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

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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.

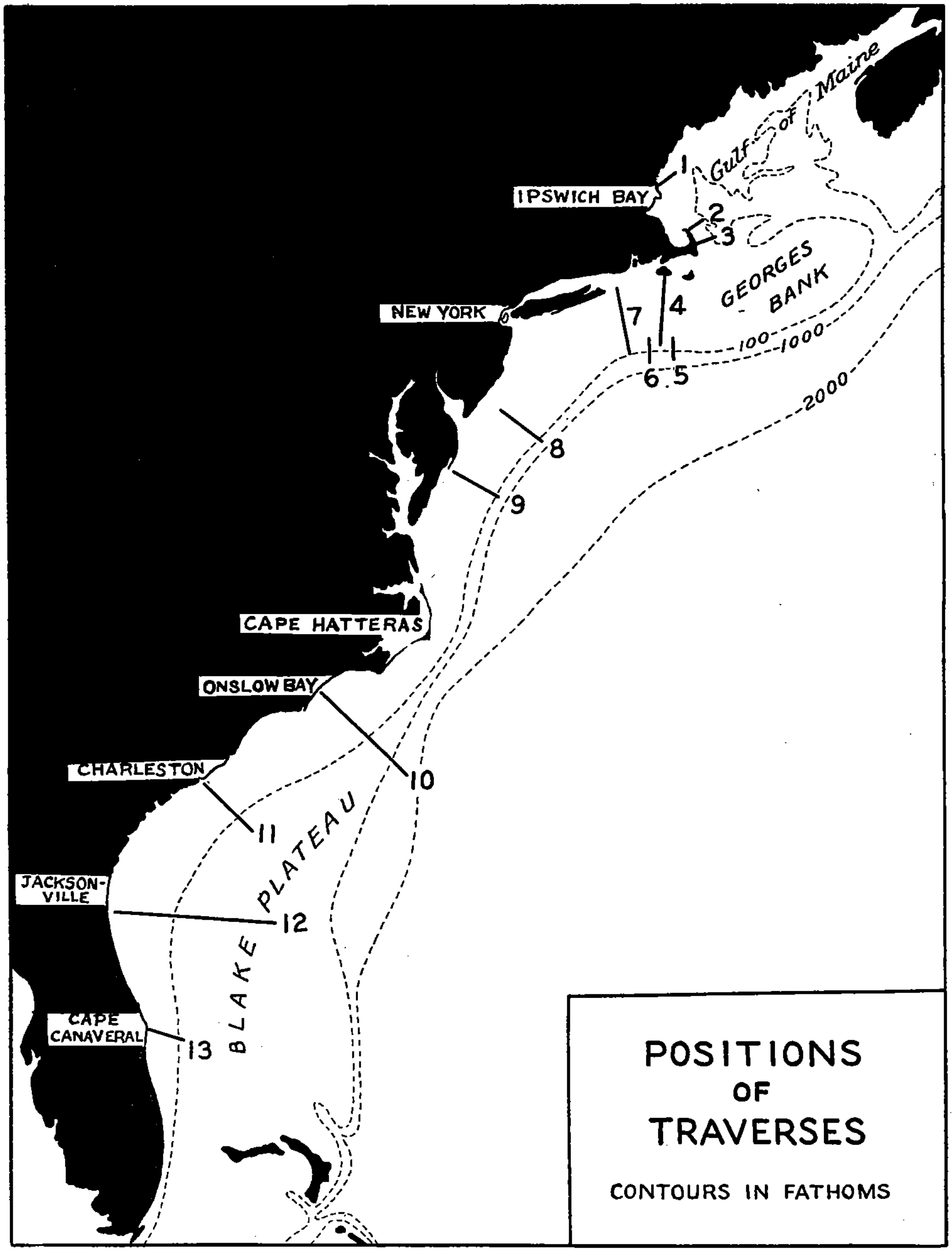
Gulf of Maine
IPSWICH BAY
1
2
3
GEORGES BANK
NEW YORK
7
4
100
1000
6
5
2000
8
9
CAPE HATTERAS
ONSLOW BAY
CHARLESTON
10
11
BLAKE PLATEAU
JACKSON-VILLE
12
CAPE CANAVERAL
13
POSITIONS OF TRAVERSES
CONTOURS IN FATHOMS

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 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.

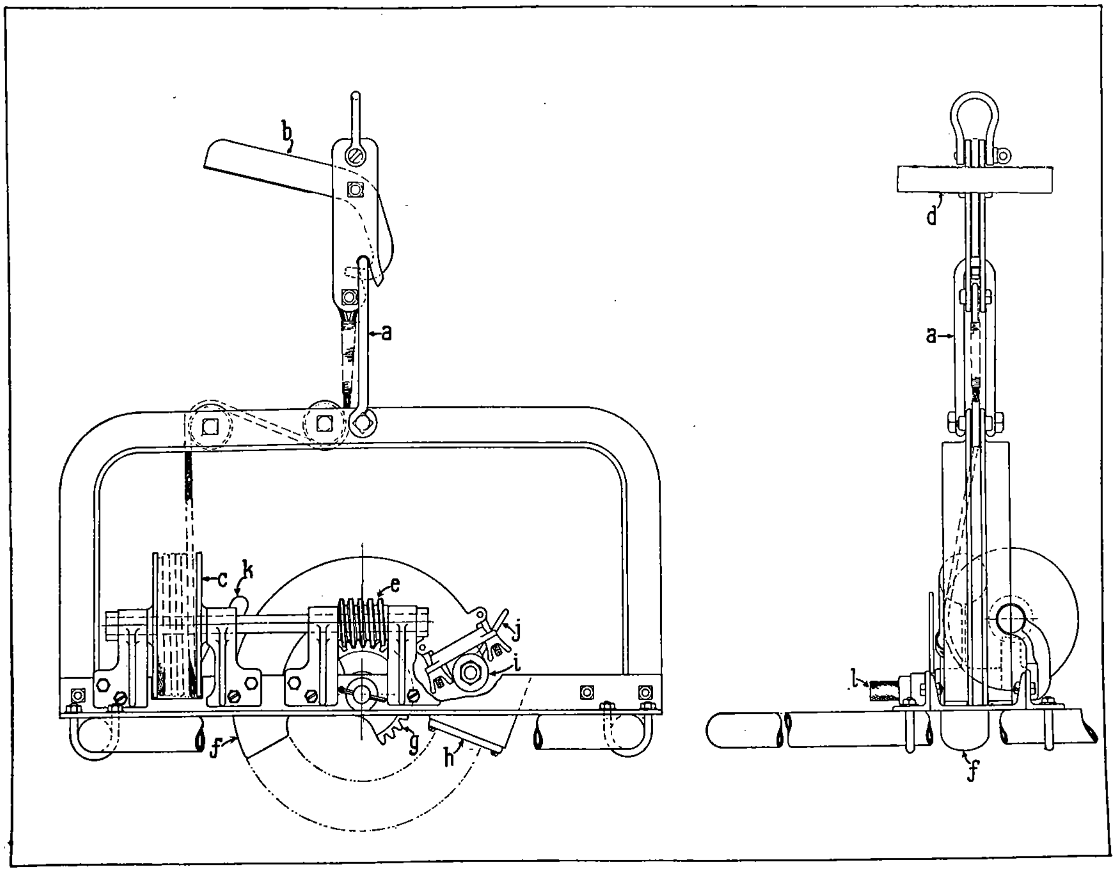

FIG. 2.—The dredge. About one twelfth natural size.

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.

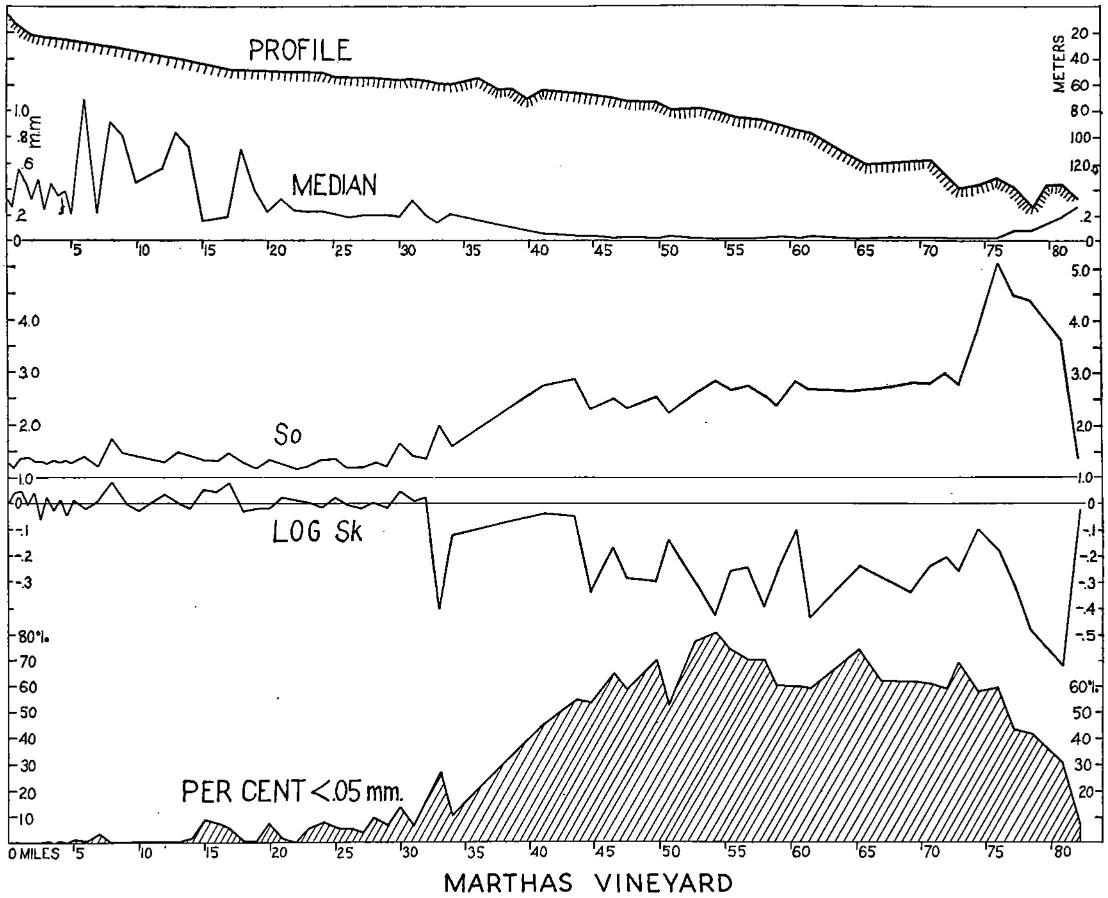

FIG. 3.—Series 4, see Fig. 1.

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 (33¾ 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.

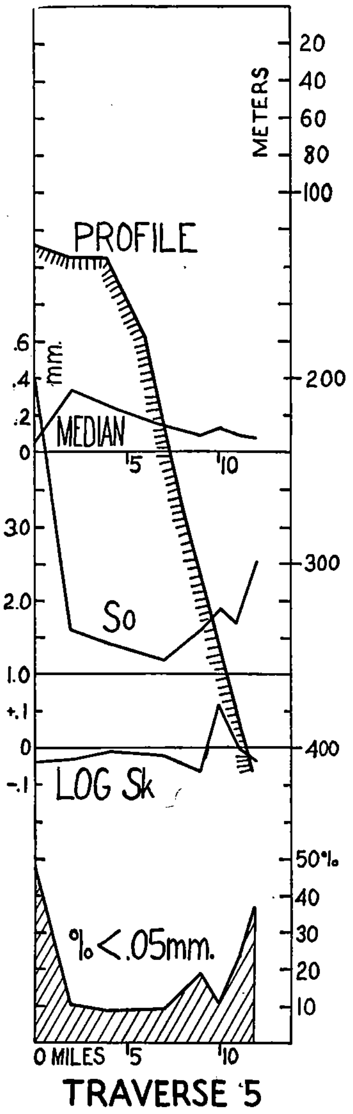

Fig. 4.—Series 5, see Fig. 1.

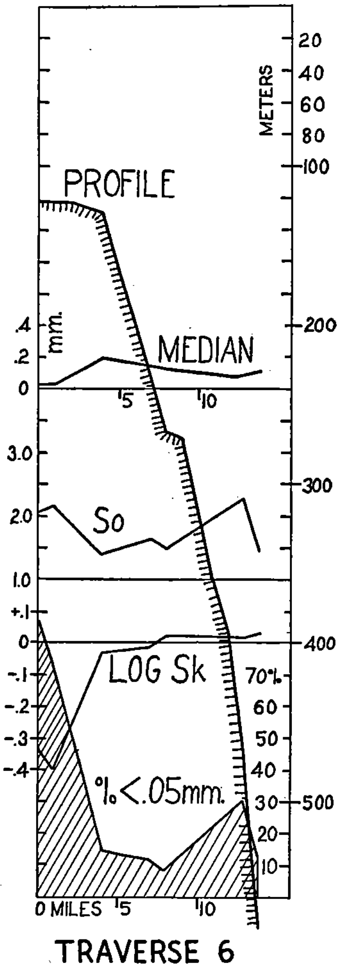

Fig. 5.—Series 6, see Fig. 1.

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.

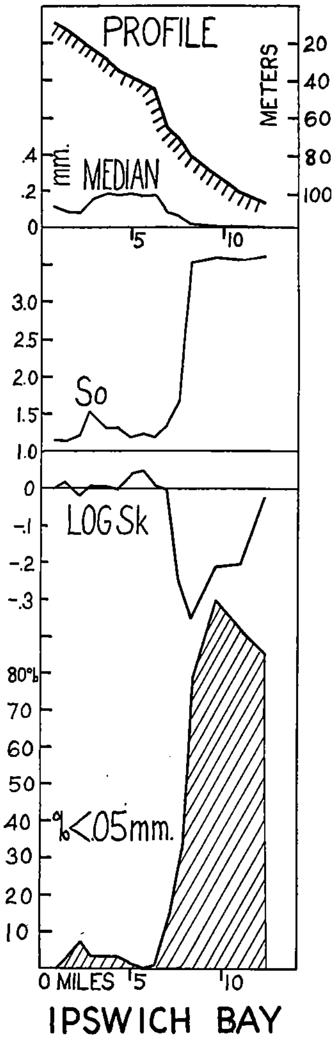

FIG. 6.—Series 1, see Fig. 1.

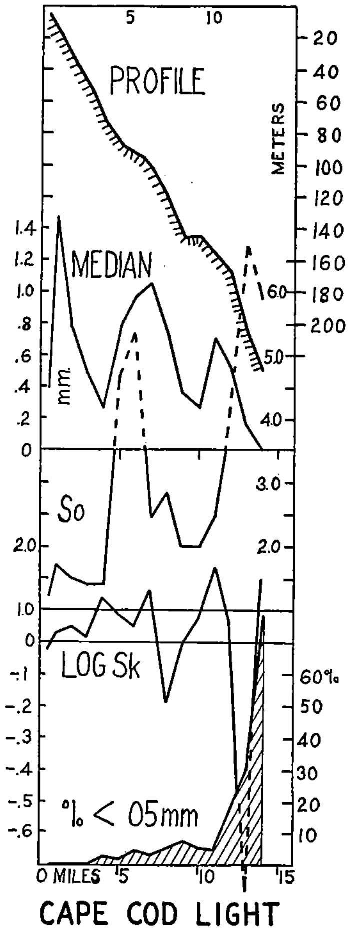

FIG. 7.—Series 2, see Fig. 1.

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.

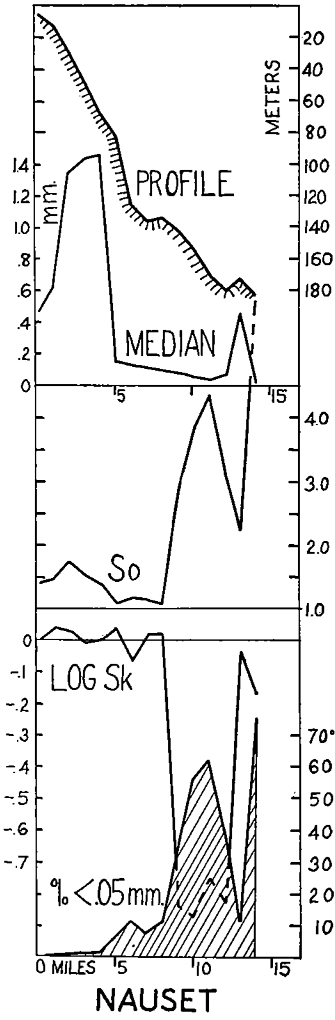

Fig. 8.—Series 3, see Fig. 1.

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.

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 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

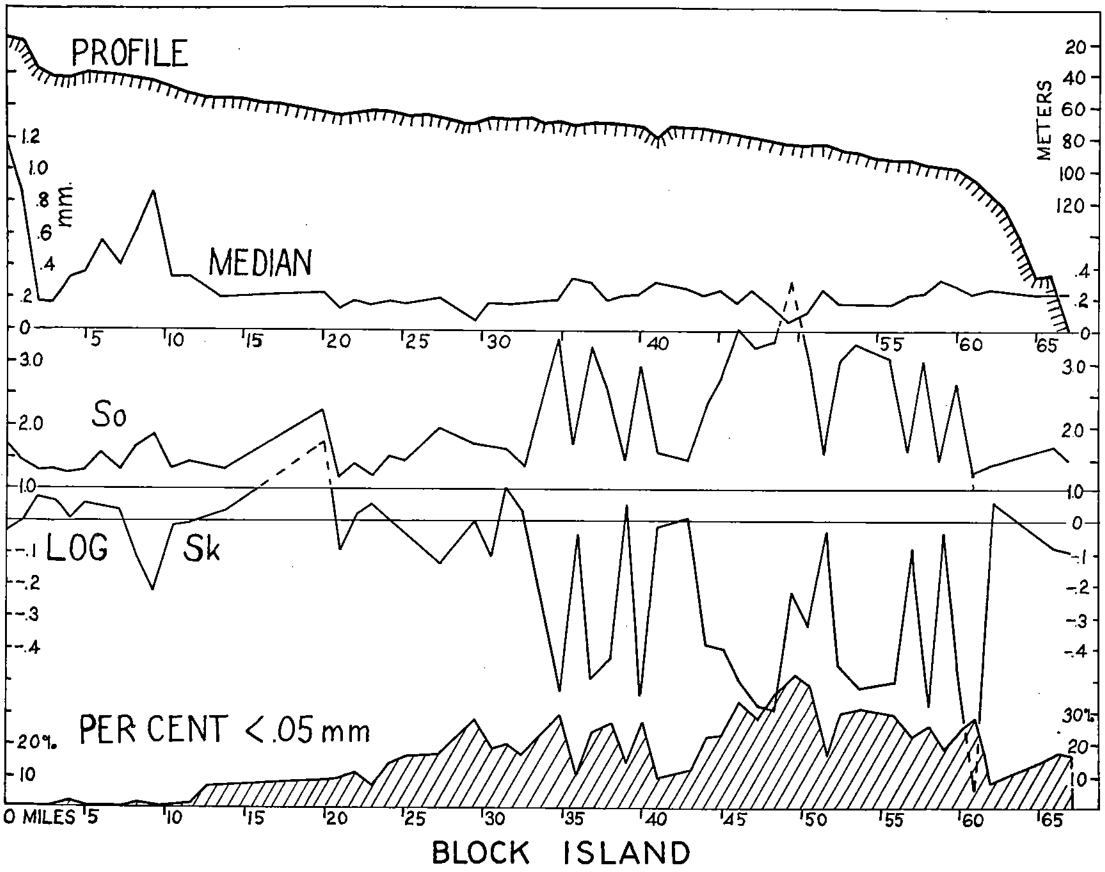

FIG. 9.—Series 7, see Fig. 1.