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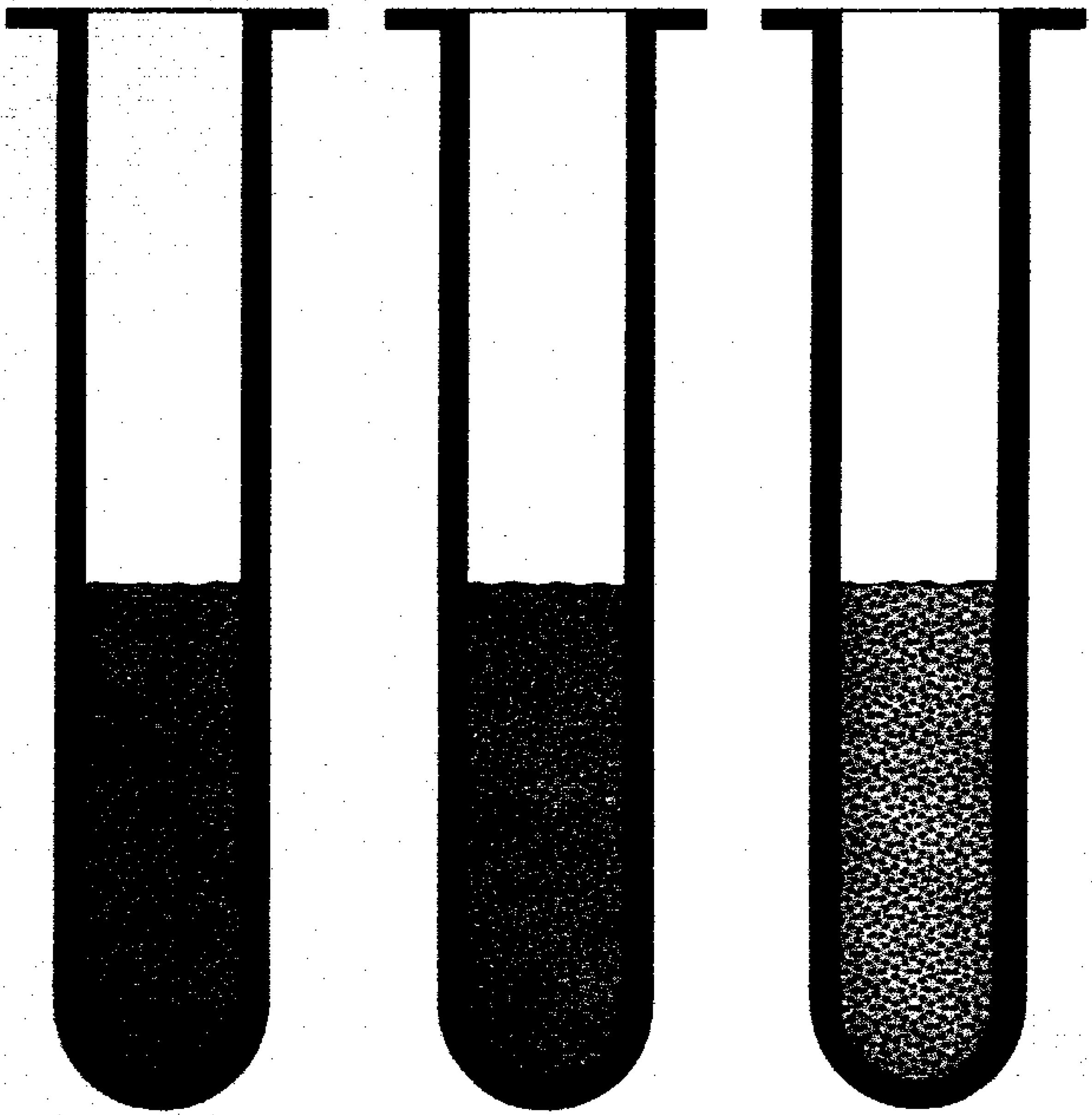

DEL-SG-8-72
college of marine studies university of delaware newark, delaware 19711
This work is a result of research sponsored by NOAA Office of Sea Grant, Dept. of Commerce, under Grant no. 2-35223

BIOGEOCHEMISTRY OF SEDIMENTS OF DELAWARE BAY

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DECEMBER 1972

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Abstract

Surface Holocene sediment samples from middle Delaware Bay and cored Holocene samples from lower Delaware Bay have been studied in a preliminary way for general sediment characteristics, pH, Eh, organic carbon, hydrogen, carbohydrates, amino acids, hydrocarbons, chlorophyll-derived pigments, carotenoid pigments, and humic acids. Samples from a core near Wilmington Canyon on the continental slope off Delaware Bay were analyzed for organic carbon, hydrogen, and total carbohydrates.

The middle Bay sediments of fine sands, silts, and clays are locally reducing and contain moderate amounts of organic residues. The middle Bay is to some extent a settling area for organic matter but a great deal of the suspended organic matter by-passes to the open sea.

The lower Bay sediments of sands and silty and clayey sands are possessed of a more generally oxidizing environment and contain in most (but not all) instances less organic matter than the middle Bay. The lower Bay appears to be primarily a by-passing rather than a settling area for organic matter.

The pH of the surface sediments of middle Delaware Bay

(range 6.4 to 7.5) is lower than that of the Bay waters and is lower in the fine-grained sediments than in the sands. The pH of subsurface Holocene sediments in lower Delaware Bay is a little more alkaline than that of the middle Bay surface sediments as well as that of underlying Pleistocene sands (range 7.43 to 7.87), perhaps owing to higher interstitial salinity in the Holocene lower Bay sediments.

The Eh of the surface sediments of middle Delaware Bay lies in the low-positive to negative range (-135 to +240 mv) indicating reducing conditions; the values are more negative in the clayey than in the sandy sediments. The Eh of the subsurface Holocene sediments of lower Delaware Bay is low- to medium-positive (+185 to +380 mv) suggesting weakly reducing to oxidizing conditions. The Eh of the underlying Pleistocene white and brown coarse sands is more strongly oxidizing (+283 to +443 mv). The Eh values point toward better preservation of organic matter in the middle than in the lower Bay.

The calcium carbonate contents of the sediments, due mainly to mollusk-shell and other shell material, ranges from 0.73% to 6.15% in the middle Bay and from 0.05 to 17.12% in the lower Bay sediments. No relationship to bottom-sediment type, other than to shell concentrations, was observed.

The organic carbon contents of the Bay sediments comprise principally plant fragments. The surface middle Bay sediments range from 0.12 to 3.01% C, with the higher values in the clayey sediments. Comparable values in Holocene cored lower Bay sediments are 0.33 to 3.79%.

The hydrogen moiety in the Bay sediments is due not only to organic matter but also to clays and other hydrogen-bearing minerals. The values in the middle Bay sediments are 0.09 to 0.83%, and in the lower Bay subsurface sediments 0.002 to 0.285%, with the higher values tending to occur in the finer-grained sediments.

The total carbohydrates of the middle Bay sediments range in amount from 0.59 to 5.05 mg/g, and in the subsurface lower Bay sediments the range is 0.40 to 7.98 mg/g. The higher values are in the clayey and organic-rich sediments, as might be expected, and are in part related to periods of high organic productivity in the past. The free monosaccharides range from 3 to 400 micrograms/g of sediment in the middle Bay and from 0 to 0.57 ug/g in the lower Bay subsurface sediments, with the high values restricted to the clays. Free sugars generally form less than 5% of the characterizable monosaccharides in these sediments. Polymeric monosaccharides range from 46 to 1683 ug/g in the middle Bay surface sediments and 1.3 to 546 ug/g in the lower Bay cored sediments. The higher values are in the clays and are due primarily to plant fragments. Mannose decreases markedly below a depth of 430 cm in the lower Bay sediments, suggesting that source materials for this sugar, possibly marsh grasses and marine yeasts, were scarce in the area in times prior to that depth. Significantly greater parts of the carbohydrates are preserved as polysaccharide residues, including laminaran, starch, and cellulose, than in other aquatic environments studied by the writer. In the latter, humic complexes are the more important sites of carbohydrate residues.

A wide variety of protein as well as several non-protein amino acids occur in moderate amount in the surface Bay sediments. The values are much lower in the cored sediments. The amino acid concentrations in these deposits are similar to those in surface and subsurface eutrophic lake sediments.

Saturated, as well as lesser amounts of aromatic hydrocarbons occur in the surface sediments and in most, but not all, of the subsurface sediments. In the latter, the saturated hydrocarbons range from C16 to C34 and perhaps as high as C49. Odd-numbered N-paraffins predominate over even-numbered ones above, but not below, C27. $N\text{-}C_{31}H_{64}$ and $N\text{-}C_{33}H_{68}$ are predominant members in one of the subsurface sediment samples. Polar substances exceed hydrocarbons in most of the benzene-methanol extracts studied.

Chlorophyll-derived pigments are relatively low in amount in the subsurface sediments, but have not yet been studied in the surface sediments. Carotenoid pigments are rare to absent in the subsurface sediments. The scarcity of these organic pigments indicates that oxidation had degraded them to a considerable degree in the lower Bay prior to their incorporation in the sediments.

Humic acid residues in the surface Bay sediments range from

0.03% to 1.34% of dry sediment whereas in the subsurface lower Bay sediments the values are 0.09 to 0.43%. The humic acids comprise from 10 to nearly 50% of the organic carbon in these samples, and are thus an indication of the relatively high degree of humification to which the organic matter of this Bay is subjected before its incorporation in the sediments.

Analyses of core samples from near Wilmington Canyon on the Continental Slope offshore of Delaware Bay shows that those sediments are several times richer in organic materials than are those of the middle and lower Bay. The Canyon area is much more favorable for the accumulation and preservation of organic matter than is the Bay.

Introduction

The sediments of Delaware Bay consist of fine sands, silts and clays of light to dark gray color and containing abundant shell fragments in many areas.

In the present study the sediments from cores in lower Delaware Bay and surface samples from the middle part of Delaware Bay were studied for some of their organic residues (Figures 1-3, Tables 1, 2). The surface sediments from middle Delaware Bay consist of fine-to medium-grained gray, in part silty, shelly, and carbonaceous sands and dark gray silty, sandy carbonaceous clay. Tubular, gelatinous structures perhaps representing tubificid larval tubes or amphipod tubes are common in or on the surface sediments. Mollusks, estuarine Foraminifera and Ostracoda are rare to common in occurrence. The carbonaceous matter consists mostly of grains of coal and fragments of plants.

The subsurface Holocene sediments are more than 30 feet thick in the middle part of lower Delaware Bay but thin to a few feet along the margins of the Bay where they are underlain by coarse white or ferruginous Pleistocene sands (Fig. 2). The Holocene sediments consist of basal mollusk-shell beds grading upward into shelly foraminiferal fine sands, sandy clays and silty clays.

Hydrogen-ion Concentration

The hydrogen-ion concentration in the surface sediment samples from middle Delaware Bay varies from pH 6.4 to 7.5 (Table 2), and is thus lower than that of the Bay waters which are 8 or above. According to Biggs (1972) the pH values of the surface sediments along the eastern margin of Delaware Bay and in a broad band along the western part of the Bay but not immediately next to the shore are less than 7; the eastern middle part of the Bay and the western margin are above 7. This pH zonation is related to grain size according to Biggs, being generally below 7 in the clayey sediments and above 7 in the sandier sediments. The difference according to Biggs is due to deoxygenation and chemical alteration by organic decay of the alkaline sea water in the interstices of the clayey sediments; freer interchanges with alkaline sea water keeps the pH levels above 7 in the sandy sediments.

In the subsurface sediments of lower Delaware Bay the pH values of the clayey and finely sandy Holocene sediments range from 7.69 to 8.75 (Fig. 2) whereas in the underlying Pleistocene sands pH values are 7.43-7.87. The generally more alkaline values of the sediments in the lower Bay than in the middle Bay are probably caused by the higher salinity of the interstitial waters of the lower Bay, and perhaps lesser microbial activity.

Oxidation-reduction Potentials

The Eh values, corrected for the Eo of the calomel measuring electrode (+245mv), of surface sediment samples from middle Delaware Bay ranged from -135 to +240 mv (Table 2). The more negative Eh values are in the finer-grained silty and clayey samples.

The Eh values of the Holocene fine-grained clayey and silty sands from cores in lower Delaware Bay range from +185 to +380 mv (Fig. 2) while the Eh values of the underlying Pleistocene sands range from +283 to +443 mv. The Eh values of the lower Bay samples are generally oxidizing rather than reducing as is the case in the middle Bay surface samples.

A general result from the Eh measurements is that there appears to be a tendency toward preservation of organic matter under negative Eh conditions in the middle Bay and oxidation of organic matter in the lower Bay under positive Eh conditions.

Calcium Carbonate Content

The calcium carbonate of the surface sediments of middle Delaware Bay (Table 1) occurs mainly as shell fragments. This material varies from 0.73% to 6.15% in the samples analyzed and shows no obvious relationship to type of bottom sediment.

The calcium carbonate contents of cores Holocene sediments from lower Delaware Bay (Tables 3, 4), also due to shell material, range from 0.05 to 17.12%.

Organic Carbon of Sediments

The organic analytical methods used in this study are described elsewhere (Swain, 1970). The organic carbon contents of surface sediments from middle Delaware Bay range from 0.12% to 3.01% and is generally higher in the clayey and silty sediments than in the clean sands (Table 1).

In the cored sediments of lower Delaware Bay, the organic carbon ranges from 0.33% to 3.79% (Tables 3, 4).

In both parts of the Bay the organic carbon consists primarily of disseminated carbonaceous residues of plants. In the surface sediments there is also a contribution from particles of coal.

Hydrogen Contents of Sediments

The hydrogen content of the sediments of middle Delaware Bay ranges from 0.09 to 0.66% (Table 2). The hydrogen occurs in the disseminated organic matter as well as in the clay minerals of the sediments. No relationship of the hydrogen contents to sediment type is obvious.

The cored sediments in lower Delaware Bay are generally lower in hydrogen content than the middle Bay sediments, ranging from 0.002 to 0.285% (Tables 3, 4).

Total Carbohydrates

The total carbohydrate contents of surface sediment samples from middle Delaware Bay are relatively low, ranging from 0.59 mg/g to 5.05 mg/g (Table 5). In general the higher values are in the silty and clayey sediments, although several clean sand deposits had values of 1 mg/g or more probably owing to plant fragments.

The total carbohydrates of cored Holocene sediments at one locality in lower Delaware Bay range from 0.40 to 7.98 mg/gm between depths of 40.6 and 477.5 cm (Table 6). There is a change at 177.8 cm. below which the total carbohydrates decrease from an average of 3.07 to 0.82 mg/g. There is no obvious sedimentary cause of this decrease in the fine silty sands of the core and it is likely that a change in the amount of source material occurred at the time represented by that depth in the core. Possibly marsh-development around the Bay became widespread at that time, and caused an increase in carbohydrate residues in the sediments.

Free Sugars

The free sugars in the sediments are those which can be extracted with boiling water.

The free sugars in surface sediment samples from middle Delaware Bay range from 3 to 400 micrograms per gram of dry sediment (Table 7). The high value is in carbonaceous clay while the sands generally have low values. Galactose and glucose are the only free monosaccharides detected.

The free sugars in a core from lower Delaware Bay (Table 8) range from 0 to 57 micrograms per gram of dry sediment (Swain and Bratt, 1972). Glucose and galactose are the predominate monosaccharides but small amounts of mannose, arabinose, xylose, ribose, and rhamnose occur in a few samples.

The free sugars form generally less than 5% of the total characterizable monosaccharides and less than 0.01% of the total carbohydrates as determined by a phenol:sulfuric acid test.

Polymeric Sugars

The carbohydrate materials extracted from the sediments by treatment with dilute sulfuric acid are assumed to be in polymeric form.

The acid-extractable sugars in the surface sediment samples from middle Delaware Bay ranged from 46 to 1683 micrograms per gram (Table 9), the high value being in a carbonaceous clay. The free sugars are thus about 6 to 30% of the polymeric sugars in these samples.

The acid extractable sugars in cored Holocene sediments from lower Delaware Bay range from 1.3 to 546 micrograms per gram with the high value being in gray clay (Table 10).

Particulate plant material as well as lesser contributions from animal shells probably provide the main resources of both the polymeric and the free sugars in those samples. Unlike the total carbohydrate analyses in the cored sediments neither the free nor the polymeric sugars show a marked reduction below 177 cm. The reason for this variation is not known but may in part be related to the aldehyde versus the glycoside state of the sugar residues; the former being more abundant at depths below 177 cm. in the core analyzed.

Mannose is moderate in amount to a depth of about 430 cm. (Table 10). The source of the mannose was previously suggested to be some of the marsh grasses (especially *Spartina* and *Distichlis*) that surround the bog, and in which mannose is a prominent sugar (Swain and Bratt, 1972), or perhaps in marine yeasts. Below 430 cm. the mannose content of the core decreases markedly as a probable result of a less productive source region prior to the 430 cm level. If the downward decrease in mannose were more gradual the change might be explained by progressive degradation of the organic matter, but the abrupt change observed implies an environmental modification.

Polysaccharides

Polysaccharide residues of sufficient length to react with specific enzyme preparations were analyzed in the Delaware Bay samples. The enzymes used were laminarase, α-amylase, β-amylase, and cellulase.

The polysaccharide residues in surface samples from middle Delaware Bay contain β-1-3, α-1-4, and β-1-4 structures indicating the presence of laminarase, starch, and cellulose (Table 11). The highest values are in gray carbonaceous clay.

The core samples of Holocene sediments from lower Delaware Bay also yielded small amounts of the polysaccharides noted above (Table 12). There is no apparent decrease in polysaccharide residues to depths of 421 cm, in fact there is some indication of increased amounts at the deeper levels. The indications are that after burial in the sediments the polysaccharide residues are fairly stable for several thousand years. It appears that significant parts of the sugar residue is preserved as polysaccharide fragments rather than in humic complexes.

Amino Acid Residues

A surface sediment sample in middle Delaware Bay yielded 10.38 micromoles per gram of protein amino acids (Table 13). Cystine and methionine were not detected as such, but cysteic acid and methionine sulfoxide seem to occur as degradation products of those two components. In addition the following unidentified amino acids or other substances were present in the analysis:

1. near threonine
2. near glutamic acid (could be asparagine, sarcosine, citrulline, or α-aminobutyric acid)
3. near tyrosine (=glucosamine?)
4. near phenylalanine (=galactosamine?)
5. near lysine

The core samples from lower Delaware Bay contained much lower amounts of protein amino acids than the surface samples.

Reuter (1971) reported high concentrations of combined amino acids in Delaware Bay suspended matter and sediments compared to that in other unpolluted rivers, and that the pattern of amino acid distribution (predominant glycine and alanine) suggested partially digested sewage.

In the present study, glycine and alanine predominate in the surface sediment analyzed but aspartic acid was low in amount (Table 13). In several of the cored sediment samples, however, aspartic acid was relatively high (Table 13). Both methionine sulfoxide and cysteic acid occur in the sediment samples, and the 5 other substances listed above are also present in the sediments. In addition, an unidentified component occurs before compound no. 3, above.

The data indicate that although an order of magnitude decrease in amino acids occurs from the present surfact to depths of a few centimeters below the surface, a wide variety of both proteinaceous and non-proteinaceous amino acids persist to depths of 5 meters or more in Holocene sediments.

Hydrocarbons

Six surface samples from middle Delaware Bay were analyzed for lipoid substances by benzene + methanol extraction and separation on alumina columns. The heptane eluates representing mainly saturated hydrocarbons average about 1/3 of the lipoid extract and are twice to 3x the amounts of benzene eluates (mainly aromatic hydrocarbons) (Table 14).

Twenty-two Holocene core samples from lower Delaware were analyzed for higher molecular weight hydrocarbons by solvent extraction, column chromatography and gas chromatography (Table 15). The weights of the heptane eluates (mainly saturated hydrocarbons) range from 0 to 21/6% of the extracts and benzene eluates (mainly aromatic hydrocarbons) range from 0 to 28.1% of the samples. The saturated hydrocarbons range in carbon number from C_{16} to C_{34} and perhaps as high as C_{49}?

One of the saturated hydrocarbon fractions was analyzed by gas chromatography by P. M. Gerrild of U.S. Geological Survey who found that the sample showed "little or no preference for odd over even carbon-numbered N-paraffins up to about C_{27}, but a definite predominance of odd over even homologues heavier than about C_{28}. It is apparent that N-$C_{31}H_{64}$ and N-$C_{33}H_{68}$ are the most abundant members present." (Written communication dated July 20, 1971).

Reuter (1971) studied benzene and methanol extracts of Delaware Bay sediments and noted that polar compounds predominated over the hydrocarbons in his extracts. The same is true in the cored sediments studied here from lower Delaware Bay (Table 15), but in surface sediments of middle Delaware Bay (Table 14) hydrocarbons more or less equal polar substances in amount. The reason for this variation is not known at present.

Infrared absorption spectra were run on several of the benzene-methanol extracts. These showed absorption of 2800-2960 cm^{-1} (C-H stretching), 1720-1780 cm^{-1} (C=O stretching), and 1360 cm^{-1}(C-H bending). Part of the absorbance may be due to the presence of organic acids in the samples, in view of the large proportion of non-hydrocarbons in lipid extracts (Table 15).

Pigments

Chlorophyll-derived pigments were extracted from some of the core samples (Table 16) with 90% acetone and the extracts scanned in the visible spectrum at 660-665 nm. Sedimentary chlorophyll degradation products (SCDP) range from 0.81 to 3.58. This is equivalent to approximately 17.5 to 77.7 ppm.

of pheophytin a, the principal component of the extract. These values are low for aquatic sediments in an organically productive low energy environment, but are comparable to those obtained in tidal flat sediments of Tomales Bay, California, a fairly high energy environment (Swain, Paulsen, and Ting, 1964).

The chlorophyll-derived pigments in short core samples from middle Delaware Bay (Table 17) are even lower in average amount than in lower Delaware Bay. The reason for this variation is not known.

Carotenoid pigments were searched for in 90% methanol extracts of some of the cored samples from lower Delaware Bay but only traces were found.

Humic Acid Residues

Humic acid preparations were made of selected surface and core samples. Ten to 15-gram wet samples of surface sediment were extracted with 5% NaOH and the humic acids were precipitated with an excess of hydrochloric acid. The washed and dried residues on an ash-free basis, are given in percent by weight of the dried sediment in Table 18. It was found that the humic acid preparations contained considerable mineral salts in the surface sediments but very little in cored sediments from lower Delaware Bay. Although the humic acids vary widely in weight percent the clayey and finely sandy and silty sediments contain higher percentages than do the coarser and sandier sediments in correspondences to the concentrations of the other organic components studied. The sample containing abundant coal fragments (Sg-20W-7) yielded the largest amount of humic acids.

The humic acids from core 21 lower Delaware Bay do not attain the higher values recorded in the surface sediment samples but are more uniformly in the range of 0.1 to 0.3% (Table 19). There does not appear to be a definite correspondence of high humic acid content and clayey and silty sediments as in the surface samples. This suggests that there is vertical redistribution of water-soluble humic acids after deposition in these sediments which levels out the original variations that are related to grain size of sediments.

Sediments from Wilmington Canyon Area, Atlantic Ocean

A core approximately 40 feet long from the edge of Wilmington Canyon was obtained in October, 1969 by R. Sheridan and party aboard the research vessel USS Eastward. This Canyon lies offshore of Delaware Bay and receives erosional products coming from the Bay. The core was taken in water 1000 feet deep. The sediments consist of Holocene diatomaceous clays and silts containing abundant planktonic Foraminifera and Radiolaria. The organic carbon content of 33 samples of the sediments cored averages 2.32% (Table 20). This is twice the carbon content of the 35 surface samples from middle Delaware Bay (ave. 0.98%) and about three times the carbon content of 50 subsurface Holocene samples from Delaware Bay (ave. 0.78%).

The hydrogen content of the Wilmington Canyon core samples also is higher than that of most of the Delaware Bay samples, reflecting both higher organic and clay contents of the Canyon sediments.

The total carbohydrates of the Wilmington Canyon sediments is also high, averaging 4.46%. This is more than three times the total carbohydrates of surface middle Delaware Bay samples and 2-1/2 times the values from cored Holocene sediments from lower Delaware Bay.

It is apparent that the continental slope environment is more favorable than either middle or lower Delaware Bay for the accumulation and preservation of settled organic matter. A similar situation was found in the deep waters of the Gulf of California (Swain and Bratt, 1972).

Conclusions

From the distribution of organic residues in the relatively small number of sediment samples analyzed it appears that the main reservoir of organic matter lies in the middle Bay area. This area must supply food for benthic organisms throughout the middle and lower Bay areas. Widespread dredging or filling in the middle part of the Bay might exert an imbalance in the food chain of Delaware Bay that would prove detrimental to shell fish and game fish populations in the Bay.

Acknowledgments

Support for this study was provided by the Sea Grant program at the University of Delaware.

The assistance is gratefully acknowledged of the following student assistants: Michael Otley, James Huss, Judy M. Bratt, Pamela van Zyl, Janet Eike Johnson, Alan Crossan, Glenn Elliott, Robert Berman, Charles Weil, Donald Zalusky, Joseph Pignatello, and Jane Nidzgorsky. The first three accomplished a major part of the field and laboratory work.

Drs. Robert B. Biggs, John C. Kraft and Robert E. Sheridan of the University of Delaware also provided valuable advice and assistance. The amino acid analyses were supervised by Dr. Irving Liener of the University of Minnesota.

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Table 1 Sediment types, depths, and locations of Delaware Bay surface sediments

Station	Type of Sediment	Depth (m)	Latitude	Longitude
4a	Si,Cl,Sd	16.5	39-14.00	75-18.25
4b	Si,Cl,Sd	16.5	39-14.00	75-18.25
9	Si,Cl,Sd	3.3	39-12.6	75-21.05
12	Si,Cl,Sd	3	39-22.40	75-29.65
13	Sd	3.0	39-22.55	75-28.15
20	Si,Cl	8.3	39-19.60	75-20.55
22	Si,Cl,Sd	8.3	39-20.25	75-24.75
23	Sd	5.7	39-20.90	75-24.35
25	Si,Cl	2.7	39-06.60	75-20.35
27	Si, Sd	3.3	39-07.60	75-20.05
31	Si, Sd	7	39-08.10	75-17.65
34	Sd	3.3	39-08.75	75-15.85
35	Sd	15	39-09.05	75-14.75
36	Sd	5.3	39-09.35	75-14.10
38	Sd	3.7	39-10.90	75-11.50
39	Si, Sd	5.3	39-10.70	75-09.80
43	Sd	4.3	39-21.50	75-23.85
47a	Si, Sd	3.7	39-15.00	75-23.40
47b	Si,Cl	3.7	39-15.00	75-23.40
50	Sd	7.3	39-15.85	75-21.35
51	Sd	16.6	39-16.10	75-20.60
54	Sd	5.7	39-17.35	75-18.80
60	Si, Sd	4	39-13.9	75-21.10
61A	Sd	4	39-14.30	75-21.70
61B	Si,Cl,Sd	4	39-14.30	75-21.70
65	Si, Sd	6	39-16.70	75-23.40
75	Si, Sd	15.3	39-06.15	75-18.85
77A	Sd	4.3	39-02.85	75-16.90
80	Sd	9.7	39-04.95	75-16.50
82	Sd	7.7	39-06.00	75-16.80

Abbreviations: Si,Cl,Sd=silty, clayey sand; Sd,Cl,Si=sandy, clayey,silt; Sd=sand; Cl,Si=Clayey silt, etc. (also see Table 2 for size analyses)

Table 2 Moisture content, sediment types, carbonate content, organic carbon, hydrogen, pH and Eh of sediment samples from middle Delaware Bay.

Station	% Sand	% Silt	% Clay	% Moisture	%Org. C	% H_2	pH	Eh(MV)	% Carbonate
4A	52.7	-	(+5)47.3	32.8	1.284	.316	7.1	+345	1.97
4B	49.3	-	(+5)50.7	39.3	1.234	.435	7.1	+270	3.04
9	62.2	25.6	12.2	26.8	1.268	.244	7.0	+ 50	5.61
12	75.5	16.4	8.1	25.6	0.664	.215	6.75	+140	2.42
13	99.6	-	(+5) 0.4	18.1	0.530	.112	6.8	+345	1.31
20	3.4	74.6	22.0	53.7	3.022	.831	7.05	0	2.30
22	54.5	31.6	13.9	35.0	1.422	.428	7.2	+ 95	2.71
23	98.5	-	(+5) 1.5	14.5	1.275	.085	7.0	+240	n.d.
25	2.0	72.5	25.5	52.4	3.274	.759	6.4	+ 10	4.96
27	81.9	-	(+5)18.1	23.1	0.336	.107	6.95	+210	2.70
31	7.61	19.4	4.5	27.0	1.175	.224	6.7	-155	3.36
34	95.5	-	(+5) 4.5	20.3	0.141	.107	7.4	+280	3.11
35	94.4	-	(+5) 5.6	17.3	0.472	.105	7.0	+ 25	3.95
36	95.9	3.8	0.3	20.9	0.216	.104	7.0	+ 70	2.11
38	100	0	0	15.9	0.037	.038	7.2	+325	1.56
39	87.8	11.4	0.8	22.4	1.130	.104	6.95	n.d.	7.47
43	99.0	-	(+5) 1.0	18.5	0.308	.069	6.9	+250	2.83
47A	7.7	-	(+5)92.3	53.4	2.923	.641	7.2	-135	0.91
47B	90.9	7.1	7.0	17.6	0.522	.128	7.1	+ 20	1.06
50	94.2	4.7	1.1	20.8	0.374	.432	7.15	+ 50	3.29
51	89.4	4.6	2.0	20.0	1.492	.158	7.25	- 15	2.81
54	100	0	0	12.2	0.045	.026	7.0	+325	1.15
60	77.5	18.9	3.6	28.9	1.441	.509	6.65	- 15	4.05
61A	90.8	7.0	2.0	20.0	0.698	.140	6.9	+ 30	2.58
61B	55.8	35.6	8.6	33.1	0.924	.193	7.2	+115	2.99
65	6.51	32.3	2.6	40.8	1.294	.349	5.85	- 35	1.14
75	72.5	25.9	1.6	20.3	0.278	.098	n.d.	n.d.	1.66
77A	62.5	-	(+5)37.5	34.5	1.150	.307	n.d.	n.d.	3.18
80	98.5	n.d.	n.d.	20.0	0.123	.102	n.d.	n.d.	0.75
82	99.9	-	(+5) 0.1	19.5	0.129	.090	n.d.	n.d.	1.75

Table 3 Moisture, carbonate, organic carbon and hydrogen in lower 10 feet of Core 21 Delaware Bay

Depth (cm)	% moisture	% carb.	% C	% H
182.9-198.1	22.7	17.1	3.78	0.05
198.1-213.4	21.0	14.4	2.24	0.45
213.4-228.6	29.9	1.9	0.92	0.03
228.6-243.8	27.7	3.4	0.74	0.03
243.8-259.1	25.9	0.7	0.51	0.03
259.1-274.3	22.8	4.9	0.37	0.02
274.3-289.6	21.1	1.7	0.34	0.03
289.6-304.8	29.4	14.1	0.55	0.00
304.8-320.0	31.3	0.7	0.76	0.01
320.0-335.3	27.8	2.3	0.53	0.04
335.3-350.5	21.5	1.9	0.31	0.04
350.5-365.8	25.5	0.2	0.51	0.03
365.8-382.0	24.1	0.6	0.49	0.02
382.0-396.2	27.2	1.7	0.59	0.03
396.2-411.5	22.5	4.6	0.79	0.04
411.5-426.7	21.1	0.1	0.44	0.03
426.7-442.0	19.9	1.7	0.72	0.02
442.0-457.2	18.1	1.4	0.24	0.02
457.2-472.4	27.4	0.7	0.40	0.01
472.4-487.6	28.5	0.3	0.44	0.02

Table 4 Moisture, carbonate content, organic carbon and hydrogen in upper part of Core 24, Delaware Bay

Depth cm	% Moisture	% Carbonate	% Carbon	% Hydrogen
0	35.8	3.9	0.99	0.2268
4	34.2	7.7	0.99	0.2589
8	24.7	6.6	0.51	0.1253
12	29.8	2.6	0.45	0.1246
16	27.9	0.1	0.62	0.0921
20	19.1	1.8	0.42	0.1094
24	19.9	1.9	0.50	0.1318
28	17.9	7.4	0.30	0.1294
32	20.3	1.4	0.40	0.1356
36	17.9	9.5	0.36	0.1156
40	18.2	0.3	0.35	0.1427
44	17.7	1.9	0.33	0.1430
48	19.6	0.8	0.47	0.1063
52	16.9	1.0	0.26	0.0982
56	17.1	2.4	0.31	0.1396
60	35.6	3.0	1.05	0.2382
64	37.9	8.0	1.26	0.2384
68	38.3	0.1	1.19	0.1895
72	38.9	0.1	0.89	0.1199
76	40.8	0.1	0.89	0.2545
80	42.6	2.8	0.86	0.2344
84	40.4	0.7	0.90	0.2459
88	36.3	0.7	0.79	0.2155
92	41.3	0.9	1.16	0.2629
96	38.1	1.0	1.19	0.2871
100	37.1	2.3	1.16	0.1852
104	39.6	1.2	1.29	0.1829
108	41.6	3.1	0.85	0.2245
112	40.4	1.8	1.51	0.2853
116	40.7	1.6	0.79	0.1629

Table 5 Total carbohydrates of surface sediment samples from Middle Delaware Bay

Station	Sediment Type	Total Carbohydrates mg/g
4a	silty clayey sand	1.492
4b	sandy clayey silt	1.575
9	silty clayey sand	1.433
12	silty clayey sand	1.187
13	sand	0.344
20	clayey silt	5.050
22	silty clayey sand	0.910
23	sand	1.073
25	clayey silt	2.946
27	silty sand	0.603?
31	silty sand	1.522
34	sand	0.366
35	sand	0.627
36	sand	0.697
38	sand	0.134
39	silty sand	0.977
43	sand	0.415
47A	silty sand	4.095
47B	clayey silt	1.091
50	sand	0.680
51	sand	1.013
54	sand	0.059
60	silty sand	1.299
61A	sand	0.872
61B	silty clayey sand	1.029
65	silty sand	2.515
75	silty sand	0.418
77A	sand	1.859
80	sand	0.391
82	sand	2.295

Table 6 Total carbohydrates in mg/g
Middle and lower parts of Core 21, Delaware Bay

Depth (cm)	Total Carboh (mg/g)
40.6-45.4	2.66
50.8-55.9	4.00
61.0-66.0	7.98
71.1-76.2	5.00
81.3-86.4	3.96
91.4-96.5	1.88
101.6-106.7	1.66
121.9-127.0	1.14
132.1-137.2	2.56
142.2-147.3	1.97
152.4-157.5	2.29
162.6-167.6	2.17
172.7-177.8	2.60
182.9-188.0	0.60
198.1-203.2	0.46
213.4-218.4	0.40
228.6-233.7	0.41
243.8-248.9	0.49
259.1-264.2	0.69
274.3-279.2	0.52
289.6-294.6	0.70
304.8-309.9	0.65
320.0-325.1	0.62
335.3-340.4	0.60
350.5-355.6	0.71
365.8-370.8	0.58
382.0-386.1	0.70
396.2-401.3	1.18
411.5-416.6	1.11
426.7-431.8	2.27
442.0-447.0	1.61
457.2-462.3	0.89
472.4-477.5	1.11

Table 7 Free sugar residues in surface samples from Delaware Bay sediments in micrograms, by enzymatic analyses

Station	pH	Eh	Description	gal	glu
Sg-9-W-71	7.0	+ 50	Carbonaceous, shelly sand	1	2
Sg-35W-71	7.0	+ 25	Gray, shelly sand	6	0
Sg-47W-71 top	7.2	-135	Carbonaceous clay	0	300-400
Sg-47W-71 bottom	nd	nd	Gray, shelly sand	0	4

Table 8 Free sugars in Core samples from lower Delaware Bay

Depth (cm)	Description	gal	glu	man	ara	xyl	rib	rha	E
40.6-45.7	fine gray, clayey silty sand	0	2.0	0	0	0	0	0	2.0
50.8-55.9	fine gray clayey sand	0	4.0	0	0	0	0	0	4.0
61.0-66.0	fine gray very clayey silty sand	0	2.0	0	0	0	0	0	2.0
71.1-76.2	fine gray, glauc. clayey sand	0	0	0	0	0	0	0	0
81.3-86.4	fine gray glauc. sand	0	1.0	0	0	0	0	0	0
91.4-96.5	fine gray glauc. sand	0	4.0	0	0	0	0	0	4.0
101.6-106.7	fine gray glauc. sand	0	1.0	0	0	0	0	0	1.0
111.7-116.8	fine gray glauc. sand, shells	0	1.0	0	0	0	0	0	1.0
121.9-127.0	fine gray glauc. sand	4.6	2.4	1.6	0.5	0.5	0	0	9.6
142.2-147.3	fine gray glauc. sand	3.9	2.7	0	0	0	0	0	6.6
152.4-157.5	fine gray glauc. sand, shells	1.3	0.7	1.3	0.6	1.2	0.6	1.5	7.2
162.2-167.6	fine gray clayey glauc. sand, shells	0	1.2	0	0	0	0	0	1.2
172.7-177.8	fine gray glauc. sand	1.3	1.7	0.2	0.6	0.4	0	0	4.2
259.1-264.2	fine sand	0	1b	0	0	0	0	0	1.0
289.6-294.6	fine sand	0	0	0	0	0	0	0	0
325.1-330.2	fine carbonaceous sand	32c	25b	0	0	0	0	0	57.0
335.3-340.0	fine sand, few shells	0	1b	0	0	0	0	0	1.0
355.6-360.7	fine sand	0	0	0	0	0	0	0	0
381.6-386.1	fine sand	3b	0	0	0	0	0	0	3.0
396.2-401.3	fine sand	0	11b	0	0	0	0	0	11.0
406.4-411.5	fine sand, Elphidium	1b	2b	0	0	0	0	0	3.0
416.6-421.6	fine sand, Elphidium	6b	0	0	0	0	0	0	6.0
426.7-431.8	gray silty clay	1b,c	26b	0	0	0	0	0	27.0
441.9-447.0	fine shelly sand	1c	1b	0	0	0	0	0	2.0
452.1-457.2	fine shelly sand	11b	0	0	0	0	0	0	11.0
462.3-467.4	fine shelly sand	2b	1b	0	0	0	0	0	3.0
472.4-477.5	fine very shelly sand	2b	1b	0	0	0	0	0	3.0
482.6-487.7	sandy shell bed	2b	0	0	0	0	0	0	2.0

Table 9 Acid extractable sugars in surface samples from Delaware Bay, in micrograms per gram

Station No.	gal	glu	man	ara	xyl	rib	rha	Σ
Sg-13-W-71	22	22	18	12	11	16	27	128
Sg-18a-W-71	26	25	19	16	32	0	0	118
Sg-18b-W-71	54	27	31	31	49	21	0	213
Sg-20-W-71	50	67	54	59	95	41	21	387
Sg-23-W-71	37	40	86	27	28	0	0	218
Sg-35-W-71 (sand)	12	32	1	0	1	0	0	46
Sg-47-W-71 (top) (clay)	752	817	27	22	24	6	15	1663
Sg-47-W-71 (bot) (sand)	66	132	4	6	10	0	2	220

Table 10 Acid extractable sugars, core 21, Delaware Bay, in ppm

Depth (cm)	gal	glu	man	ara	xyl	rib	rha	
40.6-45.7	0	1.3	0	0	0	0	0	1.3
50.8-55.9	5.5	8.6	3.7	3.7	1.3	2.1	1.0	32.0
61.0-66.0	5.6	4.0	2.0	0.9	2.6	0.3	1.5	16.9
71.1-76.2	7.3	4.6	3.1	2.4	4.5	1.4	3.7	27.0
81.3-86.4	separation not attained because of high salt content, sugars present							
91.4-96.5	3.4	4.3	3.3	2.6	1.4	0.7	0.6	16.3
101.6-106.7	7.6	10.9	11.1	1.7	1.6	0.7	0.2	33.8
111.7-116.8	8.7	12.2	20.2	3.3	4.2	1.0	2.6	52.2
121.9-127.0	5.6	9.9	22.0	2.4	2.5	0	2.4	44.8
132.1-137.2	11.2	7.4	17.3	6.3	9.5	3.5	8.6	63.8
142.2-147.3	7.8	5.3	13.8	4.6	6.7	1.5	5.8	45.5
152.4-157.5	4.1	6.7	5.2	3.3	4.4	0	4.8	28.5
162.6-167.6	4.9	4.1	103.6	5.2	7.4	1.5	5.3	132.0
172.7-177.8	4.9	6.7	171.3	6.9	8.7	0	8.4	206.9
259.1-264.2	15c	10b	samples too salty for good separation of sugar					25.0
289.6-294.6	0	12b	samples too salty for good separation of sugar					12.0
325.12-330.6	32c	25b	samples too salty for good separation of sugar					57.0
335.3-340.6	37c	27b	33a	11a	15a	2a	7a	132.0
355.6-360.7	46c	37b	37a	16a	10a	2a	9a	157.0
381.0-386.1	36c	27b	17a	5a	10a	0	3a	98.0
396.2-401.3	8c	9b	16a	0	1a	0	0	34.0
406.4-411.5	20c	19b	27a	10a	16a	7a	8a	107.0
416.6-421.6	47c	55b	samples too salty for good separation of sugar					102.0
426.7-431.8	122c	74b	167a	55a	47a	30a	51a	546.0
441.9-447.0	41c	39b	2a	1a	2a	0	2a	87.0
452.1-457.2	26c	18b	1a	1a	2a	0	1a	49.0
462.3-467.4	31c	28b	1a	1a	2a	0	1a	64.0
472.4-477.5	32c	31b	1a	0	1a	0	1a	66.0
482.6-487.7	44c	39b	2a	1a	2a	0	2a	90.0

Table 11 Polysaccharide residues in surface sediments from Delaware Bay in micrograms per gram of glucose released by indicated enzyme

Sample	Description	laminarase	α-amylase	β-amylase	cellulase
Sb-9-W-71	Carbonaceous shelly sand	1.0	0	3.0	2.0
Sb-35-W-71	Gray shelly sand	7.0	0	3.0	3.0
Sb-47-W-71 (top)	Carbonaceous clay	17.0	5.0	30.0	5.0
Sb-47-W-71 (bottom)	Gray shelly sand	9.0	2.0	0	4.0

Table 12 Polysaccharide residues in core samples from part of Core 21, lower Delaware Bay

Depth	Laminarase	α-amylase	β-amylase	Cellulase
40.6-45.7				
50.8-55.9				
61.0-66.0				
71.1-76.2				
81.3-86.4				
91.4-96.5	0	0	0	0
101.6-106.7	0	0	0	0
111.7-116.8				
121.9-127.0				
142.2-147.3	0			
152.4-157.5	0	0	0	0
162.7-167.6	0	0	4.0	0
172.7-177.8	0	0	0	3.0

Table 13 Amino acid residues in surface sediment and core samples from Delaware[1] in micromoles per gram of clay sediment

Sample	lys	his	arg	asp	thr	ser	glu	pro	gly	ala	1/2 cys	val	met	ile	leu	tyr	phe	Σ
Sg-47-W-71	0.67	0.18	0.48	0.05	0.73	0.76	0.18	0.78	1.79	1.27	0	0.97	0	0.60	0.96	0.28	0.68	10.38
21cc 54-56	0.92	0.01	0.13	0.96	0.06	0.09	0.08	0.05	0.62	0.13	0	0.05	0	0.03	0.06	0.02	0.04	2.35
21cc 38-40	0.03	0.01	0.01	0.13	0.06	0.08	0.09	0.07	0.23	0.11	0	0.05	0	0.03	0.05	0.02	0.05	1.02
21cc 22-24	tr	tr	0	0.14	0.02	0.05	0.02	tr	0.13	0.04	0	0.01	0	0.01	0.02	tr	0.04	0.48
21cc 12-14	0.05	0.01	0.04	0.26	0.10	0.10	0.18	0.10	0.41	0.22	tr	0.09	tr	0.05	0.10	0.10	0.07	1.88
21cc 2"	0.03	0.01	0.02	0.32	0.07	0.08	0.13	0.08	0.32	0.15	0	0.06	0	0.03	0.06	0.04	0.05	1.45
21aa 30-32	0.07	0.03	0.07	0.04	0.07	0.06	0.08	0.08	0.25	0.13	0	0.11	0	0.06	0.09	0.06	0.05	1.25
21aa 26-28	0.12	0.04	0.10	0.01	0.12	0.13	0.09	0.12	0.41	0.24	0	0.16	0	0.08	0.13	0.08	0.17	2.00

[1] Analyses by I. A. Liener, Dept of Biochemistry, University of Minnesota

Table 14 Hydrocarbon extractions of surface sediment samples from middle Delaware Bay

Sample No.	Benzene + MeOH ext. % of dry sample	Heptane Fr. % of ext.	Benzene Fr. % of ext.	Pyr. + MeOH Fr. % ext.	Left on column % of ext.
12	.0474	32.76	15.52	32.76	18.96
17	.1260	29.27	9.76	22.76	38.21
31	.0422	33.33	14.82	33.33	18.52
48	.0402	29.41	13.73	33.33	23.53
61	.1080	23.85	11.01	33.03	32.11
65	.0825	39.78	10.75	29.03	20.43

Table 15 Hydrocarbon analyses of core samples from part of Core 21 lower Delaware Bay

Depth (cm)	Wt. spl. (g)	Extr. % of spl.	Heptane Fr. % of extr.	Benzene Fr. % of extr.	Pyr + MeOH Fr. % of extr.	Polar cpds. % of extr.
72.6- 77.6	24.69	0.12	3.7	5.3	6.3	84.7
77.6- 82.6	24.62	0.03	16.0	19.5	46.3	18.2
82.6- 87.6	25.06	0.15	11.8	3.5	6.4	78.3
87.6- 92.6	23.59	0.17	9.8	8.8	23.7	57.8
92.6- 97.6	25.33	0.65	3.4	0.4	4.8	91.4
97.6-102.6	24.55	0.06	6.8	7.4	13.5	72.3
102.6-107.6	25.41	0.26	16.5	20.0	17.1	46.5
107.6-112.6	24.55	0.06	9.6	28.1	9.6	52.7
112.6-117.6	23.91	0.15	21.6	4.6	3.0	70.8
117.6-122.6	23.07	0.12	nd	nd	nd	nd
122.6-127.6	25.19	0.53	2.9	8.9	4.3	83.1
127.6-132.6	23.43	0.10	nd	nd	nd	nd
132.6-137.6	22.90	0.39	7.9	23.7	10.8	57.5
137.6-142.6	23.71	0.59	7.1	0	2.5	90.4
142.6-147.6	27.12	0.19	13.1	18.8	5.7	62.5
147.6-152.6	23.84	0.27	0	0	7.4	92.6
152.6-157.6	24.38	0.89	0.3	0	3.1	96.6
157.6-162.6	23.52	0.72	9.6	0.9	1.8	87.8
162.6-167.6	20.98	0.28	8.3	0	3.0	88.7
167.6-172.6	24.89	0.34	6.7	17.0	22.7	53.6
172.6-177.6	23.35	0.45	0	0.86	nd	nd
177.6-182.6	26.88	0.41	7.6	11.6	38.7	42.1

Table 16 Chlorophyll-derivative pigments in Core 21 samples from southern Delaware Bay: SCDP (sedimentary chlorophyll degradation product: (E) (vol. solvent) ÷ dry wt. of sample
Sediments are fine clayey silty sand.

Depth in core (cm)	SCDP	Pheophytin ppm
182.9-198.1	2.15	47
198.1-213.4	1.59	35
213.4-228.6	1.02	22
228.6-243.8	1.15	25
243.8-259.1	1.34	29
259.1-274.3	1.61	35
274.3-289.6	2.71	60
289.6-304.8	2.34	51
304.8-320.0	2.45	54
320.0-335.3	1.85	41
335.3-350.5	2.42	53
350.5-365.8	3.59	79
365.8-382.0	2.23	49
382.0-396.2	2.06	45
396.2-411.5	2.02	44
411.5-426.7	1.92	42
426.7-442.0	2.73	60
442.0-457.2	1.87	41
457.2-472.4	1.03	36
472.4-487.6	0.813	18

Table 17 Chlorophyll-derivative pigments in short-core samples from Delaware Bay: SCDP (sedimentary chlorophyll degradation product: (E)(vol. solvent) ÷ dry wt. of sample; sediments are fine clayey and silty sand.

	SCDP	approx. ppm pheophytin
Core 11		
10- 20 cm	1.10	24
40- 50 cm	1.23	27
70- 80 cm	0.53	12
100-110 cm	1.52	33
130-140 cm	0.58	13
160-170 cm	1.06	23
Core 41		
80-90 cm (above bottom)	0.25	5.5
10-20 cm (above bottom)	0.60	13
Core 42		
10- 20 cm	0.28	6
50- 60 cm	0.12	3
80- 90 cm	0.05	1
110-120 cm	0.26	14.5
140-150 cm	0.26	14.5
170-180 cm	0.27	6
Core 49		
10- 20 cm	0.33	7
40- 50 cm	0.05	1
70- 80 cm	0.06	1
Core 52		
20- 30 cm	0.15	3
40- 50 cm	0.24	5
100-110 cm	0.13	3
Core 57		
20- 30 cm	0.50	10
40- 50 cm	1.01	22
70- 80 cm	0.54	12
100-110 cm	0.06	1

Table 18 Humic acids in surface sediments of Delaware Bay in percent of dry sediment

Sample Numbers	Sediment type	Humic Acids
Sg-9W-71	gray very fine silty sand	0.51
Sg-13W-71	brown manganese coated sand	0.33
Sg-18aW-71	gray silty sand	0.37
Sg-18bW-71	gray silty sand	0.73
Sg-20W-71	gray silty sand, coal fragments	1.34
Sg-23W-71	gray conglomeratic sand, plant fragments	0.03
Sg-25W-71	gray very fine silty sand	0.92
Sg-35W-71	gray fine to coarse sand	0.04
Sg-47W-71 top	gray, very fine silty, clayey sand	0.85
Sg-47W-71 bottom	gray silty sand	0.08
Sg-51W-71	gray fine to coarse sand, shells	0.42

Table 19 **Humic** acids from sediments of Core 21, lower Delaware Bay in percent of dry sediment

Depth (cm)	Type of Sediment	Humic acids
72.6- 77.6	fine gray clayey sand	0.31
77.6- 82.6	fine gray clayey sand	0.18
82.6- 87.6	fine gray clayey, shelly sand	0.20
87.6- 92.6	fine gray sand	0.21
92.6- 97.6	fine gray sand, few shells	2.15
97.6-102.6	fine gray sand	0.19
102.6-107.6	fine gray sand	0.09
107.6-112.6	fine gray sand	0.13
112.6-117.6	fine gray sand	0.15
117.6-122.6	fine gray sand	0.23
122.6-127.6	fine gray sand	0.15
127.6-132.6	fine gray, shelly sand	0.13
132.6-137.6	fine gray sand	0.10
137.6-142.6	fine-medium gray silty sand	0.43
142.6-147.6	fine gray clayey sand, common shells	0.15
147.6-152.6	fine gray clayey sand, few shells	0.15
152.6-157.6	fine gray sand, few fossils	0.26
157.6-162.6	fine gray sand, Elphidium abundant	0.05
162.6-167.6		0.35
167.6-172.6	fine gray, shelly sand	0.13
172.6-177.6	fine gray, shelly sand	0.11
177.6-182.6	sandy, mollusk-shell bed	0.02

Table 20 Organic carbon, hydrogen, and total carbohydrate contents of diatomaceous silts and clays from Wilmington Submarine Canyon Area, Atlantic Ocean, Core E4, 1969 values refer to dried sediments

	Depth cm	Organic C %	Hydrogen %	Total Carbohydrates mg/g
E4 D top	0-2	2.01	1.31	2.93
	14-16	2.04	1.37	5.02
	28-30	2.47	1.66	3.66
	42-44	1.81	1.60	2.36
	60-62	1.94	1.77	2.06
E4 D bot	62-64	1.97	1.51	2.72
	76-78	2.14	0.61	4.72
	90-92	2.23	1.62	4.02
E4 C top	122-124	1.87	1.45	5.10
	138-140	2.80	0.82	2.12
	158-160	2.65	1.26	5.64
	176-178	2.44	0.90	4.50
E4 C bot	182-184	2.18	2.81	3.92
	196-198	2.13	1.01	2.13
	214-216	2.30	0.65	8.16
	232-234	1.91	1.62	26.40
E4 B top	242-244	2.90	0.78	2.59
	256-258	2.95	0.83	4.21
	270-272	2.58	0.71	2.20
	284-286	3.14	0.83	2.37
E4 B bot	302-304	2.84	0.83	2.42
	316-318	2.31	0.65	4.07
	345-347	3.20	0.98	1.98
	361-363	2.31	0.68	2.49

Table 20 (cont'd)

Depth cm		Organic C %	Hydrogen %	Total Carbohydrates mg/g
E4 A top	363-365	2.06	0.53	3.68
	377-379	1.57	1.40	3.61
	391-393	2.04	1.22	5.95
	405-407	2.16	1.54	7.23
E4 A bot	423-425	2.21	1.37	2.86
	437-439	2.44	1.24	3.03
	451-453	2.76	1.70	2.48
	465-467	2.10	1.16	5.37
	475-477	2.06	1.17	5.04

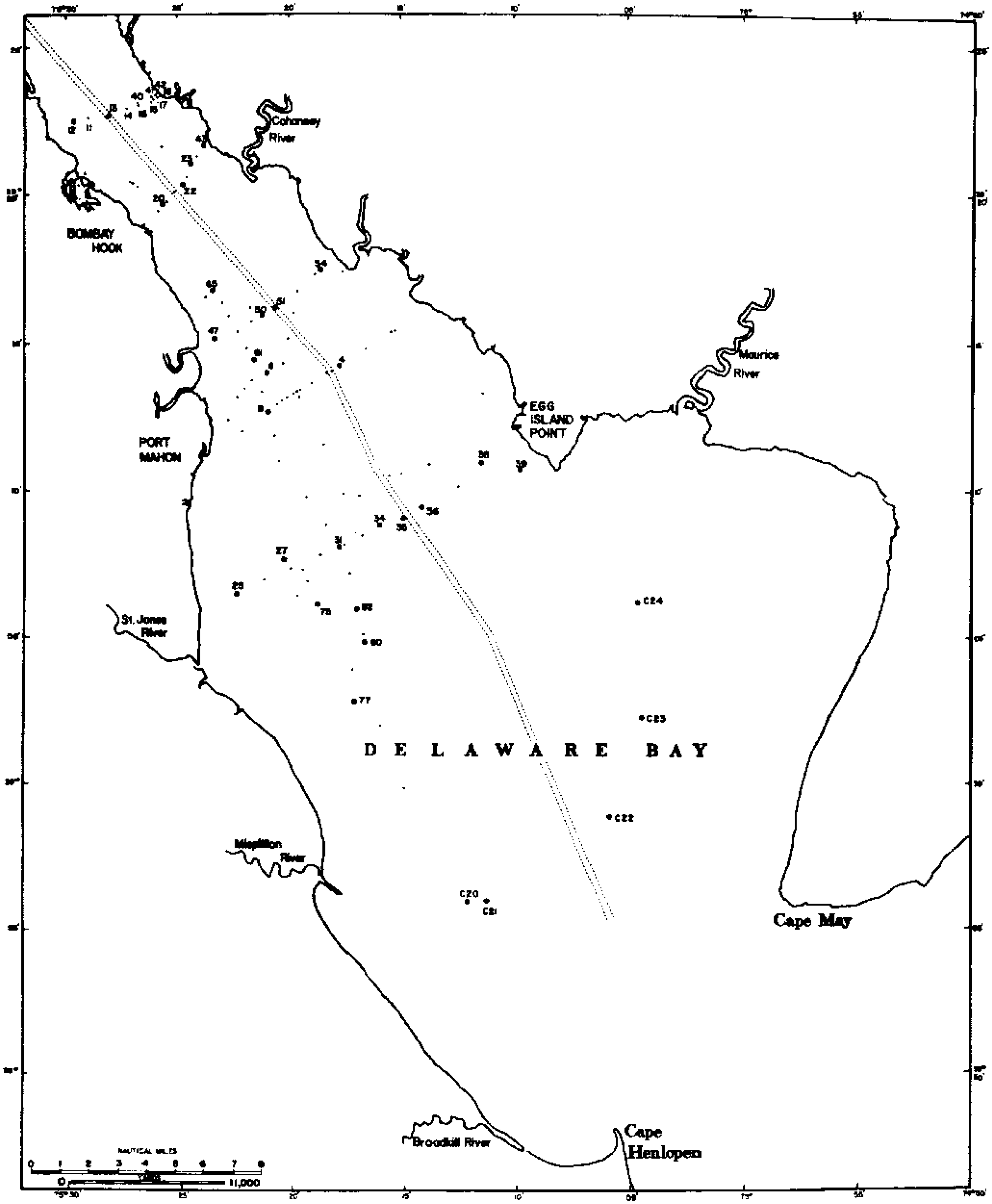

Figure 1. ● 12, etc. Surface sediment stations sampled by R. Biggs and party
• Unnumbered dots are other stations sampled but not analyzed
⊙ C20, etc. Core locations

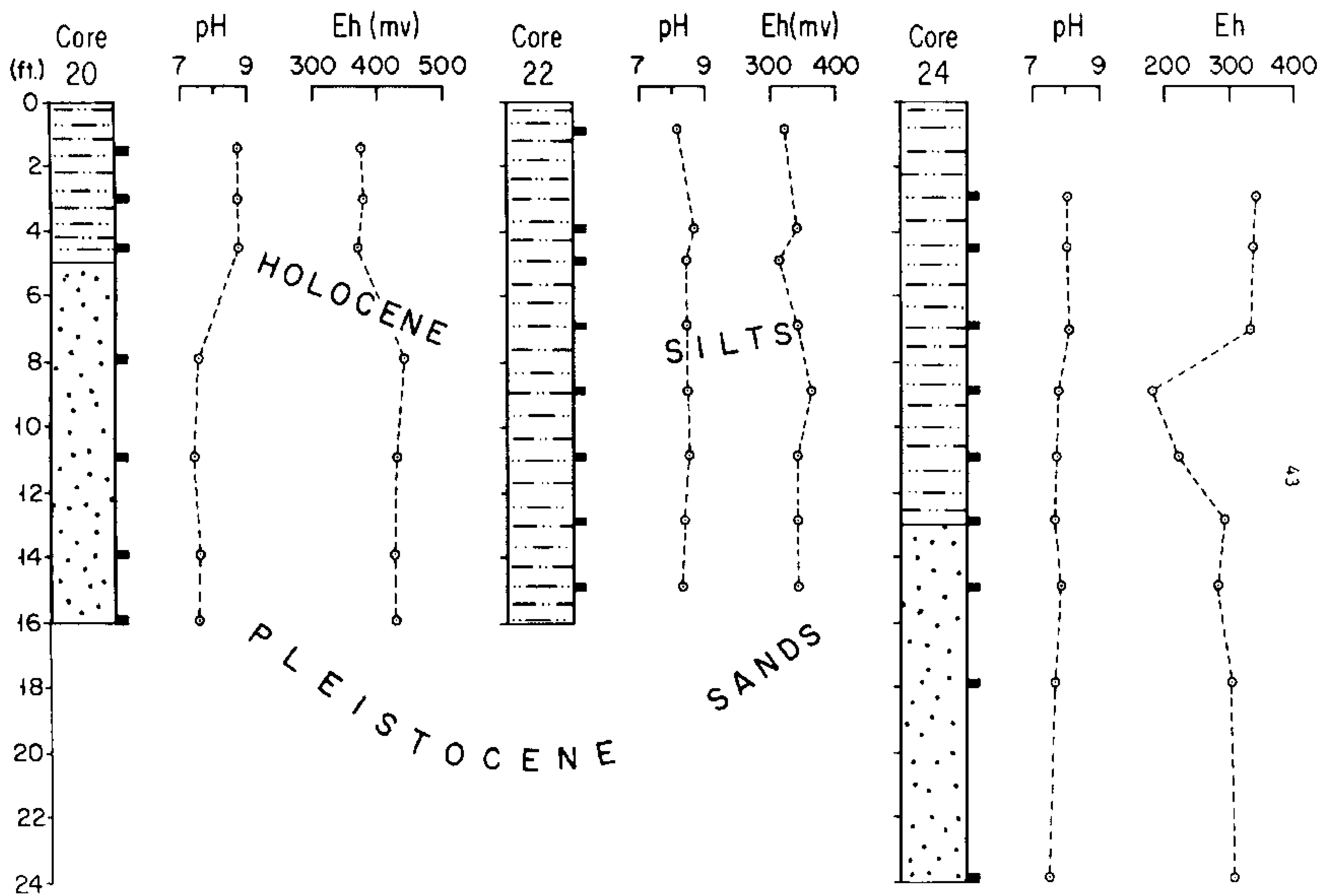

Figure 2
pH and Eh values in core samples from lower Delaware Bay

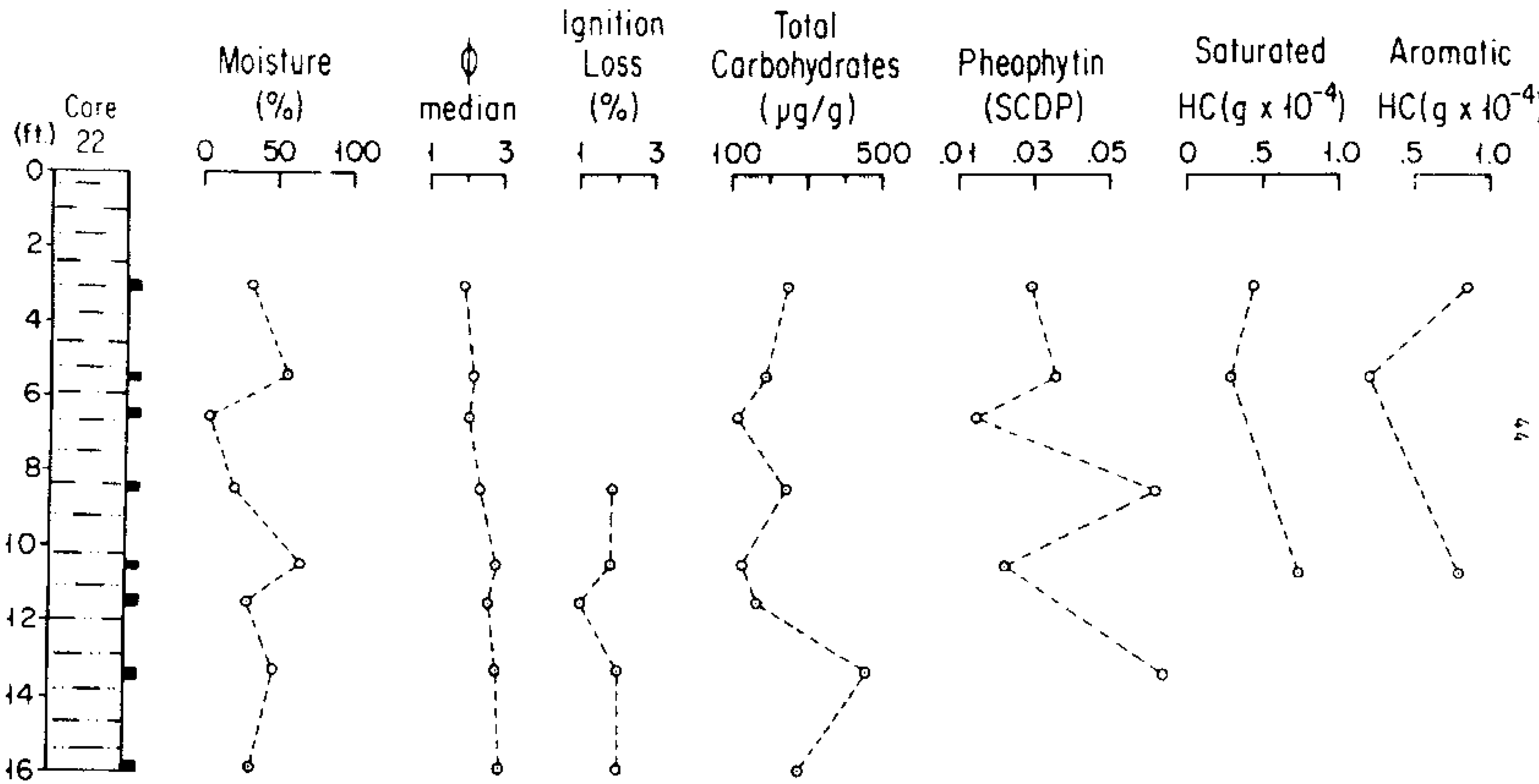

Figure 3

Some properties of sediments of core 22, Delaware Bay

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