United States Department of the Interior

Geological Survey

Sediment Parameters for a Fine-grained Sediment Deposit on the Southeastern New England Continental Shelf

By Richard R. Rendigs, Michael H. Bothner, and Lawrence J. Poppe

Open-File Report 81- 1334

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

1981

TABLE OF CONTENTS

Sediment Parameters for a Fine-grained Sediment Deposit on the Southeastern New England Continental Shelf

Richard R. Rendigs, Michael H. Bothner, and Lawrence J. Poppe

ABSTRACT

An area of fine-grained sediments south of Martha's Vineyard, Massachusetts, has been interpreted as a contemporary deposit. Textural analysis of cores from this area indicates that the deposit consists of sandy to clayey silts overlying a well sorted relict sand. The maximum thickness of the fine sediments is about 6 meters as determined from a core near the center of this deposit.

The mineralogy of the <2 um size fraction is similar in both the fine sediments of the contemporary deposit and the underlying coarse sands. The assemblage consists of about 60% illite, 20% chlorite, and 10% kaolinite with minor amounts of mixed-layered clay and smectites.

Heavy mineral analysis from a core near the center of the deposit reveals that opaque minerals, framboidal pyrite, muscovite, hornblende, garnet, and tourmaline constitute over 65% of the total downcore assemblage.

Pyrite concentrations vary widely at some intervals and may reflect areas of micro-reducing conditions within the core or changes in source area with time. A persistent mica content indicates the presence of a low-energy environment throughout the depositional history of these fine sediments.

Downcore organic carbon concentrations are generally uniform in the fine sediments and average about 1.5 percent. Surficial concentration from a core near the center of this feature is about 10 times greater

than concentrations for coarse-grained sands on the surrounding shelf.

INTRODUCTION

An area of fine-grained sediments covers approximately 13,000 km^2 of the Continental Shelf south of Martha's Vineyard (Figure 1) in water depths of 40-200 m. This area is anomalous because at comparable water depths, the surrounding shelf sediments are primarily relict sands with only small amounts of silt. This deposit is the largest accumulation of fine-grained sediments on the Continental Shelf off the eastern United States exclusive of the Gulf of Maine.

There has been a conflict concerning the origin of this fine-grained deposit. Some investigators have interpreted it as relict, having been deposited in a relatively short time after sea level transgressed this part of the Continental Shelf about 10,000 years ago (Shepard and Cohee, 1936; Uchupi, 1963; Garrison and MacMaster, 1966; Schlee, 1973) while others have regarded it as an active area of sediment accumulation (Stetson, 1938; Emery and Uchupi, 1972; Bothner et al., 1981; Twichell et al., 1981). Recent lead-210 and carbon-14 data suggest that this area is an active sink for fine grained sediments with sedimentation rates of 25 cm/1000 years in the center of the deposit and about 50 cm/1000 years at the eastern end (Bothner et al., 1981).

The fine sediments accumulating in this deposit are thought to be winnowed from Georges Bank and Nantucket Shoals by strong tidal and storm currents and transported with the net southwesterly drift (Figure 2, Bumpus, 1976; Bothner et al., 1981; Twichell et al., 1981). Deposition appears to be favored in this area because both the tidal currents and the velocity of the southwesterly mean flow are much lower than areas to the northeast.

The purpose of this report is to describe the sediment texture, clay mineralogy, organic carbon content and heavy mineral composition of core samples recovered from this deposit. Data on the composition and nature of the surficial and subsurface sediments is important in evaluating how the depositional environment has changed with time. In addition, characterization of the sediments is important as this area is an apparent sink for fine-grained sediments and consequently also for any pollutants which may be generated by offshore resource development on Georges Bank.

METHODS

Sampling

Sediment cores available for this study (Figure 1) were collected with a variety of equipment. Two cores (4507V and 4508V) in the eastern portion of the mud patch were collected with a vibracoring apparatus which gave a maximum core recovery of almost 6 m. A hydraulically damped gravity corer (HDC) (Pamatmat, 1971) which collected cores up to 70 cm. in length was used to collect five cores (4507HDC, 4508HDC, 4712HDC, 4714HDC, and 4527HDC). It has a hydraulically slowed rate of penetration which minimizes disturbance of the surficial sediment. Cores up to 6 m in length (4711P, 4715P, 4720P and 4722P) were collected with a conventional piston corer. Cores MP1 and MP2 were collected with a conventional gravity coring device.

Vibracore and piston core samples were collected in plastic core liners (6.7 cm ID); at sea they were cut into sections of about 150 cm in length and stored at about 5° centigrade until they could be analyzed. Upon analysis the cores were later split, described, photographed and subsampled for sediment texture, clay mineralogy, organic carbon and heavy mineral analysis. Hydraulically damped gravity cores were frozen immediately after collection. They were later extruded from the fiberglass core barrels, allowed to thaw, and subsampled for textural and carbon analyses.

The two gravity cores (MP1 and MP2) were analyzed for Eh and ph immediately after recovery using an Orion 407A specific ion meter by inserting appropriate electrodes into the sediment through pre-drilled ports in the plastic core liners.

Textural Analysis

The gravel, sand, and finer material were separated by standard sieving techniques. The sand-size fraction was analyzed by a rapid sediment analyzer (Schlee, 1966). The silt and clay fractions were analyzed with a Coulter counter.

Clay Mineralogy

A subsample of clay sized material was separated with a centrifuge and suction filtered onto a silver filter (Hathaway, unpublished data). Filters were Xrayed on a Philips diffractometer with Cu K-alpha radiation after exposure to ethylene glycol, and again after heating to 400°C and 500°C. The relative percentages of clay minerals were determined semiquantitatively using procedures similar to those of Biscayne (1965).

Organic Carbon Determination

Organic carbon values were determined on sediments that were dried, ground, and leached with 2N HCl overnight at room temperature. The sediment residue was then filtered onto a pre-ashed glass fiber filter, rinsed, dried and analyzed with a Leco induction furnace.

Heavy-Mineral Analyses

Ten samples from core 4711, near the center of this feature (Figure 1), were analyzed for heavy minerals by conventional heavy-liquid techniques (Carver, 1971). Bromoform (specific gravity 2.85) was used to separate the heavy minerals from the 62.5-125 micron (very fine sand) size fraction. The conventional range of 125-250 micron (fine sand) was not used because of the lack of abundance of this size fraction throughout the core.

The heavy-mineral fraction was coned and quartered and the grains were mounted loosely on glass slides. This method was chosen over the permanent mount method because it permitted individual grains to be examined and freely orientated under reflected and transmitted light, and also enabled selection of individual grains for analysis with Xrays or scanning electron microscopy. An average of about 500 mineral grains were identified from each sample using a binocular microscope.

Results and Discussions

Texture

The textural data from piston and vibracores indicates that the silty sediment found in all the cores is somewhat variable in uniformity and thickness (Figure 3, Table 1). The maximum thickness recorded was almost 6 m from core 4722P near the center of this feature, although seismic data suggests that there are pockets of the fine sediment which may be as much as 13 m thick in the eastern part of this feature (Twichell et al., 1981). Underlying the fine sediment is a coarse to medium relict sand.

The major size-class of cores 4507V and 4508V, from the eastern end of the fine grained feature, is a uniform silty sand. The silty sands display a light green to olive gray coloration, 5Y4/2, (Munsell Soil Color Chart), and visually display no obvious bedding or grading; scattered shell hash is found throughout both cores. A clean, well-sorted subarkosic to arkosic medium grained sand (5Y6/1) about 50 cm in thickness constitutes the basal portion of core 4507V (Figure 3; Table 1).

The longest core, 4722P, penetrated to almost 6 m within the sediment and is composed primarily of a uniform medium-fine grained silt (5Y4/2). Distinct horizontal laminae (0.3-1.0 cm thick) of primarily coarse silts and very fine sands were evident at the 100, 150, 250, and 350 cm intervals within the core. Scattered shell hash was found at various intervals and the core did not penetrate to the underlying sands. Seismic records indicate that the silt may be 12 m thick at this site (Twichell et al., 1981).

Cores recovered near the center of this fine grained feature, 4711P and 4720P, were about 5 m and 3 m in length, respectively. 4711P is a uniform silt (5Y4/1) to about 330 cm below which a distinct lithologic transition occurs (Figure 3, Table 1). Coarse silts grade to fine sands which in turn grade to coarse sands near the base of the core. These underlying basal sands (5Y7/1) are subarkosic to arkosic, well sorted, and are angular to subrounded.

Core 4720P is composed of a uniform medium-silt (5Y4/1) to a depth of about 20 cm (Figure 3, Table 1). Again, the size class decreases to medium sands down to a depth of about 270 cm. where a major component of gravel (in the form of shell hash) occurs. From 280-300 cm there is very coarse shell hash within a matrix of medium-coarse sands.

Core 4715P is about 175 cm in length and is more variable in overall texture (Table 1). Uniform silty-sands (5Y4/1) are found to a depth of about 50 cm; below this beds of sandy silts alternating with sandy-silty-clays are the major textural component to a depth of about 140 cm. Within this 90 centimeter interval, sand lenses are found from 80-110 cm, and a wood fragment (0.5-1 cm in diameter) is present at about the 112 cm interval. A lithologic break occurs below 140 cm where the sandy-silty-clays grade to medium sands (5Y5/3) which in turn grade to coarse arkosic sands at the 170-175 cm interval.

Core 4527V is slightly over 5.5 m in length; the core is a uniform silty sand (5Y4/2) with no obvious bedding or grading. Shell hash is randomly distributed throughout the core and a horizontal black mottled organic band, 0.5 cm thick, is found at the 45 cm interval. This is presumably due to accumulated organic matter.

The cores from the eastern end of this feature (4507V and 4508V) are coarser textured than the piston cores near the center of the deposit. This may result from incomplete sediment sorting during transport from sediment source areas northeast of this feature or stronger tidal currents at this end of the deposit which do not allow the fines to settle out.

The uniform texture of the silty portions of the cores from the center of the fine-grained deposit implies a less energetic environment and a relatively unchanged depositional history with time. Thin laminae of slightly coarser grained material in core 4722P may reflect resuspension and transport of slightly coarser grained sediments from the eastern portion of the deposit by storms and storm generated currents.

The core from the western end of the deposit (4715P) appears to reflect a more varied depositional history. Varying texture, wood fragments, and alternating lenses of sand and mud imply a less stable depositional environment throughout time. This area may be more readily influenced by resuspension of sediments from storms and stronger tidal flows.

Underlying the silty deposit are Holocene basal sands which are continuous with the Long Island shelf surface to the west (Twichell et al., 1981). Three cores 4507V, 4711P, and 4720P penetrate into these underlying sands (Figure 3, Table 1). Within these cores there is an upward decline in grain size of the sands reflecting decreasing current regimes and less energetic depositional environments over time. Carbon-14 dates show that the oldest fine-grained sediments directly overlying the sand (4711P) are about 8600 years old (Bothner et al., 1981). Samples of the sand collected from the adjacent Long Island shelf were dated at about 11,000 years old.

As sea level transgressed this part of the shelf, a hydraulically less energetic environment conducive for the deposition of finer grain sizes was established; this is reflected in the progressive upward decline of grain size of the underlying Holocene sands, and the subsequent deposition of the overlying finer grained silts.

Except for those cores that penetrate into the basal sands, downcore textural variability is quite uniform. The textural uniformity of the surface silts is reflected with depth implying that the current regime and depositional history has not markedly changed during the period of fine-grained deposition.

Clay Mineralogy

The semiquantitative results of the <2 u size fraction from selected cores shows that illite is the major clay mineral and that the concentration of illite is uniform in all the cores ($59 \pm 6\%$, Table 2). Chlorite and kaolinite average about 20% and 10%, respectively, with smaller amounts of mixed-layered clays and smectites comprising the remainder of the assemblage. There is little fluctuation of the clay minerals with depth even through the textural transition from silts to clean sands in cores 4507V, 4711P, and 4720P (Figure 4).

The relative concentration of clay minerals is very similar to those reported by Hathaway (1972) and Bothner et al., (1979) for the Atlantic Continental Margin area.

The uniformity within the clay mineral assemblage suggests the same source material for a wide area of the Continental Shelf. The source material is thought to be unweathered Paleozoic and older rocks transported from northern Appalachian regions to the Continental Shelf during glacial times (Hathaway, 1972).

Organic Carbon

The concentration of organic carbon for surface sediments near the center of this fine-grained feature (4712 HDC) is 2.03% (Table 1), this is about 10 times higher than surrounding coarse-grained shelf sediments adjacent to this deposit. Slight decreases in organic carbon content with depth from the cores may reflect an increase of carbon to these surface sediments. This may result from an increase in primary production due to higher nutrient fluxes from surrounding areas or an apparent increase due to a diagenetic loss of organic carbon with depth due to biological influences within the sediment.

As is commonly found, the organic carbon concentration is inversely related to the sediment size (Froelich et al., 1971). This is evident in core 4711P where concentrations range from 1.50% near the surface in silty sediments to less than 0.20% in the basal sands (Figure 5). High organic carbon values are associated with the finest grain size sediments due to the large surface area of fine-grained sediments available for adsorption and because organic material is typically fine grained.

Organic carbon concentrations of near surface sediments from selected cores from the Georges Bank and Nantucket Shoals areas average about 0.08% (Bothner et al., 1979). Fine-grained sediments and the associated organic carbon are resuspended by storms and winnowed from these areas and transported in a southwesterly direction to the fine-grained deposit. As only about 1 percent of the present-day carbon production in the fine grained area is attributed to primary production from the overlying water column (Bothner et al., 1981), additional concentrations of carbon appear to be supplemented from source areas northeast of this deposit.

Thus, the fine-grained feature appears to be a sink for fine-grained sediments and organic carbon with a common source area from Nantucket Shoals and Georges Bank.

Heavy Minerals

Six minerals constitute more than 65% of the total heavy-mineral assemblage from core 4711P (Table 3). These minerals are opaques, framboidal pyrite, muscovite, hornblende, garnet and tourmaline. In each of the ten intervals sampled in this core (Figure 6), opaques, hornblende, tourmaline, garnet, zircon and epidote occurred.

The mean and standard deviations were calculated from the heavy-mineral percentages within the core in order to determine a dominant heavy-mineral association (Table 3). The standard deviations about the mean indicate the variability within the mineral assemblage. Based on the dominance of a particular mineral (% occurrence), the mean %, and the comparatively low variability about the mean, the opaque, hornblende, garnet, tourmaline and staurolite assemblage is dominant throughout the core. This assemblage along with the moderate occurrence of muscovite and pyrite, is analagous to the mixed opaque-amphibole association described for surficial sediments for this area by MacMaster and Garrison (1966). Ross' (1970) analysis of heavy minerals from grab samples places the deposit primarily in the mixed amphibole-garnet province based on the following assemblage (in decreasing concentration): opaques, amphiboles, garnet, altered minerals and epidote. Piston cores from the Continental Slope east of the mud patch in water depths of 200-2000 m indicate an assemblage similar to core 4711P although the authigenic mineral pyrite found both in globular masses and in tests, occurs more frequently than on the shelf (Doyle et al., 1979, Woo et al., 1981).

Under winnowing, the heavy minerals can be hydraulically classified into "heavy heavies" (density 4.0 or greater) and "light heavies", density 3-4, (Woo et al., 1981). The "heavy heavies"-opaques, garnet, zircon, and rutile-are concentrated in the underlying basal sands; in this case below 330 cm where the lithologic break from silts to sands occurs (Figure 7).

The "light heavies"-muscovite, hornblende, tourmaline and staurolite-display a more uniform distribution throughout the entire length of the core and tend to be slightly more concentrated in the underlying sands; however, muscovite, which has a similar hydraulic equivalence to silts and clays, is concentrated in the fine-grained sediments. The shape factor of a mineral, availability of a particular mineral within various grain sizes, and the nature of the depositing medium are additional factors to account for the relatively uniform distribution of the light heavies throughout the silts and underlying sands.

Pyrite (density 5.01) is concentrated in the fine-grained sediments and occurs only in trace concentrations in the underlying sands. Pyrite under winnowing would be transported and deposited with fine-medium grain sands of similar hydraulic equivalence. However, pyrite is not concentrated in the sands and appears to be formed in-situ within the overlying fine-grained sediments. Pyrite is an authigenic mineral in marine sediments and forms under a limited oxygen supply in the presence of organic matter during bacterial reduction of sulfate to sulfide. Within the core, pyrite occurs predominately in the spheroidal "raspberry like" framboidal form and averages about 16% of the total heavy-mineral occurrence (Table 3). However, samples at 120, 210, 255, and 300 cm average slightly more than 25, 45, 67 and 50% respectively (Figure 8). A minor concentration (0.5%) of an elongated angular form of pyrite was also evident. This may be of detrital origin as it persists in the coarser grain sizes.

Framboidal pyrite is an aggregate of pyrite crystals built up from a single nucleus such as foraminifera or radiolarian test or a small single pyrite crystal of approximately uniform dimensions.

The framboidal form is apparently a result of a physiochemical process involving abundant sulfate (from dissolved sea-water), iron-bearing minerals (hematite, limonite, magnetite, etc.) and organic matter in sufficent concentrations, in the presence of sulfate reducing bacteria, to produce the framboidal form (Berner, 1969; Berner et al., 1979). The large framboidal pyrite concentrations may reflect areas of micro-reducing conditions within the core (Figure 8). Organic carbon concentrations were probably higher in the past, however, sufficient concentrations are still present to favor further pyrite genesis.

Reducing conditions were confirmed below 50 cm from the two gravity cores MP1 and MP2 (Eh =- 300 and -230 Mv, respectively), located to the east of 4711P (Figure 9). The Eh-Ph measurements conform to a "euxinic" marine environment (oxygen poor) and provide conditions favorable for pyrite genesis (Garrels, 1960).

Mica concentration (muscovite, biotite, and phlogopite) is persistent throughout the core and averages less than 10% of the total heavy-mineral occurrence. However, at an interval between 0-200 cm, muscovite averages slightly over 30% (Figure 10). This pronounced increase may be somewhat artifical as muscovite tends to flake along its basal cleavage more readily than other micas (Woo et al., 1981) producing an apparent increased concentration; muscovite´s density (2.8-2.9) borders that of the heavy liquid (2.85) and incomplete or irregular separations may occur producing an apparent increase in concentration.

As mica and fine-grained sediments have similar hydraulic equivalences, they tend to occur in similar depositional environments (Milliman et al., 1972). Most of the Continental Shelf sediments are essentially devoid of mica except in estuaries, portions of the Gulf of Maine, and areas beyond the shelf break. This suggests that areas absent of mica and fine-grained sediments may indicate winnowing processes and its relative intensity (Doyle et al., 1968). Conversely, areas with a significant fine fraction (silt plus clay 30%) and a persistent mica concentration may indicate areas that are sinks for fine-grained sediments.

The light-mineral fraction consists of quartz, feldspars and micas along with minor concentrations of biogenous material consisting of wood fragments, shells, and unidentifiable organic matter. Quartz makes up about 75% of the total fraction; most is arkosic to subarkosic, subangular to subrounded, and clear to translucent in coloration although about 5-10% is iron stained. Micas (predominately muscovite) and feldspars constitute the remaining fraction with shell hash, glauconite, and organic matter in globular form present in the trace amounts.

Summary

1) Size analysis of cores collected from an area of fine-grained sediment accumulation south of Martha's Vineyard indicates that the predominate textural component is silt with minor amounts of fine sand and clay. Vibracores from the eastern end (4507V, 4508V) are slightly coarser in overall texture (contain more fine sand) than are cores from the middle of this feature. This is probably due to somewhat higher current velocities in the eastern part which do not allow the fines to settle out. A core from the western end of this feature (4715P) is variable in texture probably reflecting varying current regimes and storm influenced sediment transport over time.

The thickness of the fine sediment from piston cores varies from about 0.7 m (core 4720P) to almost 6 m (core 4722P) near the center of this feature. High resolution seismic-reflection profiles have established that the maximum thickness of fine sediment is about 13 m and is found in the central and eastern portion of the fine-grained feature (Twichell et al., 1981).

Overall, the downcore textural variability within the lens of fine sediment is small, which suggests that little change has taken place in the current regime since sea level transgressed this part of the Continental Shelf about 10,000 years ago.

The fine sediments are underlain by well-sorted coarse to medium grained arkosic to subarkosic sands which are exposed on adjacent areas of the Continental Shelf and are identified as the Holocene transgressive sand sheet (Twichell et al., 1981).

2) The clay mineralogy of the less than 2 u size fraction from piston cores and vibracores is essentially uniform throughout both the fine sediments and the underlying sands.

The major clay mineral is illite averaging about 60% throughout the cores. Kaolinite and chlorite are present in amounts ranging from 15-30% and 6-25%, respectively. Smectite and mixed-layered chlorite/smectites are found in trace concentrations.

The clay mineral assemblage is very similar to that observed in other areas of the Continental Shelf and Slope and implies a common primary source. This source is thought to be Paleozoic rocks from northern Appalachian regions that were transported to the Continental Shelf and redistributed as sea level rose (Hathaway, 1972).

3) Organic carbon values in the cores range from 0.07% in the underlying clean basal sands to over 2.0% in samples containing over 95% silt plus clay. The common relationship between high concentrations of organic carbon and fine-grained sediments is clearly demonstrated in these sediments, and there appears to be no consistent downcore decrease of organic carbon independent of textural changes.

The relatively high organic carbon concentrations in the fine-grained surficial sediments from the center of this feature is about 10 times higher than surrounding coarser shelf sediments. This suggests that this feature is a sink for organic carbon.

4) The distribution and occurrence of heavy minerals throughout core 4711 revealed six heavy minerals constituting about 65% of the total assemblage. These are: opaques, framboidal pyrite, muscovite, hornblende, garnet and tourmaline. This assemblage is similar to the

"opaque-amphibole association" described for surface sediments for this area by McMaster and Garrison (1966).

The heavy minerals can be classified according to their hydraulic equivalence and their sorting in response to winnowing and transport. The denser heavy minerals (density 4.0 or greater)-opaques, garnet, rutile, and zircon, tend to be concentrated with the coarser underlying basal sands. However, the light heavies, hornblende, muscovite, tourmaline and staurolite, (density 3.0-4.0), which were expected to concentrate in the finer size fractions, demonstrate a fairly uniform distribution throughout the sands and overlying silts; this distribution may be affected by the shape factor and availability of the particular minerals. Pyrite (density 5.01) is also concentrated in the overlying silts and clays and appears to have formed in situ.

Pyrite is a common authigenic mineral of marine sediments and is present primarily in the spherical framboidal form in concentrations averaging about 16% of the total heavy mineral assemblage. Concentrations of greater than 25% were found at 120, 210, 255, and 300 cm.

Reducing conditions were confirmed from on board measurements of Eh and pH from gravity cores east of this site. Pyrite is apparently synthesized and is stable in both mildly reducing and oxidizing sediments within this fine-grained feature.

Mica distribution throughout the core is fairly uniform averaging less than 10%. The hydraulic equivalence of micas and fine-grained sediments is similar and they both tend to occur in similar depositional environments.

REFERENCES

Berner, R. A., 1969, The synthesis of framboidal pyrite: Economic Geology, v. 64, p. 383-384.

Berner, R. A., Baldwin, T., Holden, G. R., Jr., 1979, Authigenic iron sulfides as paleosalinity indicators: Journal of Sedimentary Petrology, v. 49, no. 4, p. 1345-1350.

Biscayne, P. E., 1965, Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and the adjacent seas and oceans: Geological Society of America Bulletin, v. 76, p. 803-832.

Bothner, M. H., Spiker, E. C., Ferrebee, W. M., and Peeler, D. L., 1979, Texture, clay mineralogy, trace metals and age of cored sediments from the North Atlantic Continental Shelf: U.S. Geological Survey Open-File Report 79-842, 41 p.

Bothner, M. H., Spiker, E.C., Johnson, P. P., Rendigs, R. R., and Aruscavage, P. J., 1981, Geochemical evidence for modern sediment accumulation on the continental shelf off southern New England: Journal of Sedimentary Petrology, v. 51, p. 281-292.

Bumpus, D. F., 1976, Review of the physical oceanography of Georges Banks: International Commission Northwest Atlantic Fisheries Research Bulletin, no. 12, p. 119-134.

Carver, R. E., 1971, Procedures in sedimentary petrology: New York, Wiley - Interscience, 653 p.

Doyle, L. J., Cleary, W. J., and Pilkey, O. H., 1968, Mica: its use in determining shelf depositional regimes: Marine Geology, v. 6, p. 318-389.

Doyle, L. J., Pilkey, O. H., Woo, C. C., 1979, Sedimentation on the Eastern United States Continental Slope, in Larry J. Doyle and Orrin H. Pilkey, eds., Geology of Continental Slopes, Society of

Economic Paleontologists and Mineralogists, Special Publication no. 27, p. 119-129.

Emery, K. O., and Uchupi, E., 1972, Western North Atlantic Ocean: topography, rocks, structure, water, life, and sediments: American Association Petroleum Geologists, Memoir 17, 532 p.

Froelich, P., Golden, B., and Pilkey, O. H., 1971, Organic Carbon of the North Carolina Continental Rise: Southeastern Geology, v. 13, p. 91-97.

Garrels, R. M., 1960, Mineral equilibra at low temperature and pressure: New York, Harper and Brothers, 254 p.

Garrison, L. E., and McMaster, R. L., 1966, Sediments and geomorphology of the Continental Shelf off southern New England: Marine Geology, v. 4, p. 273-289.

Hathaway, J. C., 1972, Regional clay mineral facies in estuaries and continental margin of the United States East Coast: Geological Society of America Memoir 133, p. 293-316.

McMaster, R. L., and Garrison, L. E., 1966, Mineralogy and origin of southern New England Shelf Sediments: Journal of Sedimentary Petrology, v. 36, p. 1131-1142.

Milliman, J. D., Pilkey, O. H., Ross, D. A., 1972, Sediments of the Continental Margin off the Eastern United States: Geological Society of America Bulletin, v. 83, p. 1315-1334.

Pamatmat, M. M., 1971, Oxygen consumption by the sea bed-IV. Shipboard and laboratory experiments: Limnology and Oceanography, 16, p. 536-550.

Ross, D. A., 1970, Atlantic Continental Shelf and Slope of the United States: Heavy minerals of the continental margin from southern Nova Scotia to northern to New Jersey: U.S. Geological Survey

Professional Paper, 529-b, 40 p.

Schlee, J., 1973, Atlantic Continental Shelf and Slope of the Eastern United States: Sediment texture of the northeast part: U.S. Geological Survey Professional Paper, 529-L, 64 p.

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

Shepard, F. P., and Cohee, U. V., 1936, Continental Shelf sediments off the Mid-Atlantic states: Geological Society of America Bulletin, v. 47, p. 441-458.

Stetson, H. C., 1938, The sediments of the Continental Shelf off the eastern coast of the United States: Massachusetts Institute of Technology and Woods Hole Oceanographic Institute, Papers Physical Oceanography and Meterology, v. 5, no. 4, 48 p.

Twichell, D. C., McClennen, C. E., and Butman, B., 1981, Morphology and processes associated with the accumulation of the fine-grained sediment deposit on the southern New England shelf: Journal of Sedimentary Petrology, v. 51, p. 269-280.

Uchupi, E., 1963, Sediments on the Continental Margin off eastern United States, in Geological Survey research 1963: U.S. Geological Survey Professional Paper, 475-C, p. C132-C137.

Woo, C.C., Doyle, L.H., and Pilkey, O.H., 1981, Heavy minerals in Continental slope sediments of the eastern United States: Journal of Sedimentary Petrology, in press.

Figure Captions

1. Sample locations and areal extend of the area of fine-grain sediment accumulation south of Martha's Vineyard, Massachusetts. Dotted contours show bathymetry; the solid contours show the percentage of surficial silt plus clay.
2. Mean tidal currents from Georges Bank and Nantucket Shoals along the New England Continental Shelf to the fine-grained deposit.
3. Length and lithology of piston cores and vibracores from the area of fine-grained sediment accumulation on the southern New England Shelf.
4. Downcore distribution of the major clay minerals (<2 u) from selected cores from the area of fine-grained sediments south of Martha's Vineyard, Massachusetts.
5. Organic carbon concentration (%) vs. percent sand from core 4711P. Downcore values decrease as sediments become coarser. Sloping line is a linear regression with a correlation coefficient of 0.987.
6. Heavy mineral occurrence with depth from core 4711P near the center of the fine-grained deposit. The asterisk (*) indicates the lithologic transition from silts to sands. An additional interval at 210 cm. (45% occurrence) was examined for framboidal pyrite.
7. Selected heavy mineral occurence (%) of the heavy heavies (density 4.0 or greater) and the light heavies (density 3.0-4.0) from core 4711P. The asterisk (*) indicates the lithologic break from silts to sands. An additional interval for framboidal pyrite was examined at 210 cm with a 45% occurrence.
8. Distribution of framboidal pyrite and organic carbon throughout core 4711P near the center of the fine-grained deposit.

9. Eh-pH profiles from gravity cores MP1 and MP2. Reducing conditions were encountered below 50 cm with Eh values of - 300 mv and -230 mv, respectively, and the characteristic "rotten egg-like" smell of the sediments.

10. Downcore distribution and concentration (%) of micaceous minerals from core 4711P. The transition from silts to underlying basal sand occurs at about 330 cm.

Table 1 Sediment characteristics of cores from the fine-grained deposit south of Martha's Vineyard, Massachusetts

Station/ Water Depth (M)	Latitude/ Longitude	Sample Depth (cm) within core	% Gravel	% Sand	% Silt	% Clay	% Organic Carbon
4507-V	40°11.3'N	10	0.0	51.2	39.4	9.4	0.58
91	69°47.2'W	28	0.0	54.8	37.9	7.3	0.64
		100	0.0	50.5	38.2	11.3	0.69
		180	0.0	35.6	50.7	13.7	0.75
		255	0.0	35.6	55.9	8.5	0.66
		308	0.1	37.2	51.2	11.6	0.66
		376	0.1	95.8	2.0	2.1	0.24
		383	1.1	97.7	0.9	0.3	0.07
4508-V	40°21.9'N	9	0.0	52.1	31.9	16.0	0.74
82	70°03.5'W	10	0.0	60.0	31.0	9.0	0.65
		32	0.0	59.7	35.3	5.0	0.95
		70	0.0	54.1	40.0	5.9	
		100	0.0	50.2	35.6	14.2	0.73
		110	0.0	41.6	36.5	21.9	0.80
		184	0.0	33.4	49.4	17.2	0.94
		253	0.0	32.4	51.0	16.6	1.01
		271	0.0	27.3	54.7	18.0	0.94
		296	0.0	63.8	29.8	6.9	0.59

Table 1 (cont.) -- Sediment characteristics of cores

from the fine-grained deposit south of Martha´s Vineyard, Massachusetts

		368	0.0	27.2	62.3	14.5	0.93
		428	0.0	51.5	37.3	11.2	
4527-V	40°52.2´N	75	2.8	66.3	20.3	10.6	
53	70°33.1´W	230	0.1	76.7	10.9	12.5	
		385	0.2	75.3	13.1	11.5	
		560	0.0	68.1	18.7	13.3	
4711-P	40°30.0´W	10-20	0.0	2.7	83.7	13.6	1.50
81	71.000´W	50-60	0.0	5.4	75.8	18.8	1.45
		75-85	0.0	1.8	84.7	13.5	1.63
		100-110	0.0	2.2	84.1	13.7	1.43
		120-130	0.0	1.9	68.3	29.8	1.45
		255-265	0.0	1.6	81.5	16.9	1.40
		300-310	0.0	4.2	82.4	13.4	1.41
		330-340	0.0	21.6	66.7	11.7	1.26
		370-390	0.0	72.8	22.8	4.2	0.45
		410-420	0.0	78.2	17.7	4.1	0.33
		420-430	0.0	98.5	1.1	0.4	0.11
		470-480	0.0	98.9	0.9	0.2	0.18
4715-P	40°21.4´N	7-17	0.0	0.1	64.7	35.2	1.60
83	71°30.6´W	26-36	0.3	57.1	33.7	8.9	0.45
		40-50	9.9	56.1	25.3	8.7	0.54
		60-70	0.0	35.4	43.3	21.3	0.76
		79-89	0.4	37.9	46.3	15.4	0.68

Table 1 (cont.)--Sediment characteristics of cores from the fine-grained deposit south of Martha's Vineyard, Massachusetts

		112-122	0.0	34.6	40.6	24.8	0.47
		142-152	0.0	93.4	4.5	2.1	0.19
4720-P	40°16.3´N	10-20	0.0	1.2	86.9	11.9	1.43
120							
	70°58.0´W	20-30	0.0	49.3	44.2	6.5	0.71
		70-80	0.0	97.0	2.4	0.6	0.13
		160-170	5.0	93.1	1.6	0.3	0.13
		270-280	16.4	81.7	1.2	0.7	0.12
4722-P	40°27.6´N	0-10					1.23
80	70°32.7´W	10-20	0.0	17.7	72.4	0.0	
		50-60					1.20
		90-100	0.0	2.0	85.7	12.3	
		100-110					1.28
		143-153	0.0	1.0	84.7	14.3	
		150-160					1.11
		195-205	0.0	8.7	80.1	11.2	
		200-210					1.21
		253-263	0.0	11.0	79.4	9.6	
		300-310					1.28
		350-360					1.31
		371-381	0.0	14.0	60.5	25.5	
		400-410					1.31
		426-436	0.0	17.5	69.4	13.1	
		450-460					1.04
		469-479	0.0	12.2	68.7	19.1	
		500-510					1.10
		529-539	0.0	7.2	81.3	11.5	

Table 1 (cont.)--Sediment characteristics of cores from the fine-grained deposit south of Martha's Vineyard, Massachusetts

		550-560					1.06
		568-578	0.0	8.5	77.3	14.2	
		582-592					1.14
4507 HDC	40°11.3′N	0-1	0.0	75.7	21.6	2.7	0.50
91	69°47.2′W	4.5	0.0	77.0	19.9	3.1	0.53
		13.5	0.0	61.8	34.8	3.4	0.69
		18.0	0.0	69.5	27.3	3.2	
4508 HDC	40°22.0″N	0-0.5					0.82
82	70°03.6′W	1.5	0.0	65.2	30.8	4.0	
		3.0	0.0	68.4	27.6	4.0	
		4.5	0.0	63.6	33.0	3.4	0.78
		6.0	0.0	67.8	29.1	2.1	
		7.5	0.0	65.7	30.6	3.7	
		13.5	0.0	61.8	34.8	3.4	0.69
		18.0	0.0	69.6	27.3	3.1	
4712 HDC	40°30.01′N	0-2	0.0	3.2	81.5	14.3	2.03
81	71°00.0′W	4-6	0.0	4.9	82.7	12.4	1.97
		8-10	0.0	4.0	76.7	19.3	1.85
		12-14	0.0	4.7	72.5	22.8	1.84
		14-16	0.0	5.8	79.3	14.9	
		16-18	0.0	4.0	82.1	13.9	
		18-20	0.0	6.4	77.8	15.8	1.92
		20-22	0.0	4.2	82.1	13.7	
		22-24	0.0	4.9	75.4	19.7	
		24-26	0.0	3.6	79.6	16.8	1.79
		26-28	0.0	5.6	74.7	19.7	

Table 1 (cont.)--Sediment characteristics of cores from the fine-grained deposit south of Martha's Vineyard, Massachusetts

		28-30	0.0	7.0	68.3	24.7	1.72
		30-32	0.0	5.4	79.0	15.6	
		32-34	0.0	4.2	72.3	23.5	1.71
		40-42	0.0	4.0	78.5	17.5	1.76
		50-52	0.0	2.7	75.0	23.3	1.64
4714 HDC	40°21.4′N	0-2	0.0	31.6	60.9	7.5	1.28
83	71°30.5′W	4-6	0.6	44.4	50.0	5.0	1.22
		8-10	0.3	37.4	52.0	10.3	1.36
		10-12	0.0	44.8	46.8	8.4	
		12-14	0.0	42.7	47.4	9.9	
		14-16	0.1	40.2	52.2	7.5	1.19
		16-18	0.0	34.5	56.7	8.8	
		18-20	0.1	40.3	49.4	10.2	1.16
		20-22	0.7	38.1	48.2	13.0	
		22-24	0.0	43.6	50.3	6.1	
		24-26	0.2	43.5	45.8	10.5	1.01
		28-30	0.0	46.0	45.8	8.2	
		32-34					0.98
		34-36	0.0	47.5	46.0	6.5	
		40-42	0.8	38.8	51.1	9.3	1.27
		44-46	2.2	45.3	44.7	7.8	
		54-56	1.0	41.8	40.3	16.9	1.13

V - Vibracore

P - Piston core

HDC - Hydraulically damped core

Table 2. Results of clay mineral analysis of the 2u-size fraction of selected cores from the area of fine-grained sediment accumulation.

Station	Depth (cm)	% Illite	% Chlorite	% Kaolinite	% Mixed layer Illite/Smectite	% Smectite
4507-V	10	71	20	5	3	1
	28	68	21	4	5	2
	100	66	21	10	3	TR
	180	58	21	10	10	1
	255	72	20	5	2	1
	308	61	20	7	11	1
	376	62	23	8	5	2
	383	60	21	7	11	1
	X	64±5	21±1	7±2	6±4	1.3±.5
4508-V	10	67	19	8	6	TR
	36	61	23	11	5	TR
	110	68	21	4	7	TR
	184	65	22	8	5	TR
	253	61	18	8	13	1
	271	70	17	10	2	TR
	296	64	24	7	5	0
	428	61	-	*36	-	3
	X	64±4	20±2	8±2	6±6	1.3±1.5

*Denotes % for kaolinite and chlorite combined, as the 3.58 - 3.55 doublet could not be resolved in the X-ray pattern not included in ± calculation.

Station	Depth (cm)	% Illite	% Chlorite	% Kaolinite	% Mixed layer Illite/Smectite	% Smectite
4527 HDC	0-1	54	33	11	2	TR
	1-3	58	29	11	2	TR
	3-5	58	29	11	2	TR
	5-7	59	29	10	2	0
	9-11	64	23	11	2	0
	17-19	56	29	13	2	0
	21-23	60	23	14	3	0
	25-27	61	24	13	2	0
	29-31	64	20	13	3	0
	33-35	63	22	13	2	0
	37-39	64	22	12	2	0
	41-43	64	25	10	1	0
	*75	64	17	16	-	3
	*560	61	24	11	-	4
	$\bar{X}$	61±3	25±4	12±2	2±.6	0.6±1.4

*Sample from vibracore at same location.

Station	Depth (cm)	% Illite	% Chlorite	% Kaolinite	% Mixed layer Illite/Smectite	% Smectite
4711-P	10-20	65	12	19	4	0
	50-60	56	28	10	6	TR
	75-85	64	29	5	2	0
	100-110	65	29	5	1	TR
	120-130	60	18	19	3	0

Table 2 (Cont.)--Results of clay mineral analysis of the 2u-size fraction of selected cores from the area of fine-grained sediment accumulation.

Sation	Depth (cm)	% Illite	% Chlorite	% Kaolinite	% Mixed layer Illite/Smectite	% Smectite
	165-175	50	20	23	7	0
	255-265	60	15	18	7	TR
	300-310	60	19	18	3	TR
	330-340	54	12	24	10	0
	370-380	54	18	24	4	0
	410-420	60	12	21	6	1
	420-430	58	19	20	3	TR
	470-480	59	25	14	2	TR
	$\bar{X}$	59±4	20±6	17±7	4±3	-
4715-P	26-36	65	27	7	1	TR
	40-50	61	27	10	1	1
	60-70	62	27	9	1	1
	79-89	60	24	13	3	0
	112-122	63	26	8	3	TR
	142-152	68	20	10	2	TR
	$\bar{X}$	63±3	25±3	9±2	2±1	.6±.6
4720-P	10-20	63	18	16	3	0
	20-30	65	16	17	2	TR
	70-80	70	19	9	2	TR
	160-170	61	19	17	3	0
	270-280	64	13	18	5	TR
	$\bar{X}$	64±3	17±3	15±4	3±1	-
4722-P	10-20	55	20	25	TR	0
	90-100	47	22	22	9	0
	143-153	67	27	6	TR	0
	195-205	51	21	21	7	TR
	253-263	58	15	25	2	0
	371-381	65	19	11	5	0
	426-436	53	16	28	3	0
	469-479	55	19	21	5	0
	529-539	51	19	20	8	TR
	568-578	56	19	22	3	TR
	$\bar{X}$	56±6	20±3	20±7	5±3	-

TR - Trace
V - Vibracore
P - Piston Core
HDC - Hydraulically damped core

Table 3. Heavy-mineral assemblage from core 4711P near the center of the fine-grained feature. The assemblage is dominated by opaque minerals, hornblende, garnet, tourmaline, and staurolite.

Mineral	% occurrence in core	Mean (%) + standard distribution throughout core	Range throughout core - %
Opaque minerals	100	22.5 ± 18.4	5.3 - 58.3
Fram. Pyrite	80	16.6 ± 24.2	0.0 - 67.2
Muscovite	80	11.7 ± 15.6	0.0 - 42.8
Hornblende	100	5.9 ± 3.0	2.5 - 12.1
Garnet	100	5.7 ± 4.3	1.0 - 12.8
Tourmaline	100	3.5 ± 2.1	0.7 - 7.0
Staurolite	80	3.3 ± 2.7	0.0 - 6.1
Glauconite	80	3.3 ± 4.3	0.0 - 14.4
Pyroxene	90	3.2 ± 2.5	0.0 - 6.5
Zircon	100	3.0 ± 1.7	0.5 - 5.9
Leucoxene	90	2.0 ± 2.6	0.0 - 9.0
Epidote	100	1.8 ± 1.2	0.3 - 3.9
Biotite	80	1.2 ± 1.1	0.0 - 2.7
Phlogopite	60	1.1 ± 1.2	0.0 - 3.3
Rutile	80	0.6 ± 0.7	0.0 - 2.5
Monazite	30	0.5 ± 1.4	0.0 - 4.4
Sillmanite	70	0.4 ± 0.32	0.0 - 0.9
Pyrite	80	0.4 ± 0.3	0.0 - 1.0
Chlorite	30	0.1 ± 0.2	0.0 - 0.6
Shell Fragments	80	8.4 ± 9.1	0.0 - 22.0
Pyritized Foram Tests	80	5.2 ± 5.6	0.0 - 17.1

Fram. Pyrite - Framboidal

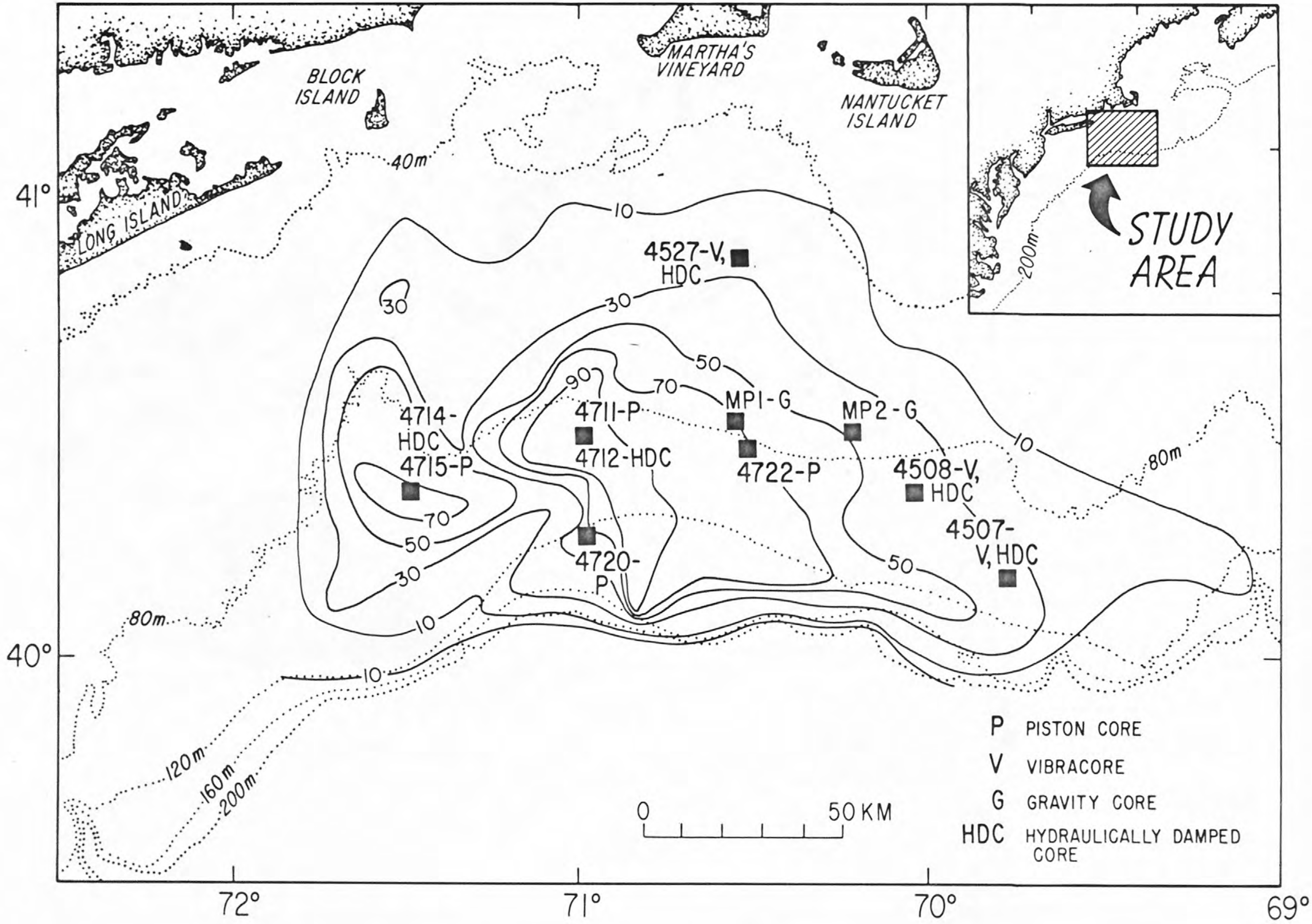

MARTHA'S VINEYARD
NANTUCKET ISLAND
BLOCK ISLAND
LONG ISLAND
STUDY AREA
200m
40m
80m
120m
160m
200m
10
30
50
70
90
4527-V, HDC
4714-HDC
4715-P
4711-P
4712-HDC
MP1-G
MP2-G
4722-P
4508-V, HDC
4507-V, HDC
4720-P
41°
40°
72°
71°
70°
69°
0
50 KM
P PISTON CORE
V VIBRACORE
G GRAVITY CORE
HDC HYDRAULICALLY DAMPED CORE

Figure 1

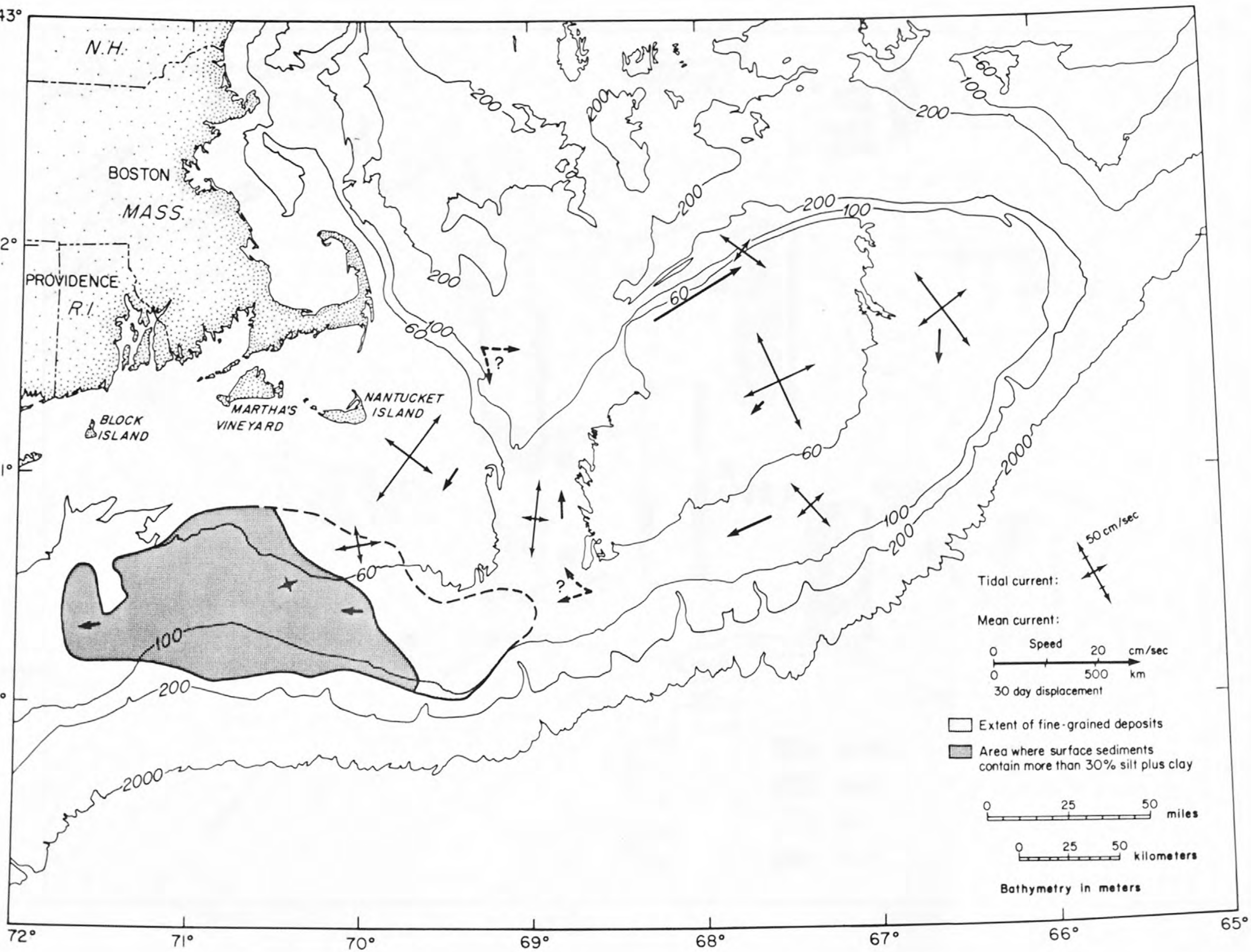

N.H.
BOSTON
MASS.
PROVIDENCE
R.I.
BLOCK ISLAND
MARTHA'S VINEYARD
NANTUCKET ISLAND
Tidal current:
50 cm/sec
Mean current:
Speed
0 20 cm/sec
0 500 km
30 day displacement
Extent of fine-grained deposits
Area where surface sediments contain more than 30% silt plus clay
0 25 50 miles
0 25 50 kilometers
Bathymetry in meters
43°
42°
41°
40°
72°
71°
70°
69°
68°
67°
66°
65°

Figure 2

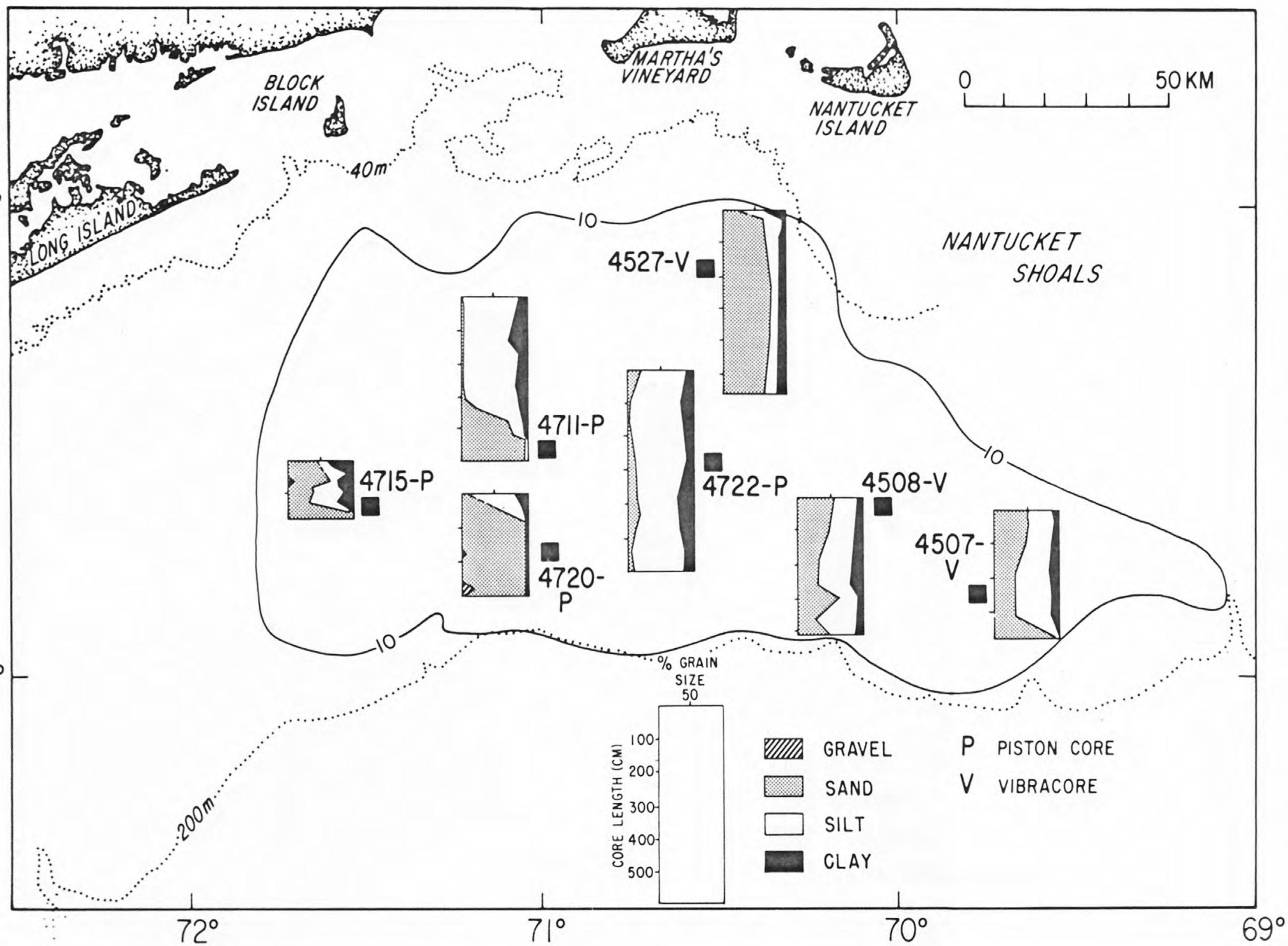
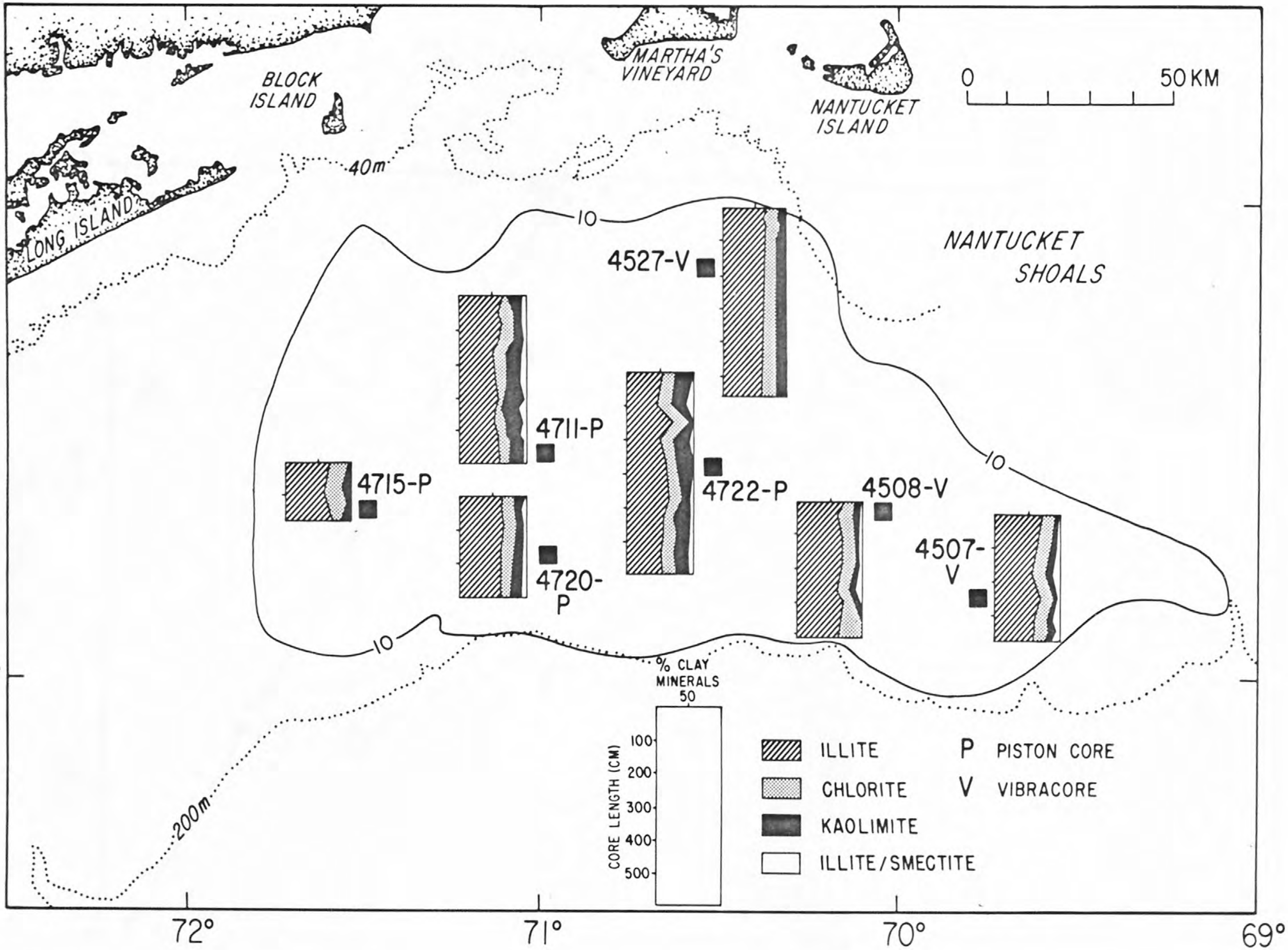

MARTHA'S VINEYARD
BLOCK ISLAND
NANTUCKET ISLAND
LONG ISLAND
NANTUCKET SHOALS
0
50 KM
40m
200m
10
41°
40°
72°
71°
70°
69°
4527-V
4711-P
4715-P
4722-P
4508-V
4507-V
4720-P
% GRAIN SIZE
50
CORE LENGTH (CM)
100
200
300
400
500
GRAVEL
SAND
SILT
CLAY
P PISTON CORE
V VIBRACORE

Figure 3



MARTHA'S VINEYARD
BLOCK ISLAND
NANTUCKET ISLAND
0
50 KM
40m
41°
LONG ISLAND
10
NANTUCKET SHOALS
4527-V
4711-P
4715-P
4722-P
4508-V
4507-V
4720-P
40°
% CLAY MINERALS
50
CORE LENGTH (CM)
100
200
300
400
500
ILLITE
CHLORITE
KAOLIMITE
ILLITE/SMECTITE
P PISTON CORE
V VIBRACORE
200m
72°
71°
70°
69°

Figure 4

Figure 5

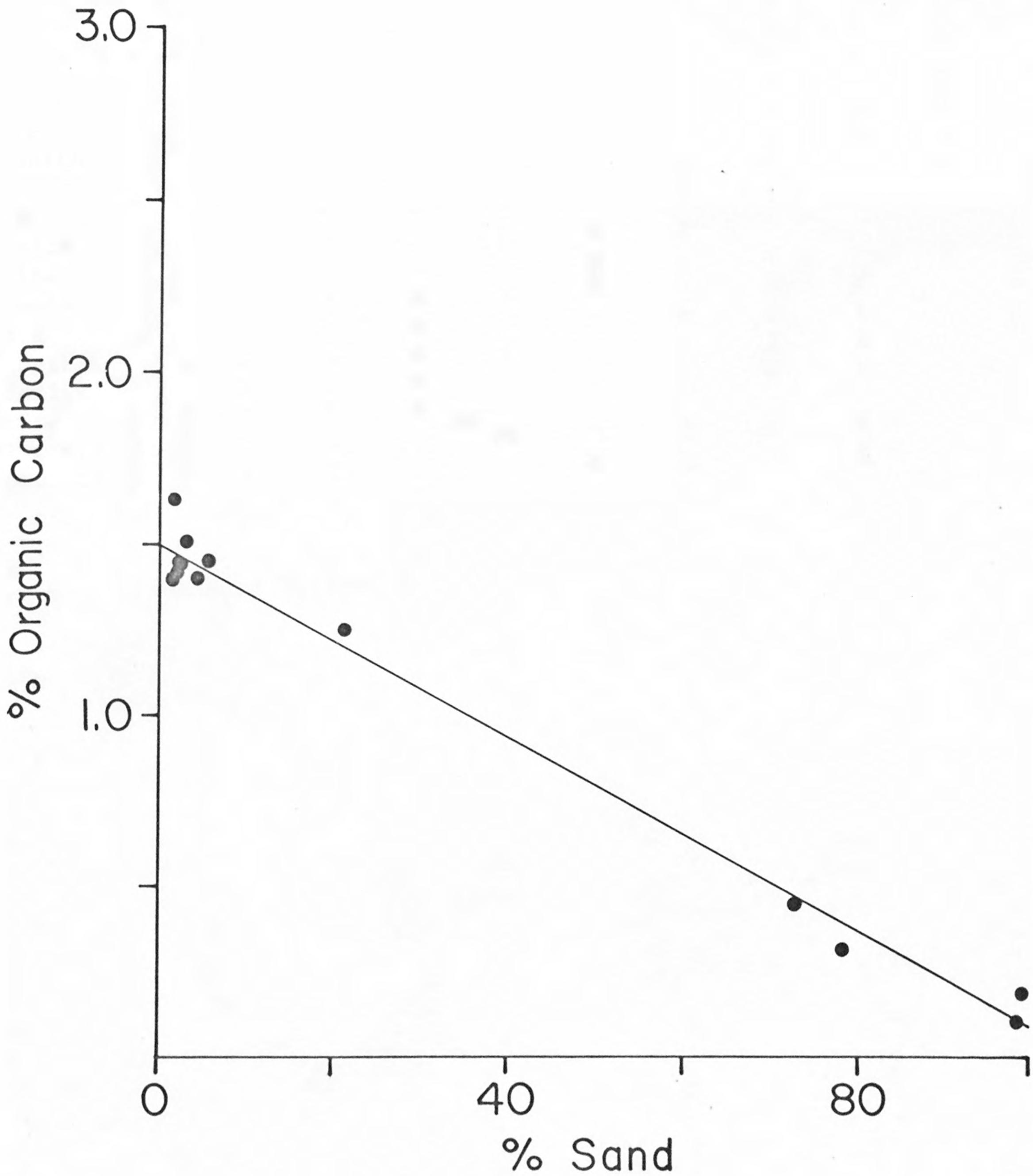


Figure 6

Heavy Mineral	Depth (cm)									
	10	120	165	255	300	330*	370	410	420	470
Opaque minerals	X	X	X	X	X	X	X	X	X	X
Hornblende	X	X	X	X	X	X	X	X	X	X
Staurolite	X	X			X	X	X	X	X	X
Tourmaline	X	X	X	X	X	X	X	X	X	X
Pyroxene	X	X	X		X	X	X	X	X	X
Garnet	X	X	X	X	X	X	X	X	X	X
Zircon	X	X	X	X	X	X	X	X	X	X
Leucoxene	X	X	X	X	X	X	X		X	X
Epidote	X	X	X	X	X	X	X	X	X	X
Sillmanite	X				X	X	X	X	X	X
Rutile	X	X	X		X	X	X		X	X
Pyrite		X	X	X		X	X	X	X	X
F. Pyrite	X	X	X	X	X	X				
Monazite					X				X	
Muscovite	X	X	X	X	X	X	X	X		
Biotite	X	X	X	X	X	X	X	X		
Phlogopite	X	X	X	X			X	X		
Glauconite	X	X	X		X		X	X		
Chlorite	X	X	X							
Shell fragments	X	X	X	X	X	X	X	X		
P. foram tests	X	X	X	X	X	X	X	X		

F. Pyrite - Framboidal Pyrite

Figure 7

Heavy Mineral		10	120	165	255	300	330*	370	410	420	470
		Depth (cm.)									
	Opaque minerals	12	7	7	5	11	17	27	35	46	58
Heavy	Fram. pyrite	7	27	3	67	51	12	TR	TR	TR	TR
Heavies	Garnet	2	1	3	1	4	6	8	9	13	11
	Zircon	1	1	2	2	2	3	4	4	5	6
	Rutile	TR	TR	TR	0	1	1	1	0	1	3
	Muscovite	28	43	30	3	3	3	TR	8	0	0
Light	Hornblende	3	5	8	4	3	6	12	9	6	3
Heavies	Tourmaline	1	2	2	1	3	4	4	4	7	7
	Staurolite	1	1	0	0	5	6	4	6	6	6

TR - Trace

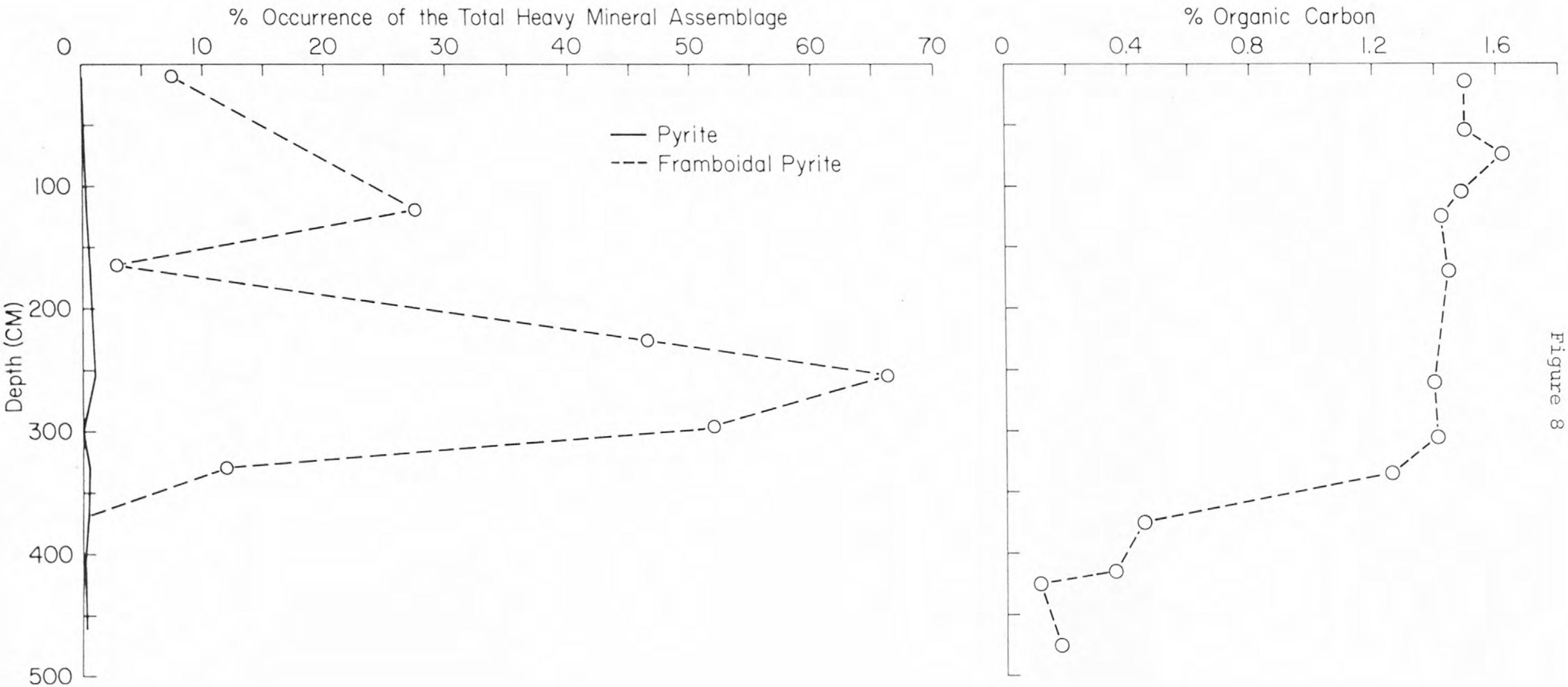
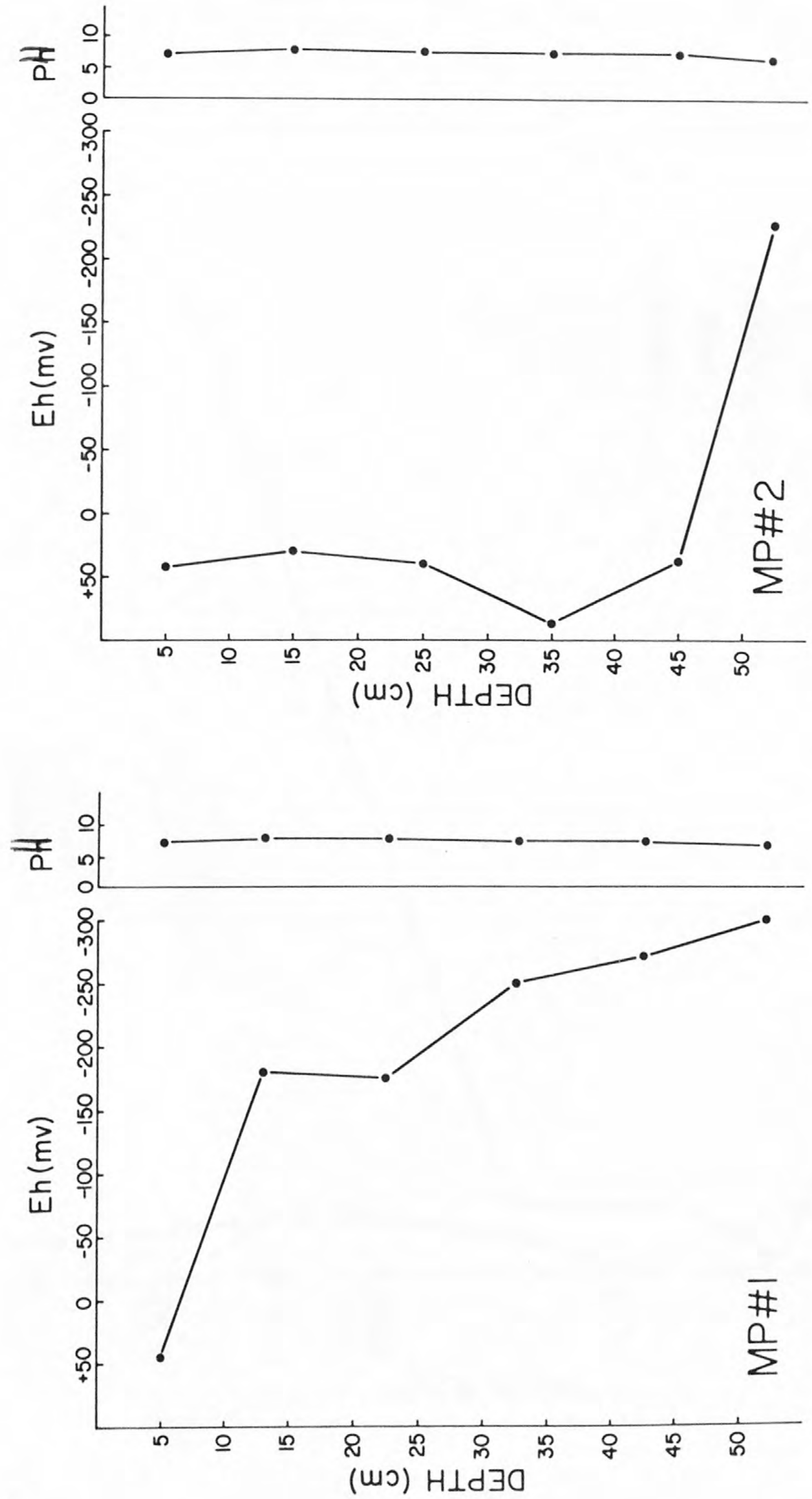

% Occurrence of the Total Heavy Mineral Assemblage
0
10
20
30
40
50
60
70
Pyrite
Framboidal Pyrite
Depth (CM)
100
200
300
400
500
% Organic Carbon
0
0.4
0.8
1.2
1.6

Figure 8

Figure 9


MP#2
Eh(mv)
pH
+50 0 -50 -100 -150 -200 -250 -300
0 5 10
DEPTH (cm)
5 10 15 20 25 30 35 40 45 50
MP#1
Eh(mv)
pH
+50 0 -50 -100 -150 -200 -250 -300
0 5 10
DEPTH (cm)
5 10 15 20 25 30 35 40 45 50

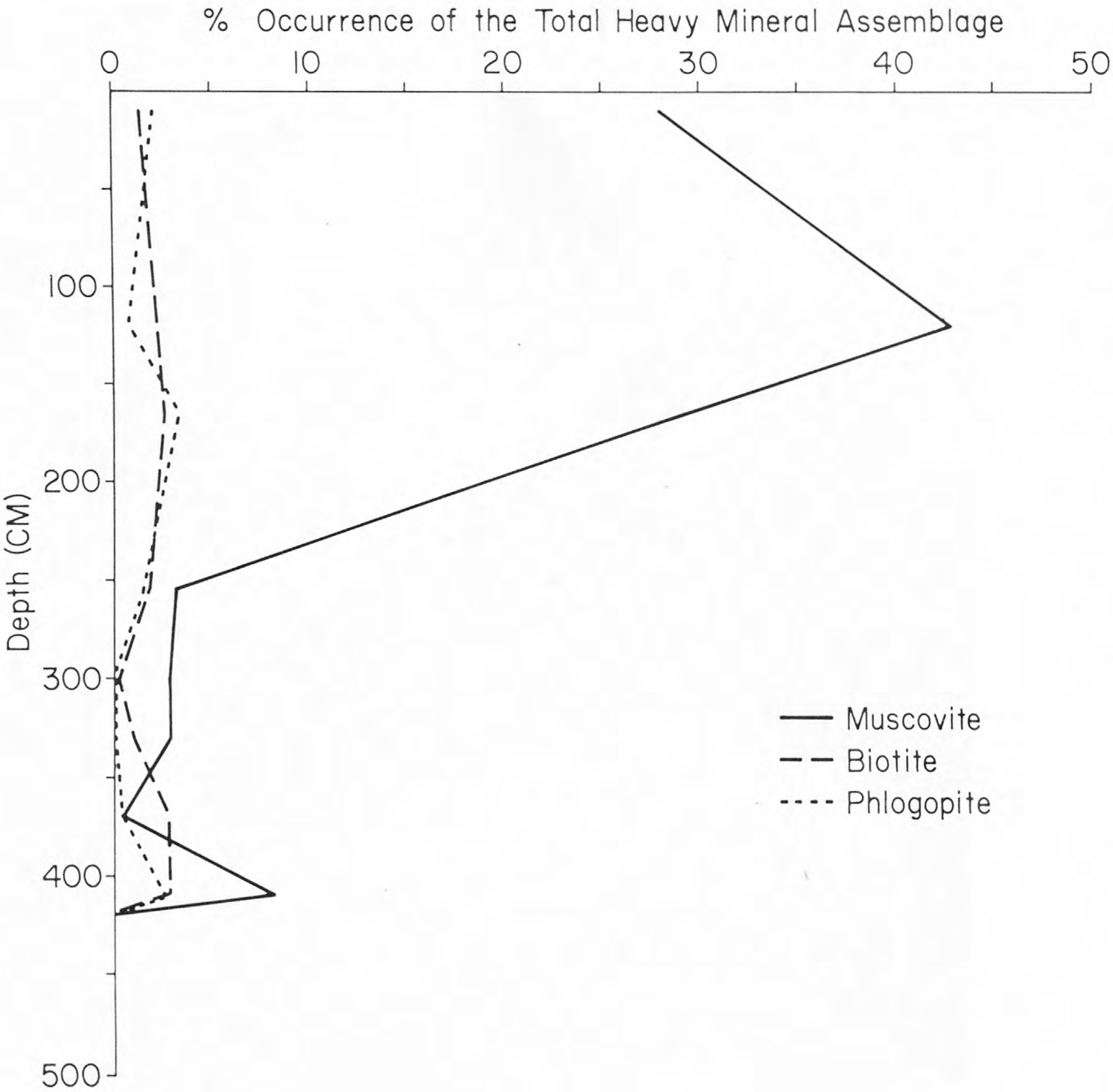

% Occurrence of the Total Heavy Mineral Assemblage
0
10
20
30
40
50
Depth (CM)
100
200
300
400
500
Muscovite
Biotite
Phlogopite

Figure 10