape Canaveral, 76.50%.

Sample 1639, 1500 meters depth, is still farther seaward on the Blake Plateau on the Onslow Bay traverse. It is a clay with a median diameter of .006 mm. and contains 50.30% of calcium carbonate. On the same traverse, just over the edge of the plateau, in 3252 meters, sample 1641, which is equally fine, contains 38.90%. The fragments were too small to be identified.

The question arises as to the origin of these shell fragments. Are they furnished entirely by animals now living in the region, or are they in part derived from the reworking of old deposits? According to Richards (11) shells of species no longer living off the New Jersey coast are often found on the beaches after storms. These same species are today restricted to more southern waters. During the course of some hydraulic dredging in the waterways back of the coastal islands the sand and silt pumped up from

50–100 ft. below mean low water, likewise contained a warm water fauna, probably derived from the Cape May formation. Farther south, on the North Carolina beaches, Pliocene and Pleistocene shells are frequently found, as well as pieces of coquina which probably came from the Pamlico formation (Richards 12). Obviously the seaward extensions of these beds are being eroded by wave action on the offshore bottoms. It is, therefore, probable that the high calcium carbonate content of the southern traverses is in part due to fossil shell fragments derived from the reworking of older deposits. As was noted above, many of the fragments are much water worn, well polished, and show a deep staining. The presence of oölites gives additional support to this theory, as it is extremely unlikely that conditions favorable for their formation exist on the surface of the present-day bottom.

DISCUSSION AND INTERPRETATION OF DATA

Historical Background

The first account of the sediments of this continental shelf was given by Pourtalès (13), from scattered samples obtained by the U. S. Coast and Geodetic Survey in the course of their charting operations. Nothing more than a rough areal description was possible from such data, but nevertheless the general character of the bottom was recognized. He distinguished a siliceous sand zone lying over the top of the shelf, two kinds of calcareous bottoms lying beneath the Gulf Stream, and the area of mud south of New England.

Murray (14) was the next to work on samples from this region, which were furnished him by Alexander Agassiz from the results of dredging by the Coast Survey Steamer "Blake." Agassiz (15, Vol. 14, pp. 269–279), mentions this report, but little was added to the original description of Pourtalès, except to point out that beneath the Gulf Stream the bottom is hard and there is no unconsolidated sediment. Both Agassiz and Pourtalès comment on a sharp boundary at the outer part of the shelf between the siliceous and calcareous sediments, and consider that it coincides with the boundary between the colder coastal water and the warm water of the Gulf Stream. The present data, given in the section on calcium carbonate, show that sediments with high percentages of calcium carbonate are found in what they considered to be the siliceous zone lying beneath the colder coastal water. There is, therefore, no sharp division between the two types of material as they had supposed.

No mechanical analyses, in the modern sense of the word, were made at that period, and, as was common in the older reports, marine sediments were treated as though they had little geological significance.

The Profile of Equilibrium

The profile of equilibrium, as defined by Fenneman (16) is the form which the water would impart to the shore profile, or surface of the bottom within the neritic zone, if allowed to carry its work to completion. It is dependent upon the adjustments between current, slope and load, and represents a balance between the forces available to do the work and the work which has to be done, i.e., the interaction of the waves and currents with the material available to them. The fully graded profile is a smooth curve, concave upward, and steeper near the beach than in its outer parts. We should not expect to find it developed off every shoreline. It would be the exception as so many factors interfere with the work that the waves are trying to do. It represents the theoretical form which should eventually be arrived at, but seldom is.

Johnson (17, chap. 5) has called attention to the common error of confusing the profile of equilibrium with wave base. The latter is the ultimate abrasion platform towards which the land mass would eventually be reduced by marine erosion should conditions remain stable. It will lie as far below the surface of the water as wave action is effective. The profile of equilibrium may be established temporarily at a higher level, and it should not be assumed that in this position it marks the limit down to which the waves are capable of working. From this level downwards erosion may proceed slowly, but it has not ceased.

With these points in mind let us examine the profiles described here in relation to their sediments and see whether or not they fulfill the conditions which might be expected under this theoretical concept. They were constructed from the soundings taken when each sample was obtained.

According to Johnson (18, p. 494 and Fig. 242) conditions off the southern shore of Marthas Vineyard are favorable for an unusually perfect development of the profile. The sea is working with unconsolidated glacial debris, and the initial slope of the bottom approximates what the waves are trying to produce. His profile is carried out only about 7 1/3 miles, but with the present data it can be extended, as Series 4 was taken in the same position. Figure 3 shows that this unusually well-graded slope extends some 34 miles from the beach to about 60 meters of water. From this point to the continental margin the bottom becomes more irregular, and it is probable that here the fully developed profile ceases. The water deepens and it is obvious that the transporting power of tidal and wave generated currents cannot be so vigorous. The sediments themselves corroborate this in a rather striking way. Out to the zone in which the topography becomes irregular, sorting remains excellent and the skewness values are small. Farther out sorting becomes very markedly poorer (except at the break in slope), and the large negative skewness values indicate that the mode is on the coarse side of the median. The balance between the amount of work to be done and the capacity to do it has been upset, deposition is dominant over transportation. As we have seen from the description of this line, what is actually happening is that silt, clay, and colloid are being added to old eolian deposits which the sea has been unable to entirely remove. It should be noted that grade size, as exemplified by the median diameter, fluctuates rapidly throughout the whole profile, and that the same well graded slope is developed alike in coarse and fine sands.

As a further illustration that a profile of equilibrium has been established on the inner part of this traverse, the data furnished by a sediment trap are pertinent. This trap, which had been described elsewhere (19) was left for ten days in 16 meters of water, about a mile offshore. Due to its construction only the qualitative results were considered to be significant.

The material caught had a median of .01 mm., a sorting of 6.60, plus log *Sk* of .24 and contained 58% of silt and clay. Forty two percent was sand from the normal bottom ranging as high as 1.1 mm. in diameter, which accounts for the poor sorting of the sample. The actual bottom at this point is a well sorted sand with a median of .56, an *So* of 1.38, a plus log *Sk* of .05 mm. containing traces of silt and clay or colloid too small to affect the statistical constants. It is obvious that much material which cannot be deposited is being transported seaward over this bottom. Therefore, the profile is in adjustment with the forces which govern it. The finer grades, are probably derived from the rapid erosion of the Nashaquitsa Cliffs, made up in part of Coastal Plain deposits which contain many clay formations, and in part of glacial outwash.

The other New England traverses do not show a well developed profile of equilibrium. There is a suggestion of it in the first few miles of the two Cape Cod lines, and the sediments, which are sands, are well sorted. Here too, the median diameter bears no relation to sorting, and the values may be large or small. However, as Johnson points out, the slope of the original glacial embankment is so steep that the waves have not been able to construct a graded terrace. Furthermore, this is a region of strong, longshore tidal currents which doubtless remove much of the debris cut from the cliffs, and further hinder the development of a terrace. The well sorted sands are found to a depth of 70 meters on the Cape Cod Light line and to 132 meters off Nauset.

On the Ipswich traverse conditions are similar to those mentioned above for there is a suggestion of a profile accompanied by well sorted sands for the first few miles. Here again, however, the slope of the original bottom is too steep, and the time too short since the sea assumed its present level, for a well graded terrace to have been developed. What we have of it, however, serves as an example of a profile in a youthful stage.

The Block Island traverse crosses the continental slope with its gentle gradient. There is a poorly developed profile for the first thirty odd miles, with the bottom consisting of fairly well sorted sands, and the usual fluctuating medians. Beyond this, sorting becomes much poorer, due to the addition of large amounts of silt and clay to the original bottom sediments. Here we are obviously entering a region where deposition is dominant over transportation, and not until all the irregularities have been filled with this finer material will a graded profile be established. The inner end of this profile cannot be compared with that found off Marthas Vineyard. Here the sea evidently has not yet been able to obliterate the initial irregularities. This is probably due to the fact that owing to its location, this line is not in a position to receive as much debris as did the inner end of the Vineyard traverse, whose shoreward end begins off a long line of rapidly wasting cliffs.

The two lines from the central section are not significant for this discussion, especially as the New Jersey line begins 24 miles off shore. In neither of them has the sea been able to smooth out completely the original irregularities of the bottom (Figs. 8–9).

Three of the four lines south of Cape Hatteras show an exceptionally smooth profile (Figs. 12–15). It must be remembered that as none of them begins exactly at the beach the characteristic concave section adjacent to the strand is absent from the graphs. There are two ways in which these profiles differ from those off New England. First, the slope of the shelf is more gradual so that at equal distances from shore the water is much shallower, and secondly, the Gulf Stream effects their outer ends. These profiles are constructed from soundings taken about every two miles, instead of every mile as is the case in the northern lines. Even so, the grading to the break in slope is very smooth. The initial irregularities, slight though they may have been, are now removed and we know from the statistical constants that the bottom is being actively scoured by wave generated and tidal currents. The Coastal Plain beds which make up the near shore bottoms are, for the most part, poorly consolidated. Consequently the supply of sediment with which the sea must work is large. The natural slope of these beds is very gentle, and the attempt of the sea to establish the inner part of the profile has resulted in the formation of extensive barrier beaches, at some distance from the real shoreline, built from material which is being carried landwards. If observations with sediment traps could be made they would undoubtedly show that a great deal is also being carried seaward beyond the continental margin. Nevertheless a balance has been attained between the amount of material available and the transporting ability of the sea. It is obvious that in the case of these southern lines the profile of equilibrium is far above wave base, as at the break in slope the water is still 15–20 meters shallower than at the outer end of the well graded profile off Marthas Vineyard. We are dealing, therefore, with the inner end of a profile developed, for the most part, by erosion, and with a slope largely determined by initial dip. The outer end where deposition would normally take place has been truncated by the Gulf Stream. The line off Cape Canaveral shows a suggestion of a profile on its inner portion but due to its geographical position it cannot develop further.

Taking the east coast as a whole, the best, well-graded profile of equilibrium is found on the Marthas Vineyard traverse even though it has been built only half way across the shelf since the sea attained its present level. It so happens that more of the requirements have been fulfilled here than in any other instance and have resulted in what theoretically should be found off all coasts when the sea has been at work a sufficient length of time. The sedimentary evidence supplements the topographic in fixing the place at which the present grading ceases.

Depth of Wave and Current Action

Proceeding seaward from the shoreline physical oceanographers distinguish four subdivisions of the water in the Western Atlantic. First, there is the relatively fresh band of water known as Coastal Water lying over the continental shelf, reaching in general, to a maximum depth of 200 meters. Following this there is a more saline strip known as Slope Water covering the continental slope. Then comes the still more saline Gulf Stream, and lastly the Sargasso Water (Iselin, C. O.'D. 20). The Gulf Stream is the only one of these that has any effect upon the bottom. South of Cape Hatteras, the Slope Water is pinched out, and the Gulf Stream impinges against the continental slope with the result that the bottom here, and for some distance out over the Blake Plateau, is swept bare of sediment. The actual bottom velocities are not known but temperature and salinity sections indicate that the rate of flow must be considerable because of the steep slant of the isotherms and isohalines above the slope. Surface velocities may reach 2 1/2 to 3 knots.

North of Cape Hatteras the Gulf Stream bends sharply away from the slope and the bands of Slope and Coastal Water lie above the sediments with which we are dealing. The velocities of these currents taken at the surface are very slow, amounting to only a few miles a day, and entirely insufficient to transport any but the very finest particles.

Currents generated by wave and tidal action are, therefore, the only ones which really affect the bottom deposits over the surface of the shelf, and the good sorting which many of these sediments show is a measure of their importance. It is impossible to estimate the relative effectiveness of these two types of currents in shallow, coastal waters, because quantitative data are practically non-existent. In any event they are probably operating in conjunction most of the time.

First, let us take the case for tidal currents. Bottom currents have been measured by the author on the shelf, about 20 miles south of Block Island, through one complete tidal cycle, and for shorter periods on the top of Georges Bank. Readings were made in summer with a smooth sea so that only tidal currents were being recorded. Off Block Island an anchor station was maintained for 15 hours with readings at least every half hour. So far as I am aware these are the only bottom measurements that have ever been taken on the shelf, although surface currents, and those some distance down have been measured frequently. The current meter and the apparatus for operating it have been described eleswhere (21). Readings were taken alternately 11 inches and 5 feet 10 inches above the bottom. The tidal currents on the shelf, as is well known, have a rotary flow, swinging completely around the compass in a twelve hour period. On the Block Island station the highest velocities recorded at the 11 inch level were 7 cms. sec. or a little less than 0.2 knots, for the peak of the flood, and 8 cms. sec. for the peak of the ebb. From these two maxima the current slacked off to 1 cm. sec. At the 5 feet 10 inch level the highest velocity was 9.5 cms. sec. On Georges Bank where the surface currents are much stronger, the highest reading obtained at the 11 inch level was only 12.76 cms. sec. from a station in 140 meters of water. Georges Bank is a special case due to peculiar topographic conditions, and higher velocities are to be expected here as it acts as a bar to the tide flowing into and out of the deep basin of the Gulf of Maine.

From the hydrographic data we know that in winter, wave action extends to the bottom all over the shelf (Iselin 20). In summer the water is strongly stratified as to density, which is dependent on temperature and salinity. In winter, however, the water has a uniform density from top to bottom, having been completely stirred by the gales which at this season are more frequent and violent. At the place where the current was measured off Block Island the sediments are well sorted, with a median of .19 mm., a sorting of 1.34, and a log *Sk* of −.01. Silt and clay make up only 12% of the sample. This, and all the other well sorted bottoms such as the inner halves of the northern lines and the whole surface of the shelf from New Jersey south, are obviously being acted on directly by the sea. Coarse grade size combined with good sorting can mean only that. If we may take the above figures from the Block Island station as representative of the velocities of tidal currents over the shelf, and there is no reason to think that they are not, it is unlikely that the tides alone would have much effect on the sediments. They might keep the silt and clay sizes in transit to deeper water, but they could not sort the sands. We have no figures for the velocities of wave generated currents, but as they are known to extend to the bottom, the combination of the two, such as must occur during any gale, evidently produces a current with sufficient velocity to move the sediments. Wave action could stir and lift the particles. Then slow currents might move them, at least for short distances.

Some evidence as to the limiting depth of vigorous current action may be obtained from the sediments themselves. The depth at which silt, clay, and colloid begin to appear marks the place at which agitation of the bottom deposits by tidal and wave generated currents ceases. It does not mean that current action is completely lacking beyond this depth, in fact the hydrographic data indicate that it is not, but that it has become weak, and is not capable of doing much work. Erosive power is probably entirely absent and transporting power reduced to a minimum. The rapid rise in the relative percentage of the fine material beyond this depth indicates that the transition is a sharp one. On the Marthas Vineyard and Block Island and Ipswich Bay lines where the tidal currents are weak, these finer grades begin to appear in appreciable amounts in 60 to 70 meters of water. Off Cape Cod the "mud line" is found in 150 to 230 meters, and as the exposure of these lines to the storm waves is no greater than in the first instances, it is obvious that tidal currents here extend to greater depths than they do on the shelf. The

U. S. Coast and Geodetic Survey have measured the surface currents along this stretch of shoreline and find that the flood tide runs in a continuous sweep the whole length of the Cape from south to north and that the ebb runs in the reverse direction. Velocities up to 1 1/2 knots have been recorded. These parts of the Gulf of Maine and Georges Bank are special cases and the velocities of the tidal currents are much greater than would be expected on the open shelf. From the evidence presented by the other three New England lines, where tidal currents are not so vigorous, 60 to 70 meters can probably be considered the limiting depth to which wave action on this side of the Atlantic, aided only by weak tidal currents, can stir the bottom sediments.

Although the evidence is largely negative, let us see how this estimate checks with the conditions found on the other lines. On the New Jersey line very small amounts of the finer grades make their appearance in 60 to 70 meters, and on the one off Maryland at about 50 meters, but the percentage does not increase appreciably as the water deepens beyond the point that was considered the limit of effective wave action off New England. The bottom sediment really remains a sand. The absence of these finer grades is probably due to the fact that the sources of these sediments are Coastal Plain deposits from which the smaller particles have already been removed, rather than to current scour, as there is no reason to suppose that wave action or tidal currents would be any more vigorous here than farther north.

South of Cape Hatteras, as we have seen, the sediments of the continental shelf are all sands, and except for the last two samples on the Charleston line, are all within the reach of wave action as defined above. In these two, and one of them is only six meters over the limit, the finer grades, which had been entirely lacking heretofore, are beginning to make their appearance. Doubtless more of this material would be present were it not for the Gulf Stream which is probably beginning to make its influence felt on the outermost sediments of the shelf.

There is one other characteristic of the bottom sediments which occurs with enough regularity to be worth noting, namely the zone of coarse sands lying just off shore. This also is due to the action of currents, although the reason why it should occupy the position it does is not apparent. The close correspondence in the limiting depths of this zone shown by some of the New England lines is remarkable. On the Marthas Vineyard, Nauset, and Ipswich Bay traverses it begins in 25 to 28 meters of water and extends to about 50 meters in the case of the first two, and about 60 for Nauset. The Block Island traverse does not begin at the shoreline, but the outward limit of this zone is in about 45 meters. The Onslow Bay and Jacksonville lines show an increase in the medians at about 28 meters, whereas coarsening is found at about 18 meters on the Charleston line and 24 meters on the Cape Canaveral and Maryland lines. The steeper the slope of the topographic profile, the nearer the beach this zone is found. Such uniformity cannot be fortuitous, and it is undoubtedly the result of wave action, as the exposure of these lines varies less along this stretch of coastline than do the tidal conditions. Why the currents should have a greater scouring effect at these depths, as the texture indicates, is not known.

Sediments of the Break in Slope and Wind-Blown Sand

On the two New England lines which cross the shelf the sediments at the break in slope are coarser than those found in shallower water nearer shore. On the Marthas Vineyard traverse, after passing through an area of silt and clay the sediment once more is a well sorted sand. Series 5 and 6 were run from the outer end of this silt and clay zone down over the break in slope and they both exhibit the same tendencies. The silts and clays give way to well sorted sands and are in turn replaced by the finer grades under the deeper water of the continental slope. The Block Island line has a well sorted sand at the break in slope, but the sediment throughout this whole traverse remains fairly coarse without the abrupt transition found on the Vineyard traverse. The percentage of silt, clay, and colloid, however, does show an increase on the central part of the shelf.

The Onslow Bay line shows the same tendencies. Here the coarse sand and gravel is derived from shell fragments and calcareous algae. The other southern lines have the same characteristics, but in none of them is the rise of the curve for the median so pronounced.

These sands are probably residual from the shallow water conditions of the Pleistocene (Daly, R. A. 22, pp. 204–307) when these bottoms were well within the reach of vigorous wave action, or, they may even have formed part of a former strand line, as today the depth, in most cases, is ample for finer grades to accumulate, and there is no reason to suppose that their absence is caused by tidal scour. It should be noted, however, that in the case of the northern lines the increase in the median diameter is not due to the addition of particularly coarse material but rather to the fact that the silt and clay which is being deposited nearer shore is not being laid down here. Evidently insufficient time has elapsed since land and sea assumed their present position to allow the finer grained particles to travel seawards and completely bury the sediments resulting from a former level. The silts and clays on the continental slope probably were not disturbed by the lower sea level of the Pleistocene.

There is another indication of the withdrawal of the sea during the Ice Age, namely the deposits of rounded and frosted sand grains noted in the description of the Marthas Vineyard and Block Island lines. The sand is encountered fifteen miles off Marthas Vineyard in 44.9 meters of water, twenty miles off Block Island in 59.2 meters, and about the same distance off the eastern end of Long Island in 56.1 meters. On the Marthas Vineyard and Block Island traverses, this sand extends over the break in slope to the limit of dredging. The rounded grains have a fairly definite size range, from the 48 mesh, or .295 mm. sieve, to the 14 mesh of 1.165 mm. They are not very abundant when they first appear, but in samples from the middle and outer parts of the shelf the sand grades consist entirely of such grains within the limits given above. Recently, cores have been taken to the bottom of the continental slope in over 6000 meters, and even here the frosted grains are found, though they are by no means as numerous as nearer shore. The grains from samples in the middle portions of the zone of poorly sorted silts and clays have for the most part polished surfaces, although they retain the high degree of rounding. It so happens that this particular zone also contains the highest proportions of silt and clay. Numerous holothurians and worms of various kinds are abundant in this region. These animals are mud feeders, and the original ground glass surfaces may have been removed by solution and polishing during repeated passages through their guts.

It has been suggested that this sand is produced on the modern beaches of Cape Cod and then transported by currents to its present position (Alexander, A. E. 10). It can be shown, however, that grains exhibiting such a high degree of rounding are not found in the present day beaches or dunes of the Cape (Stetson, H. C. 23), and furthermore, that the currents to transport them do not exist. The only way that these grains, which are as highly rounded as those of the St. Peter sandstone, could have acquired this characteristic shape and ground-glass surface is through wind action. It is most probable, therefore that this deposit represents the remnants of an area of dunes, formed when the sea had retreated from the continental shelf. Judging by the perfection of the rounding these grains must have been through several cycles. Upon the readvance of the sea for the last time, the dunes were flattened out, and from a topographic standpoint no trace of them remains. However, the time has been so short since this took place that present day deposition has not yet been able to completely cover up the sand of which they were once made.

Ancient wind action associated with one or more glacial stages is further demonstrated by the large number of ventifacts found in the surficial frost heaved layer, and also in the fluvio-glacial beds of the Weyquosque and Hempstead formations (of Woodworth) on Cape Cod and the outlying islands. According to Kirk Bryan, in a personal communication, these ventifacts are in no way due to the wind action of the present or the immediate past. Existing dune areas have no significance in the problem, and their sands are comparatively angular. Wind blown sand of an antiquity comparable to the ventifacts is absent, and it is inferred that it drifted seaward and now lies to the east and south on the continental shelf. It seems probable therefore, that the well rounded grains described above are contemporaneous with the ventifacts, and are the survivors of one or more periods of the vigorous wind action of Pleistocene times.

Source, Transportation, and Distribution

Rivers are of practically no importance in supplying sediment to the shelf at present. In New England they carry very little in suspension, and what little there is must be effectively trapped by the deep basin of the Gulf of Maine and by Long Island Sound. Delaware Bay, Chesapeake Bay, and the sounds inside the barrier beaches from Virginia south, should also act as effective settling basins. It is probable, therefore, that the sediments with which we are dealing are almost entirely derived from erosion of the coast and from the shallow-water bottoms. On the New England lines the bulk of the material is supplied by glacial debris, although a little is furnished by older formations. Cliff cutting is active, and there is probably some erosion of the near-shore bottoms as well. South of New England the situation is altogether different. Erosion of the actual land mass is reduced to a minimum, protected as it is by a long succession of barrier beaches. It is obvious, therefore, that the only sources for the sediments of the present day continental shelf are the submerged formations of the Coastal Plain which the sea is now reworking.

In a study of this sort too much attention must not be paid to variations between individual samples. There are too many unknowns among the factors controlling them to make such detailed work of much value. In the present state of our knowledge of marine conditions only the major trends can be considered. To go further would only result in confusion, and we would fail to distinguish the woods because of the trees. Diverse as the sediments of the continental shelf appear when considered in small units, there is a certain uniformity in their arrangement when they are considered by regions. For instance, the lines from the glaciated section, irrespective of the slope of the topographic profile, have certain characteristics in common. They all start with a zone of relatively fine, well sorted sands near shore, followed by a belt of coarse sands and gravels, still well sorted, which are in turn succeeded by a zone of silts and clays lying on the middle and outer parts of the shelf. The lines from this region which cross the break in slope show a definite coarsening of texture there. All the traverses show a remarkable correspondence in the depth of water at which these zones occur, and this is obviously the controlling factor as the lines are of varying length. Consequently, on the lines from the Gulf of Maine where deep water is soon reached, the succession of zones is necessarily compressed into a few miles. The fact that any arrangement of the sediments is discernible at all when the heterogeneous nature of the supply is considered, is a clear indication that the present ocean is acting on them. The deposits left by the last retreat of the Wisconsin ice in regions which are now submerged were doubtless much the same as those which are found on land today. It should be remembered that at that time, a large part, if not the whole of the surface of the shelf stood above sea level, and that considerable portions of the Gulf of Maine were dry. Direct deposition from the melting ice itself did not occur south of Marthas Vineyard, but the shelf must have been covered with fluvio-glacial outwash. The readvancing sea was compelled to work with material of all textures, from clay to gravel and cobbles, distributed at random as is usual with glacial deposits. In the relatively short time that has elapsed since the sea assumed its present level it has re-sorted and redistributed these sediments, and the excellent sorting found in the inner halves of these traverses indicates that all traces of glacial conditions have been already obliterated, except possibly on portions of the Cape Cod Light Series.

The lines south of Cape Hatteras form another unit. They all have a belt of relatively fine, well sorted quartz sand near the shoreline followed by a zone of coarser sand, still retaining the good sorting, which extends just over the break in slope, where it is swept away by the Gulf Stream. In the case of these lines, the readvancing sea at the close of the Wisconsin found essentially the same material that was left behind on its retreat, and it was not forced to redistribute large deposits of glacial outwash. The sorting, however, is no better than that now found on the inner halves of the New England lines where the sea advanced over deposits of poorly sorted material. This indicates that the values for sorting given for the whole shelf are probably normal for sediments within the reach of wave action, and also that the conditions of a marine environment are quickly established in unconsolidated material.

There is another characteristic of the sediments of the Southern Section which likewise is an indication that the sea is acting on them. At the inner margin inorganic sand, largely quartz, is dominant over shell detritus. Progressing seaward shell detritus and oölites gradually replace the inorganic material, until in samples from the outer parts of the traverses they sometimes make up as much as 75 or 80% of the whole. Although physically the material has changed, texturally it has not, as the statistical constants show, and the sand persists, coarse and well sorted, to the continental margin. The sea has been able to produce a sediment of constant texture using very different materials which shows that marine conditions are uniform over a wide area, and that the bottom deposits have adapted themselves to their environment.

Farther seaward, we find what will eventually be a limestone forming on the continental slope and over the Blake Plateau from the growth of organisms which secrete skeletons of the more massive type; corals, bryozoans, calcareous algae and the like. Under ordinary conditions the continental slope is mantled with deposits of silt and clay, but here this limestone is allowed to form because the Gulf Stream effectively prevents the settling out of the detritus derived from the erosion of the shelf.

Conditions of Deposition, Past and Present

It has become almost an axiom that the distance from shore and the depth of water are the controls of texture, and the farther from the source of supply and the deeper the water, the finer is the resulting sediment. This is true in part, but to this generalization, as is the case with so many others, there are many exceptions, and it must be accepted with caution. The rule is doubtless more applicable to sediments laid down in inland waters, such as large lakes, and the epicontinental seas of the Palaezoic and Mesozoic, than to those deposited along the borders of one of the major oceans. For instance, the deeper, central parts of the basin of the Gulf of Maine now contain silts and clays in spite of the heterogeneous mass of sediment deposited from the ice sheet, and the shallower margins have coarser sediments. In the case of the continental shelf there is no steady decrease in grade size in a seaward direction. Too many other factors have entered in to upset this balance.

Shepard and Cohee (24) dealing with the mid-Atlantic section alone, consider this lack of outward grading an indication that the shelf is not adjusted to present day conditions, and that the sediment is largely residual from Pleistocene time. The present data do not support this view. When an expression for sorting is used, and particularly when enough closely spaced samples are taken, certain relationships and certain uniformities of distribution are found which are not apparent when one section was considered by itself.

Taken as a whole, the sediments of the continental shelf are becoming adjusted to present sea level, although in some cases the adjustment is not yet complete. Obviously sediments derived from the erosion of old marine deposits which have been laid down under a variety of conditions retain some of their former characteristics, and the silt and clay deposits on the downwarped shelf south of New England have not yet been able completely to bury ancient dune sands. There are plenty of indications, however, that the ocean at its present level is making its influence felt.

The varied sedimentary conditions that are found today on the different parts of the continental shelf have been duplicated many times in the formation of the Coastal Plain, whose history has been one of continuous change. The sediments of this geologic unit comprise a wedge-shaped mass resting on a basement of older, more indurated rocks which have been peneplaned. The formations of the Coastal Plain itself are, for the most part, unconsolidated or semi-consolidated sands, clays, marls, and limestones, laid down in the form of a gentle monocline, which thickens in a seaward direction. According to Stephenson (25) this monocline has been intermittently tilted seaward along an axis parallel to the coast, and, in general, this axis advanced eastward with each successive tilting movement. This resulted in elevating the inner portion of the shelf and depressing the outer. During the formation of this wedge of sediments the sea advanced and retreated many times. Erosion alternated with deposition and numerous unconformities are found in the stratigraphic column. The different formations are not continuous throughout the whole area, "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" (Stephenson, L. W. 25 p. 462). This is exactly the picture which the modern sediments present. To cite but one illustration, off southern New England deposition of silts and clays is occurring on the central portions of the shelf because at present this segment of the continental margin is warped down below the reach of effective current scour. South of Cape Hatteras erosion is taking place and older marine deposits are being reworked because the water is relatively shallow. The sand which is transported to the break in slope is swept away by the Gulf Stream. Somewhere a sandstone is probably being laid down in deep water, and its formation is contemporaneous with future shales which are accumulating in water much shallower. This instance could be multiplied many times. One has but to look at the graphs of the statistical constants to recognize how diverse are the types of sediments, and recognize that conditions of deposition which have produced the Coastal Plain in its present form are still being re-enacted. It is the modern exemplification of a scheme of things which has been in operation since first beds were laid down in the Upper Cretaceous. The whole history of Coastal Plain deposition has been one of continual change, rapid fluctuations are the rule, and conditions as we find them today, and the results which they are producing, are merely repeating the same patterns. This must be borne in mind when considering the present data in connection with the principles governing the transportation and deposition of sediments in any other large body of water.

SUMMARY AND CONCLUSIONS

1. Eight traverses were run across the continental shelf between Cape Cod and Cape Canaveral, beginning as near the beach as possible and continuing over the break in slope. Three were taken in the Gulf of Maine beginning at the shoreline and running to the bottom of the basin, and two short ones were made crossing the break in slope south of New England. Samples were never taken more than two miles apart and frequently at intervals of a mile or even half a mile.

2. A special kind of dredge was constructed to take a uniform sample and seal it off from the water to prevent washing on the upward trip.

3. The New England lines, in general, have a common pattern for the distribution of the sediments, and although in the shorter lines from the Gulf of Maine the different zones are compressed into a fewer number of miles, they can still be clearly distinguished. In an offshore direction they occur in the following order: relatively fine, well sorted sand; coarse, well sorted sand; and poorly sorted silts and clays. At the break in slope is a well sorted sand. There is a remarkably close correspondence in the depth of the water at which these zones are encountered on the different lines although the topographic profile, which governs the distance from shore at which they occur varies.

4. The New Jersey and Maryland lines show fairly well sorted sands out to the break in slope, with little diminution of the median diameters.

5. The four traverses south of Cape Hatteras, in general, share the same characteristics. There is a near shore belt of fine, well sorted quartz sand, and from this point to the break in slope the sand is coarse and well sorted. The inorganic material is gradually replaced by shell fragments and calcareous oölites. Below the break in slope the Gulf Stream carries away all sediment.

6. The $CaCO_3$ content is low north of Cape Hatteras but reaches high percentages in the southern lines, particularly in samples from the outer parts of the shelf.

7. A profile of equilibrium has developed on the inner portions of some of the New England lines, as is demonstrated by the sedimentary as well as the topographic data. South of Cape Hatteras the water over the shelf is relatively shallow and the full width

of the shelf may be considered as the inner part of the profile of equilibrium which has been truncated by the Gulf Stream.

8. Hydrographic data indicate that in winter the water over the shelf is everywhere stirred by the wind from top to bottom. The sedimentary data show that this stirring by wave action alone is feeble below 60 to 70 meters. Bottom scour is probably accomplished by a combination of tidal currents and wave action, and is not due to the currents which control the general oceanic circulation.

9. The well sorted sands at the break in slope are probably residual from Pleistocene conditions when the sea stood at a lower level. On the northern lines, although the water is deep enough for the deposition of silts and clays, present sea level has been attained so recently that the finer grade sizes have not been able to work out from shore and bury them. The rounded, frosted quartz sand, which is found on the northern lines, is considered to have been derived from Pleistocene dunes which were formed on the shelf during the repeated withdrawals of the sea throughout that period.

10. Rivers are contributing little or nothing to the present sediment of the continental shelf. Off New England the sea is working with material directly eroded from the shore, as well as with a certain amount eroded from the offshore bottoms. The source is glacial debris, and to a minor degree, Cretaceous and late Tertiary deposits. From New Jersey southward the present day sediments are derived entirely from the reworking of the topmost deposits of the Coastal Plain which are now beneath the sea.

11. There is no steady gradation of the sediments from coarse to fine in an offshore direction. There is, however, a certain uniformity in their arrangement when they are considered by regions. Depth of water appears to be the controlling factor. The present depth is largely governed by warpings of the Coastal Plain and not by erosion or deposition.

12. The sediments of the continental shelf are, for the most part, becoming adjusted to present sea level; in some places the adjustment is still in progress. The factors governing conditions of sedimentation in a major ocean are so different from those obtaining in an inland basin or an epicontinental sea, that comparison is difficult, and the arrangement of sediments in one cannot be regarded as typical for the other.

13. Coastal Plain sediments are noted for their rapid stratigraphic changes. The same diversity is found in the modern sediments covering the top of the shelf, upon which the present day ocean is directly acting. Evidently conditions of transportation and deposition have remained much the same since the Upper Cretaceous.

TABLE I

MECHANICAL ANALYSES
STATISTICAL CONSTANTS

Sample	Distance from Starting Point (miles)	Depth (meters)	Q_1 (mm.)	M (mm.)	Q_3 (mm.)	So	Log Sk
SERIES 1: Stations on a line running 35° from can buoy No. 1 at entrance to Essex River, Ipswich Bay, Mass.							
1	0	9	.13	.12	.10	1.15	.00
2	7/10	12	.11	.09	.08	1.14	.02
3	1 4/10	18	.11	.09	.07	1.20	−.02
4	2 1/10	24	.25	.16	.10	1.54	.01
5	2 8/10	28	.25	.18	.14	1.34	.01
6	3 5/10	35	.24	.18	.13	1.33	.00
7	4 2/10	37	.24	.19	.16	1.21	.04
8	4 9/10	41	.22	.17	.14	1.25	.05
9	5 6/10	47	.22	.18	.15	1.21	.01
10	6 1/10	66	.12	.09	.06	1.36	.00
11	6 8/10	71	.08	.06	.03	1.67	−.24
12	7 5/10	82	.04	.01	.003	3.54	−.35
13	8 8/10	91	.02	.007	.001	3.62	−.21
14	10 1/10	101	.02	.008	.001	3.57	−.20
15	11 4/10	106	.02	.006	.001	3.64	−.02
SERIES 2: Stations on a line running 46° from beach at Cape Cod Light.							
1	1/2	5	.470	.390	.310	1.23	−.02
2	1	12	2.700	1.500	.900	1.73	.03
3	2	32	1.300	.780	.530	1.56	.05
4	3	48	.670	.460	.330	1.42	.02
5	4	70	.420	.255	.212	1.41	.14
6	5	85	4.000	.780	.186	4.64	.09
7	6	91	5.500	.970	.190	5.37	.05
8	7	103	3.100	1.050	.530	2.42	.17
9	8	121	1.700	.740	.205	2.88	−.20
10	9	145	.722	.360	.180	2.02	.00
11	10	144	.590	.270	.144	2.02	.07
12	11	156	2.400	.720	.380	2.51	.24
13	12	167	2.300	.520	.135	4.13	.06
14	13	203	.430	.160	.009	6.76	−.80
15	14	230	.035	.004	.001	5.92	.20
SERIES 3: Stations on a line running 80° from beach at Nauset Coast Guard station, Cape Cod.							
1	1/5	5	.660	.465	.330	1.41	.00
2	1 1/5	22	.980	.630	.440	1.48	.04
3	2 1/5	28	2.450	1.350	.800	1.75	.03
4	3 1/5	49	2.200	1.440	.920	1.54	−.01
5	4 1/5	67	2.050	1.460	1.056	1.39	.00
6	5 1/5	81	.175	.154	.148	1.09	.04
7	6 1/5	126	.147	.135	.105	1.18	−.07
8	7 1/5	135	.135	.114	.100	1.16	.02
9	8 1/5	133	.118	.105	.099	1.09	.02
10	9 1/5	141	.100	.091	.012	2.89	−.84
11	10 1/5	152	.059	.045	.004	3.85	−.87
12	11 1/5	170	.062	.035	.003	4.40	−.75
13	12 1/5	180	.073	.061	.007	3.12	−.83
14	13 1/5	172	.980	.460	.201	2.21	−.03
15	14 1/5	183	.048	.010	.001	5.85	−.17
SERIES 4: Stations on a line running 183° from outer beach, Tisbury Great Pond, Martha's Vineyard.							
1	1/8	7	.430	.335	.260	1.28	.00
2	1/2	12	.320	.260	.230	1.18	.04
3	1	16	.820	.560	.430	1.38	.05
4	1 1/2	19.5	.620	.450	.320	1.39	−.01
5	2	22	.420	.310	.250	1.30	.04
6	2 1/2	22.5	.580	.480	.340	1.31	−.07
7	3	24	.290	.230	.190	1.24	.02
8	3 1/2	24	.560	.440	.320	1.32	−.03
9	4	25	.450	.350	.275	1.28	.01
10	4 1/2	26	.470	.380	.275	1.31	−.05
11	5	26	.255	.200	.160	1.26	.01
12	6	27.5	1.500	1.100	.780	1.39	−.02
13	7	29	.230	.190	.160	1.20	.01
14	8	29	1.750	.920	.580	1.74	.08
15	9	32	1.200	.820	.570	1.45	.00
16	10	33.5	.600	.440	.300	1.41	−.03
17	12	37	.740	.560	.450	1.28	.03
18	13	38	1.250	.840	.570	1.48	.00
19	14	41	1.000	.730	.510	1.40	−.02
20	15	43.5	.220	.158	.125	1.33	.05
21	16	45.5	.230	.170	.136	1.30	.04
22	17	47.5	.300	.186	.140	1.46	.08
23	18	48	.900	.720	.540	1.29	−.03
24	19	49	.450	.400	.340	1.15	−.02

TABLE II

SIZE FRACTIONS
Based on percentage of total weight.

Sample	Gravel 1–30 mm.	Sand 0.05–1 mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0.001 mm.
SERIES 1.					
1	0	100.0	0	0	0
2	0	97.0	3.0	0	0
3	0	92.5	4.7	1.8	1.0
4	0	96.0	1.0	2.0	1.0
5	0	96.0	1.0	2.0	1.0
6	0	96.0	1.8	1.2	1.0
7	0	98.0	1.0	1.0	0
8	0	99.2	.8	0	0
9	0	98.5	1.5	0	0
10	0	85.0	8.0	4.0	3.0
11	0	69.0	18.0	6.0	7.0
12	0	21.0	50.0	13.0	16.0
13	0	2.0	55.2	19.3	23.5
14	0	8.0	51.0	18.5	22.5
15	0	14.0	42.0	21.0	23.0
SERIES 2.					
1	3.0	97.0	0	0	0
2	69.0	31.0	0	0	0
3	35.0	65.0	0	0	0
4	8.0	92.0	0	0	0
5	12.7	84.8	0.5	2.0	0
6	46.5	51.5	0.5	1.5	0
7	49.0	46.3	1.2	1.6	1.9
8	51.0	46.0	1.0	1.5	0.5
9	40.5	54.5	1.3	2.7	1.0
10	16.0	76.8	1.7	2.6	2.9
11	11.0	83.5	1.2	2.3	2.0
12	39.0	56.5	1.0	1.5	2.0
13	39.0	44.0	4.8	4.9	7.3
14	13.0	57.5	7.7	9.6	12.2
15	1.3	19.7	28.0	25.0	26.0
SERIES 3.					
1	9.0	91.0	0	0	0
2	23.0	77.0	0	0	0
3	64.0	36.0	0	0	0
4	70.0	29.5	0.5	0	0
5	77.0	22.0	0.6	0.4	0
6	2.0	91.5	2.3	2.0	2.2
7	0	88.5	5.5	2.0	4.0
8	0.5	92.5	2.0	2.0	3.0
9	0.2	88.8	4.5	2.8	3.7
10	0	65.0	14.5	7.5	13.0
11	0	43.2	31.1	9.7	16.0
12	0.3	37.7	33.0	10.3	18.7
13	0.1	58.9	17.5	9.5	14.0
14	24.5	64.5	5.0	2.3	3.7
15	1.0	23.0	35.0	18.0	23.0
SERIES 4.					
1	1.5	98.5	0	0	0
2	0	100.0	0	0	0
3	17.0	83.0	0	0	0
4	7.0	93.0	0	0	0
5	.2	99.8	0	0	0
6	.6	99.4	0	0	0
7	.2	99.0	.7	.1	0
8	2.0	98.0	0	0	0
9	1.3	97.7	.7	.3	0
10	.1	99.7	.2	0	0
11	.1	98.3	1.0	.6	0
12	57.0	42.4	.6	0	0
13	.2	96.4	1.7	1.7	0
14	40.6	59.4	0	0	0
15	35.0	65.0	0	0	0
16	6.0	93.3	.7	0	0
17	12.0	87.3	.7	0	0
18	36.0	63.6	.4	0	0
19	25.0	73.1	1.0	.7	.2
20	2.3	88.7	5.0	2.0	2.0
21	6.9	85.3	3.8	2.0	2.0
22	2.3	92.2	3.1	1.4	1.0
23	9.0	90.3	.5	.2	0
24	.5	98.9	.4	.2	0

TABLE I (*Continued*)

MECHANICAL ANALYSES
STATISTICAL CONSTANTS

Sample	Distance from Starting Point (miles)	Depth (meters)	Q_1 (mm.)	M (mm.)	Q_3 (mm.)	So	Log Sk
SERIES 4 (*Continued*)							
25	20	49	.300	.230	.170	1.33	−.02
26	21	49	.420	.330	.270	1.25	.02
27	22	49	.280	.240	.210	1.15	.01
28	23	49.5	.280	.230	.190	1.21	.00
29	24	50	.295	.230	.170	1.32	−.02
30	25	53	.290	.210	.160	1.35	.02
31	26	54	.210	.180	.150	1.18	−.01
32	27	53.5	.230	.200	.165	1.18	−.02
33	28	54	.260	.200	.155	1.29	.00
34	29	55	.250	.210	.170	1.21	−.02
35	30	56	.330	.190	.120	1.66	.04
36	31	55	.460	.320	.230	1.41	.01
37	32	56	.290	.210	.160	1.35	.02
38	33	59	.180	.145	.045	2.00	−.41
39	33 3/4	59	.290	.210	.115	1.59	−.12
40	41	63	.160	.061	.021	2.76	−.04
41	43 1/2	65	.125	.044	.014	2.90	−.05
42	44 3/4	67	.074	.048	.014	2.30	−.35
43	46 1/2	69	.072	.035	.0115	2.50	−.17
44	47 1/2	71	.070	.042	.013	2.32	−.29
45	49 3/4	72	.053	.029	.008	2.54	−.30
46	50 3/4	77	.089	.047	.018	2.22	−.14
47	52 3/4	76	.048	.026	.007	2.62	−.30
48	54 1/4	78.5	.045	.022	.0056	2.84	−.43
49	55 1/2	83	.052	.026	.0072	2.69	−.26
50	56 3/4	84	.062	.030	.0081	2.76	−.25
51	58	85	.054	.033	.0081	2.58	−.40
52	59	88	.072	.041	.013	2.36	−.26
53	60 1/2	93	.089	.035	.011	2.84	−.10
54	61 1/2	95	.068	.042	.0094	2.69	−.44
55	65 1/4	116	.052	.026	.0074	2.66	−.24
56	67	119	.073	.037	.010	2.70	−.28
57	69 1/4	117	.065	.034	.0082	2.82	−.34
58	70 3/4	117	.072	.034	.0092	2.80	−.24
59	72	129	.082	.035	.0092	2.99	−.21
60	73	138	.062	.029	.0080	2.78	−.26
61	74 1/2	135	.120	.034	.0080	3.87	−.10
62	76	130	.130	.031	.0050	5.10	−.17
63	77 1/4	136	.280	.089	.014	4.47	−.30
64	78 3/4	153	.230	.090	.012	4.37	−.48
65	81	135	.350	.200	.027	3.60	−.62
66	82 1/4	147	.370	.270	.190	1.39	−.02
SERIES 5: Stations on a line beginning 40 07 N, 70 30 W, 74 miles south of Martha's Vineyard, and crossing the break in slope.							
1	40 07 N 70 30 W	128	.280	.058	.011	5.04	−.04
2	40 05 N 70 30 W	134	.520	.340	.210	1.57	−.03
3	40 03 N 70 30 W	135	.360	.250	.175	1.43	.00
4	40 00 N 70 30 W	215	.175	.145	.115	1.23	−.02
5	39 58 N 70 30 W	300	.160	.107	.062	1.61	−.06
6	39 57 N 70 30 W	337	.290	.135	.082	1.88	.12
7	39 56 N 70 30 W	370	.165	.097	.057	1.70	.00
8	39 55 N 70 30 W	410	.195	.080	.030	2.55	−.04
SERIES 6: Stations on a line beginning 40 11 N, 70 48 W, 71 miles south of Martha's Vineyard, and crossing the break in slope.							
	40 11 N 70 48 W	122	.042	.029	.0095	2.10	−.32
2	40 10 N 70 48 W	122	.052	.034	.011	2.17	−.40
3	40 07 N 70 48 W	128	.270	.200	.140	1.39	−.02
4	40 03 N 70 48 W	228	.230	.140	.085	1.64	.00
5	40 02 N 70 48 W	265	.210	.135	.092	1.51	.03
6	39 58 N 70 48 W	469	.210	.090	.041	2.26	.03
7	39 57 N 70 48 W	680	.170	.110	.078	1.47	.04

TABLE II (*Continued*)

SIZE FRACTIONS
Based on percentage of total weight.

Sample	Gravel 1–30 mm.	Sand 0.05–1 mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0.001 mm.
SERIES 4 (*Continued*)					
25	3.1	89.2	3.7	2.0	2.0
26	0	98.0	.8	.6	.6
27	0	99.6	.4	0	0
28	0	94.0	2.1	2.0	1.9
29	.2	91.8	3.5	2.5	2.0
30	.2	93.8	2.8	1.7	1.5
31	1.4	92.6	3.0	1.0	2.0
32	.5	95.5	1.5	1.5	1.0
33	.4	89.6	4.6	2.4	3.0
34	1.0	92.5	3.4	1.3	1.8
35	1.0	85.5	7.5	2.3	3.7
36	1.0	93.0	2.9	1.7	1.4
37	1.0	83.0	9.0	3.3	3.7
38	1.0	72.2	16.3	4.0	6.5
39	1.0	89.0	7.2	1.6	1.2
40	.2	54.8	31.7	6.5	6.8
41	.2	44.8	30.0	17.0	8.0
42	0	46.7	38.1	6.2	9.0
43	0	35.0	49.0	10.2	5.8
44	0	41.2	45.1	8.0	5.7
45	0	30.0	49.2	8.4	12.4
46	0	48.0	42.0	6.0	4.0
47	0	22.9	55.1	10.5	11.5
48	0	19.2	57.1	11.3	12.4
49	0	26.5	52.5	10.0	11.0
50	0	30.1	49.9	11.0	9.0
51	0	30.0	49.0	11.0	10.0
52	0	40.0	46.0	6.5	7.5
53	0	40.0	43.2	9.1	7.7
54	0	41.0	41.0	7.3	10.7
55	0	25.8	54.2	9.6	10.4
56	0	38.0	44.7	8.4	8.9
57	0	38.0	43.2	9.8	9.0
58	0	39.0	43.5	8.5	9.0
59	0	41.5	40.5	10.0	8.0
60	0	31.0	49.0	9.8	10.2
61	1.0	41.0	38.6	10.9	8.5
62	.5	40.0	34.3	14.7	10.5
63	6.0	51.5	26.5	9.5	6.5
64	3.5	54.5	26.0	9.0	7.0
65	3.0	66.0	20.0	5.7	5.3
66	1.0	91.3	5.0	1.7	1.0
SERIES 5.					
1	2.0	50.5	31.0	8.5	8.0
2	7.5	82.5	6.0	2.5	1.5
3	4.0	87.5	5.5	2.0	1.0
4	0.1	90.4	5.5	3.0	1.0
5	0.3	80.7	13.0	3.8	2.2
6	3.0	87.0	7.0	2.3	0.7
7	0.3	77.7	15.0	3.8	3.2
8	0.5	62.5	26.0	4.5	6.5
SERIES 6.					
1	0.3	11.7	70.0	8.0	10.0
2	1.0	25.0	56.5	8.2	9.3
3	0.3	85.7	8.0	4.0	2.0
4	0.5	87.5	8.0	2.7	1.3
5	0.0	91.5	6.5	1.6	0.4
6	2.0	67.0	22.0	4.0	5.0
7	0.3	86.7	7.0	3.8	2.2

TABLE I (*Continued*)

MECHANICAL ANALYSES
STATISTICAL CONSTANTS

Sample	Distance from Starting Point	Depth (meters)	Q_1 (mm.)	M (mm.)	Q_3 (mm.)	*So*	Log *Sk*
SERIES 7: Stations on a line running 167° from the whistling buoy 1 1/4 miles southwest of Block Island.							
1	0	18	1.950	1.170	.660	1.72	−.03
2	1	20	1.280	.880	.600	1.46	.00
3	2	37	.245	.175	.150	1.28	.08
4	3	42	.245	.175	.145	1.30	.06
5	4	43	.400	.318	.255	1.25	.00
6	5	40	.490	.355	.295	1.29	.06
7	6	40	.940	.560	.370	1.59	.05
8	7 1/5	42	.410	.300	.240	1.31	.04
9	8 1/5	43	.900	.610	.320	1.68	−.11
10	9 1/5	44	1.240	.860	.360	1.86	−.22
11	10 2/5	49	.440	.330	.240	1.35	−.01
12	11 3/5	53	.490	.340	.235	1.44	.00
13	13 3/5	55	.260	.190	.150	1.32	.03
14	20	66	.730	.240	.140	2.28	.25
15	21	67.5	.156	.144	.108	1.20	−.09
16	22	65	.280	.190	.135	1.44	.02
17	23 1/5	63	.208	.160	.140	1.22	.06
18	24 1/5	64	.290	.190	.125	1.52	.00
19	25 1/5	67	.235	.170	.110	1.46	−.05
20	27 2/5	67	.350	.210	.093	1.94	−.13
21	29 3/5	71	.140	.079	.046	1.74	.00
22	30 3/5	68	.250	.170	.089	1.68	−.12
23	31 3/5	69	.320	.170	.118	1.65	.11
24	32 4/5	68	.260	.180	.135	1.39	.04
25	34 4/5	70	.370	.200	.032	3.40	−.53
26	35 4/5	72	.560	.340	.190	1.72	−.04
27	37	70	.580	.310	.054	3.28	−.49
28	38	71	.300	.190	.045	2.58	−.43
29	39	72	.360	.230	.170	1.45	.06
30	40	73	.380	.240	.044	2.94	−.54
31	41	81	.490	.310	.190	1.61	−.01
32	43	73	.410	.270	.185	1.49	.02
33	44	74	.350	.230	.062	2.37	−.39
34	45	76	.450	.260	.060	2.74	−.40
35	46 1/5	78	.340	.170	.027	3.55	−.50
36	47 1/5	80	.430	.260	.041	3.24	−.58
37	48 1/5	82	.270	.160	.024	3.35	−.60
38	49 2/5	84	.240	.072	.013	4.30	−.22
39	50 3/5	85	.250	.120	.027	3.04	−.33
40	51 3/5	84	.400	.270	.170	1.53	−.03
41	52 3/5	88	.310	.170	.033	3.06	−.45
42	53 3/5	89	.310	.170	.028	3.33	−.52
43	55 4/5	93	.290	.170	.031	3.12	−.51
44	57	93	.350	.230	.125	1.67	−.08
45	58	96	.380	.240	.040	3.08	−.58
46	59	97	.480	.330	.210	1.51	−.03
47	60	99	.440	.300	.060	2.71	−.53
48	61	104	.370	.240	.022	1.30	−.85
49	62	112	.410	.265	.200	1.42	.07
50	65	167	.370	.240	.140	1.63	−.05
51	66	166	.380	.240	.125	1.74	−.08
52	67	200	.320	.240	.145	1.49	−.09

Atlantis Station	Position	Distance between Stations (nautical miles)	Depth (meters)	Q_1 (mm.)	M (mm.)	Q_3 (mm.)	*So*	Log *Sk*
SERIES 8: Stations on a line beginning at 39 14 N, 73 54 W, off the New Jersey coast, and running offshore in a southeasterly direction.								
1245a	39 14 N 73 54 W		45.5	.630	.340	.190	1.82	.01
d		2.7	40	.500	.420	.335	1.22	−.02
c		2.7	36	.500	.370	.270	1.36	−.01
b		2.7	39	.520	.410	.285	1.35	−.05
1244a	39 07 N 73 43 W	2.6	43	.510	.385	.270	1.37	−.03
g		2.6	46	.510	.420	.305	1.29	−.05
f		2.6	53	3.000	.480	.230	3.57	.49
e		2.6	52	.470	.320	.240	1.38	.05
d		2.6	53	.570	.440	.305	1.36	−.05
c		2.6	61	.275	.240	.220	1.12	.02
b		2.6	66	.380	.245	.200	1.38	.10
1243a	38 58 N 73 23 W	3.0	63	.450	.355	.280	1.27	.00
f		3.0	74	.900	.435	.270	1.82	.11
e		3.0	78	.660	.230	.160	2.03	.30
d		3.0	77	.520	.450	.340	1.24	−.06
c		3.0	82	.320	.270	.230	1.18	.00
b		3.0	90	.480	.320	.280	1.31	.12
1242a	38 47 N 73 06 W	2.4	117.7	.240	.200	.160	1.22	−.02
c		2.4	182	.295	.195	.028	3.25	−.66
1241b		2.4	610	.165	.052	.003	6.77	−.66

TABLE II (*Continued*)

SIZE FRACTIONS
Based on percentage of total weight.

Sample	Gravel 1–30 mm.	Sand 0.05–1 mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0.001 mm.
SERIES 7.					
1	56.0	44.0	0	0	0
2	42.0	58.0	0	0	0
3	.5	99.5	0	0	0
4	1.5	98.5	0	0	0
5	.4	97.6	2.0	0	0
6	1.2	98.5	.3	0	0
7	22.0	77.4	.6	0	0
8	1.0	98.7	.3	0	0
9	19.0	79.0	2.0	0	0
10	40.2	59.3	.5	0	0
11	.5	99.0	.5	0	0
12	1.5	97.5	1.0	0	0
13	1.7	91.3	5.0	2.0	0
14	19.5	72.0	4.5	2.0	2.0
15	1.0	90.0	5.0	2.0	2.0
16	1.0	88.0	6.0	3.0	2.0
17	1.0	92.0	4.0	2.0	1.0
18	7.0	79.0	7.0	4.0	3.0
19	1.0	82.5	7.0	4.5	5.0
20	3.5	79.5	11.0	4.5	1.5
21	.1	71.9	20.0	3.5	4.5
22	0	81.5	11.0	3.5	4.0
23	.5	79.5	13.0	4.0	3.0
24	1.0	83.0	10.0	3.0	3.0
25	1.5	68.5	18.5	6.0	5.5
26	8.0	83.0	7.0	1.0	1.0
27	6.5	69.5	15.0	4.0	5.0
28	1.5	72.0	17.5	4.0	5.0
29	3.0	82.5	9.5	2.5	2.5
30	3.0	69.0	19.6	4.4	4.0
31	2.0	89.0	6.0	1.8	1.2
32	1.2	86.8	8.0	2.0	2.0
33	2.5	75.0	16.2	3.3	3.0
34	5.0	71.5	14.5	4.8	4.2
35	4.5	62.0	22.0	5.5	6.0
36	3.0	69.0	18.5	5.5	4.0
37	1.0	62.5	26.0	5.0	5.5
38	1.0	56.5	26.0	8.5	8.0
39	1.0	60.0	26.0	7.2	5.8
40	1.0	83.0	11.7	2.8	1.5
41	1.5	68.5	20.5	5.3	4.2
42	1.0	67.5	19.5	6.8	5.2
43	1.0	69.0	19.3	5.7	5.0
44	1.0	76.5	14.5	3.0	5.0
45	2.0	72.0	18.0	4.7	3.3
46	2.0	79.5	11.0	4.7	2.8
47	2.0	73.0	16.0	6.0	3.0
48	2.0	68.5	18.0	6.5	5.0
49	2.5	90.0	5.5	1.5	0.5
50	2.3	82.9	8.4	3.4	3.0
51	2.7	79.8	10.0	4.0	3.5
52	1.0	82.5	8.7	4.3	3.5

Atlantis Station	Gravel 1–30 mm.	Sand 0.05– mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0.00 mm.
SERIES 8.					
1245a	15.0	81.4	1.6	1.0	1.0
d	2.5	97.5	0	0	0
c	5.0	95.0	0	0	0
b	1.0	99.0	0	0	0
1244a	5.0	95.0	0	0	0
g	1.5	98.5	0	0	0
f	38.0	60.0	.5	.7	.8
e	4.0	95.7	.1	.1	.1
d	9.0	90.8	.2	0	0
c	.1	99.1	.1	.4	.3
b	9.2	89.5	1.0	.3	0
1243a	6.0	93.7	.2	.1	0
f	24.0	70.0	2.0	2.6	1.4
e	23.0	65.0	5.0	5.0	2.0
d	3.3	95.7	.5	.3	2
c	.2	99.0	.4	.2	.2
b	6.0	93.3	.2	.3	.2
1242a	.5	95.5	1.6	1.4	1.0
c	1.0	72.0	10.0	8.5	8.5
1241b	2.0	48.0	22.0	13.0	15.0

TABLE I (*Continued*)

MECHANICAL ANALYSES

STATISTICAL CONSTANTS

Atlantis Station	Position	Distance between Stations (nautical miles)	Depth (meters)	Q_1 (mm.)	M (mm.)	Q_3 (mm.)	*So*	Log *Sk*
SERIES 9: Stations on a line beginning at 38 12 N, 75 02 W, off the Maryland coast, and running offshore in a southeasterly direction.								
1236a	38 12 N 75 02 W		22	.520	.370	.280	1.36	.03
b		1.9	22	.420	.380	.290	1.20	−.07
c		1.9	21	.170	.160	.155	1.05	.01
d		1.9	24.5	1.550	.680	.360	2.08	.08
e		1.9	25	.410	.300	.230	1.33	.02
1237a	38 09 N 74 51 W	1.9	23.5	.160	.150	.147	1.04	.02
b		1.9	32	.310	.260	.230	1.16	.02
c		1.9	25	.610	.350	.250	1.56	.10
d		1.9	22	.410	.340	.280	1.21	.00
e		1.9	29	.400	.330	.280	1.20	.01
f		1.9	35	.420	.305	.240	1.32	.04
g		1.9	32	.820	.450	.305	1.64	.09
1238a	38 02 N 74 37 W	1.7	37	.540	.400	.290	1.36	−.01
b		1.7	40	.270	.230	.190	1.19	−.01
c		1.7	44	.265	.236	.210	1.12	.00
d		1.7	50	.200	.190	.175	1.07	−.01
e		1.7	52	.190	.175	.155	1.11	−.02
f		1.7	52	.180	.170	.150	1.10	−.03
g		1.7	49	.175	.165	.150	1.08	−.02
h		1.7	63	.195	.170	.155	1.12	.02
1239a	37 55 N 74 20 W	2.0	68	.210	.180	.160	1.15	.02
b		2.0	73	.250	.210	.190	1.15	.03
c		2.0	77	.400	.230	.180	1.49	.13
d		2.0	99	.410	.190	.150	1.65	.23
e		2.0	114	.410	.270	.190	1.47	.03
f		2.0	154	.310	.190	.145	1.46	.09
1240a	37 49 N 74 07 W		386	.250	.140	.095	1.62	.08
SERIES 10: Stations on a line beginning 34 18 N, 77 38 W, off New Topsail Inlet, Onslow Bay, North Carolina, and running offshore in a southeasterly direction.								
1633	34 18 N 77 38 W		12.5	.225	.185	.160	1.18	.02
a		1.9	13	.240	.190	.160	1.22	.03
b		1.9	13	.420	.285	.220	1.38	.06
c		1.9	16	.486	.330	.230	1.44	.01
d		1.9	18	.370	.250	.195	1.38	.06
e		1.9	19	.350	.265	.220	1.26	.04
f		1.9	20	Sample inadequate				
1634	34 09 N 77 26 W	1.9	22	.400	.250	.200	1.41	.11
a		2.2	27	.340	.245	.200	1.30	.05
b		2.2	27	.880	.480	.280	1.77	.03
c		2.2	28	1.200	.560	.300	2.00	.06
d		2.2	32	.270	.195	.185	1.21	.12
e		2.2	33	.320	.225	.190	1.30	.08
f		2.2	32	1.150	.700	.400	1.70	−.03
g		2.2	34	.420	.300	.220	1.38	.01
1635	33 58 N 77 10 W	2.2	35	.820	.480	.290	1.68	.01
a		2.5	35	1.000	.500	.310	1.80	.09
b		2.5	37	.630	.470	.340	1.36	−.01
c		2.5	38	.700	.490	.330	1.46	−.02
d		2.5	39	.400	.285	.240	1.29	.07
e		2.5	40	.600	.370	.200	1.73	−.06
1636	33 46 N 76 57 W	2.5	43	.830	.475	.250	1.82	−.04
a		2.3	42	.360	.260	.210	1.31	.05
b		2.3	44	.880	.620	.440	1.41	.00
c		2.3	47	2.100	1.450	.980	1.46	−.01
d		2.3	67	1.400	1.000	.700	1.41	−.01
e	33 39 N 76 48 W	2.3	130	On seven stations between 1636d and 1639 the bottom is hard.				
1639	33 15 N 76 14 W	40.4	1500	.019	.006	.001	4.35	−.27
1640	33 10 N 75 52 W	18.5	3062	.028	.006	.001	5.29	−.11
1641	32 57 N 75 43 W	15.0	3252	.021	.005	.001	4.58	−.07

TABLE II (*Continued*)

SIZE FRACTIONS

Based on percentage of total weight.

Atlantis Station	Gravel 1–30 mm.	Sand 0.05–1 mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0.001 mm.
SERIES 9.					
1236a	4.0	92.0	3.0	1.0	0
b	4.0	95.7	.3	0	0
c	.1	99.4	.5	0	0
d	38.5	61.0	.5	0	0
e	1.0	98.9	.1	0	0
1237a	0	99.7	.3	0	0
b	.8	98.8	.4	0	0
c	8.0	92.0	0	0	0
d	.5	99.5	0	0	0
e	.5	99.5	0	0	0
f	6.5	93.5	0	0	0
g	20.0	80.0	0	0	0
1238a	4.5	95.3	.2	0	0
b	1.0	99.0	0	0	0
c	0	100.0	0	0	0
d	.1	99.9	0	0	0
e	0	98.3	.7	.5	.5
f	.4	97.6	1.5	.5	0
g	.1	99.3	.4	.2	0
h	0	99.6	.2	.2	0
1239a	1.0	98.3	.5	.2	0
b	7.0	86.0	2.0	2.0	3.0
c	7.0	92.5	.3	.2	0
d	12.0	80.0	3.5	2.5	2.0
e	7.0	87.3	3.2	1.5	1.0
f	1.0	91.0	4.0	2.0	2.0
1240a	1.0	87.4	6.0	2.6	3.0
SERIES 10.					
1633	0	100.0	0	0	0
a	.1	99.9	0	0	0
b	0	100.0	0	0	0
c	0	100.0	0	0	0
d	0	100.0	0	0	0
e	0	100.0	0	0	0
1634	3.2	96.8	0	0	0
a	2.5	97.5	0	0	0
b	21.0	79.0	0	0	0
c	31.0	69.0	0	0	0
d	8.0	92.0	0	0	0
e	3.0	97.0	0	0	0
f	31.0	69.0	0	0	0
g	6.5	93.5	0	0	0
1635	21.5	78.5	0	0	0
a	25.0	75.0	0	0	0
b	14.5	85.5	0	0	0
c	12.0	88.0	0	0	0
d	3.5	96.5	0	0	0
e	9.0	91.0	0	0	0
1636	19.0	81.0	0	0	0
a	4.0	96.0	0	0	0
b	19.0	81.0	0	0	0
c	73.0	27.0	0	0	0
d	50.0	50.0	0	0	0
1639	0	6.0	46.0	20.0	28.0
1640	0	12.0	42.0	20.0	26.0
1641	0	10.3	38.2	20.5	31.0

TABLE I (*Continued*)

MECHANICAL ANALYSES
STATISTICAL CONSTANTS

Atlantis Station	Position	Distance between Stations (nautical miles)	Depth (meters)	Q_1 (mm.)	*M* (mm.)	Q_3 (mm.)	*So*	Log *Sk*
SERIES 11: Stations on a line beginning two miles from Charleston Lightship, 32 42 N, 79 45 W, and running offshore in an easterly direction.								
e	32 42 N 79 45 W		10	.530	.260	.180	1.71	.15
d		2.0	12	.600	.410	.200	1.73	.15
c		2.0	12	.530	.260	.210	1.59	.22
b		2.0	13	.310	.240	.210	1.21	.06
a		2.0	13	.630	.390	.230	1.65	−.02
1632	32 39 N 79 35 W	2.0	16	.190	.175	.160	1.09	.00
c		2.0	15	Consists entirely of whole shells.				
b		1.7	18	1.000	.520	.210	2.18	−.11
a		1.7	19	.980	.670	.500	1.39	.04
1631	32 35 N 79 22 W	1.7	19	.530	.360	.260	1.43	.03
h		1.7	20	.550	.420	.280	1.40	.06
g		1.7	20	.540	.340	.240	1.50	.05
f		1.7	22	.900	.540	.330	1.65	.01
e		1.7	25	.800	.460	.270	1.72	.01
d		1.7	27	.680	.390	.250	1.65	.05
c		1.7	29	.910	.550	.350	1.61	.02
b		1.7	32	.970	.650	.400	1.55	−.04
a		1.7	34	.970	.600	.360	1.64	−.01
1630	32 24 N 79 16 W	1.9	37	.460	.330	.235	1.40	.00
g		1.9	40	.740	.520	.330	1.49	−.04
f		1.9	43	.730	.490	.320	1.51	−.01
e		1.9	41	.850	.610	.370	1.51	−.07
d		1.9	50	.520	.370	.260	1.41	−.01
c		1.9	64	.550	.420	.310	1.33	−.01
b		2.0	76	.930	.630	.450	1.43	.02
a		2.0	99	.210	.168	.150	1.18	.05
1629	32 13 N 79 02 W	2.0	120	.230	.175	.140	1.28	.02
d		2.0	235	Foraminifera.				
c	32 10 N 78 59 W	2.0	419	On nine stations from 1628d to 1627 the bottom is hard.				
1627	32 00 N 78 43 W	17.0	428					
SERIES 12: Stations on a line beginning 30 22 N, 81 10 W off Jacksonville, Florida, and running offshore in an easterly direction.								
1618	30 22 N 81 10 W		20	.360	.210	.165	1.48	.13
a		2.0	20	.520	.330	.190	1.65	−.04
b		2.0	23.5	.275	.200	.155	1.33	.03
c		2.0	24	.245	.195	.165	1.22	.03
d		2.0	24	.240	.200	.160	1.22	−.02
e		2.0	27	.480	.290	.180	1.63	.01
f		2.0	28	.760	.380	.175	2.08	−.04
1619	30 20 N 80 52 W	2.0	29	.250	.200	.175	1.20	.04
a		2.0	29	.680	.410	.300	1.50	.08
b		2.0	32	.800	.475	.300	1.63	.03
c		2.0	33	.720	.400	.260	1.66	.07
d		2.5	32	.680	.470	.300	1.50	−.03
e		2.6	33	.710	.485	.320	1.49	−.01
f		2.6	33	.640	.426	.290	1.48	.01
g		2.5	33	.670	.500	.375	1.33	.00
h		2.5	36	.560	.400	.300	1.37	.02
1620	30 16 N 80 28 W	2.5	37	.570	.400	.290	1.39	.01
a		2.0	41	.610	.420	.310	1.39	.03
b		2.0	39	.670	.480	.340	1.40	.00
c		2.0	42	.680	.460	.300	1.51	−.02
d		2.2	45	Sample insufficient.				
e		2.2	50	.760	.480	.280	1.64	−.03
f		2.5	52	.500	.270	.210	1.54	.16
1621	30 17 N 80 09 W	2.5	126	Samplers came up empty.				
a		3.2	246	Foraminifera.				
b		3.2	418	On 21 stations beginning with 1621b and extending out over The Blake Plateau to 1626, the bottom was either hard or the sediment consisted of a mixture of foraminifera and pteropods.				
1626	30 22 N 78 49 W	63.0	807					

TABLE II (*Continued*)

SIZE FRACTIONS

Based on percentage of total weight.

Atlantis Station	Gravel 1–30 mm.	Sand 0.05–1 mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0 001 mm.
SERIES 11.					
e	10.5	89.5	0	0	0
d	13.0	87.0	0	0	0
c	10.5	89.5	0	0	0
b	2.5	97.5	0	0	0
a	10.5	89.5	0	0	0
1632	0	100.0	0	0	0
b	25.0	75.0	0	0	0
a	23.0	77.0	0	0	0
1631	0	100.0	0	0	0
h	2.5	97.5	0	0	0
g	5.0	95.0	0	0	0
f	20.0	80.0	0	0	0
e	18.0	82.0	0	0	0
d	13.0	87.0	0	0	0
c	21.0	79.0	0	0	0
b	22.5	77.5	0	0	0
a	23.0	77.0	0	0	0
1630	2.5	97.5	0	0	0
g	15.0	85.0	0	0	0
f	13.0	87.0	0	0	0
e	18.0	82.0	0	0	0
d	5.0	95.0	0	0	0
c	7.0	93.0	0	0	0
b	21.0	79.0	0	0	0
a	0	96.5	3.0	.5	0
1629	0	97.7	2.0	.3	0
SERIES 12.					
1618	2.0	98.0	0	0	0
a	4.0	96.0	0	0	0
b	1.0	99.0	0	0	0
c	0	100.0	0	0	0
d	2.5	97.5	0	0	0
e	6.5	93.5	0	0	0
f	19.0	81.0	0	0	0
1619	1.0	99.0	0	0	0
a	13.0	87.0	0	0	0
b	16.0	84.0	0	0	0
c	14.0	86.0	0	0	0
d	11.0	89.0	0	0	0
e	10.5	89.5	0	0	0
f	9.0	91.0	0	0	0
g	9.0	91.0	0	0	0
h	4.0	96.0	0	0	0
1620	4.5	95.5	0	0	0
a	5.0	95.0	0	0	0
b	10.0	90.0	0	0	0
c	11.0	89.0	0	0	0
e	12.0	88.0	0	0	0
f	12.0	88.0	0	0	0

TABLE I (*Continued*)

MECHANICAL ANALYSES
STATISTICAL CONSTANTS

Atlantis Station	Position	Distance between Stations (nautical miles)	Depth (meters)	Q_1 (mm.)	M (mm.)	Q_3 (mm.)	So	Log Sk
SERIES 13: Stations on a line beginning 28 29 N, 80 22 W off Cape Canaveral, Florida, running offshore in a southeasterly direction.								
1617	28 29 N 80 22 W		23	.145	.120	.087	1.29	−.06
c		2.0	24	1.400	.790	.540	1.61	.08
b		2.0	26	2.300	.970	.490	2.17	.08
a		2.0	29	.560	.390	.280	1.41	.01
1616	28 31 N 80 12 W	2.0	38	.180	.145	.120	1.22	.01
c		2.0	45	.230	.170	.145	1.26	.06
b		2.0	52	No sample.				
a		2.0	68	.340	.220	.190	1.34	.13
1615	28 29 N 80 02 W	3.0	72	Hard bottom.				
1614b	28 28 N 79 58 W	4.0	142	On seven stations from 1614b to 1613 the sediment is principally foraminifera.				
1613	28 22 N 79 46 W	14.0	487					
1612b	28 19 N 79 41 W	5.0	566	On five stations from 1612b to 1611 the bottom is hard.				
1611	28 11 N 79 30 W	12.0	731	Foraminifera and Corals.				

TABLE II (*Continued*)

SIZE FRACTIONS
Based on percentage of total weight.

Atlantis Station	Gravel 1–30 mm.	Sand 0.05–1 mm.	Silt 0.005–0.05 mm.	Clay 0.001–0.005 mm.	Colloid 0–0.001 mm.
SERIES 13.					
1617	.5	87.8	3.7	3.0	5.0
c	38.0	62.0	0	0	0
b	49.0	51.0	0	0	0
a	9.0	91.0	0	0	0
1616	0	100.0	0	0	0
c	0	100.0	0	0	0
1615a	5.0	95.0	0	0	0

BIBLIOGRAPHY

1. Twenhofel, W. H. Environment in Sedimentation and Stratigraphy. Bull. Geol. Soc. Amer., Vol. 42, 1931, pp. 407–424.
2. Krumbein, W. C. Probable Error in Sampling Sediments for Mechanical Analysis. Amer. Jour. Sci., Vol. 27, March, 1934, pp. 204–214.
3. Gripenberg, Stina. Sediments of the North Baltic and Adjoining Seas. Havsforskninginstitutets Skrift No. 96, Helsingfors, 1934.
4. Olmstead, L. B. and others. A Pipette Method of Mechanical Analysis. Tech. Bull. U. S. Dept. of Agric. No. 170, 1930.
5. Vageler, P. Der Kationen und Wasserhaushalt des Mineralbodens. Julius Springer, Berlin, 1932.
6. Casagrande, A. Die Aräometer Methode zur Bestimmung der Kornverteilung von Boden. Julius Springer, Berlin, 1934.
7. Rubey, W. W. Lithologic Studies of the Fine-Grained Upper Cret. Sedimentary Rocks of the Black Hills Region. U. S. Geol. Survey, Prof. Paper 165, 1930, pp. 1–54.
8. Trask, P. D. The Origin and Environment of Source Sediments of Petroleum. Gulf Publishing Co., Houston, 1930.
9. Galliher, E. Wayne. Cumulative Curves and Histograms. Amer. Jour. Sci., Vol. 26, Nov. 1933, pp. 475–478.
10. Alexander, A. E. A Petrographic Study of some Continental Shelf Sediments. Jour. Sed. Petrology, Vol. 4, No. 1, 1934, pp. 12–22.
11. Richards, H. G. Marine Fossils from New Jersey Indicating a Mild Interglacial Stage. Proc. Amer. Phil. Soc., Vol. 72, 1933, pp. 181–214.
12. Richards, H. G. Some Shells from the North Carolina Banks. Nautilus, Vol. 49, No. 4, 1936, pp. 130–134.
13. Rept. of the Superintendent of the U. S. Coast Survey, 1869, Appendix No. 11, L. F. Pourtales, Characteristics of the Atlantic Sea-Bottom off the Coast of the U. S., pp. 220–225.
14. Murray, John. Rept. on the Results of Dredging by the U. S. Coast Survey Steamer "Blake." XXVII, Bottom Deposits, Bull. Mus. Comp. Zool., Vol. 12, 1885–86, pp. 37–61.
15. Agassiz, A. Three Cruises of the "Blake." Bull. Mus. Comp. Zool., Vols. 14 & 15. 1888.
16. Fenneman, N. M. Development of the Profile of Equilibrium of the Subaequeous Shore Terrace. Jour. Geol., Vol. 10, 1902, pp. 1–32.
17. Johnson, W. D. Shore Processes and Shoreline Development, New York, 1919.
18. Johnson, W. D. New England-Acadian Shoreline. New York, 1925.
19. Raymond, P. E. & Stetson, H. C. A New Factor in the Transportation and Distribution of Marine Sediments. Science, Vol. 73, No. 1882, Jan. 23, 1931, pp. 105–106.
20. Iselin, C. O'D. A Study of the Circulation of the Western North Atlantic. Papers in Physical Oceanography and Meteorology, Mass. Inst. Tech., & Woods Hole Oceanographic Inst., Vol. 4, No. 4, 1936.
21. Stetson, H. C. Current Measurements in the Georges Bank Canyons. Trans. Amer. Geophysical Union, 18th Ann. Meeting, July, 1937, pp. 216–219.
22. Daly, R. A. The Changing World of the Ice Age. New Haven, 1934.

23. Stetson, H. C. Origin and Limits of a Zone of Rounded Quartz Sand off the Southern Coast. Jour. Sed. Petrology, Vol. 4, No. 3, 1934, pp. 152–153.
24. Shepard, F. P. & Cohee, G. V. Continental Shelf Sediments off the Mid-Atlantic States. Bull. Geol. Soc. Amer., Vol. 47, 1936, pp. 441–458.
25. Stephenson, L. W. Major Features in the Geology of the Atlantic Coastal Plain. Jour. Wash. Acad. Sci., Vol. 16, No. 17, 1926, pp. 460–480.