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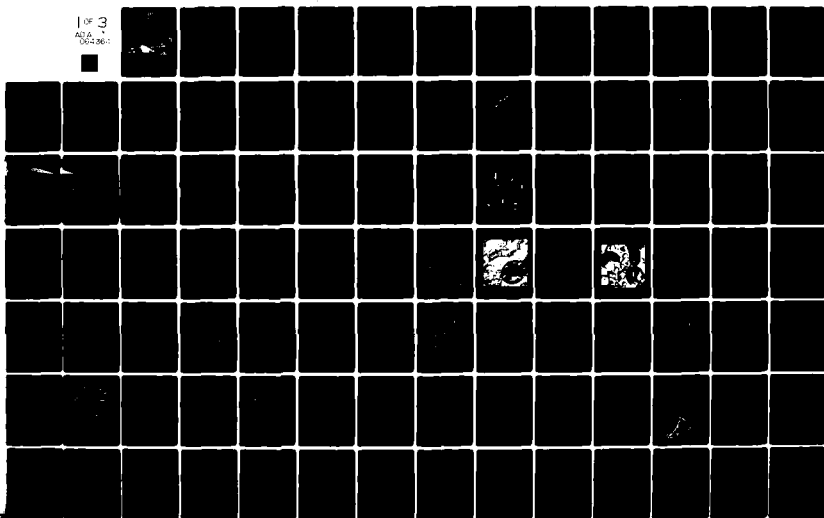   LONG RANGE SPOIL DISPOSAL STUDY. PART III. SUB-STUDY 2. NATURE,--ETC(U)
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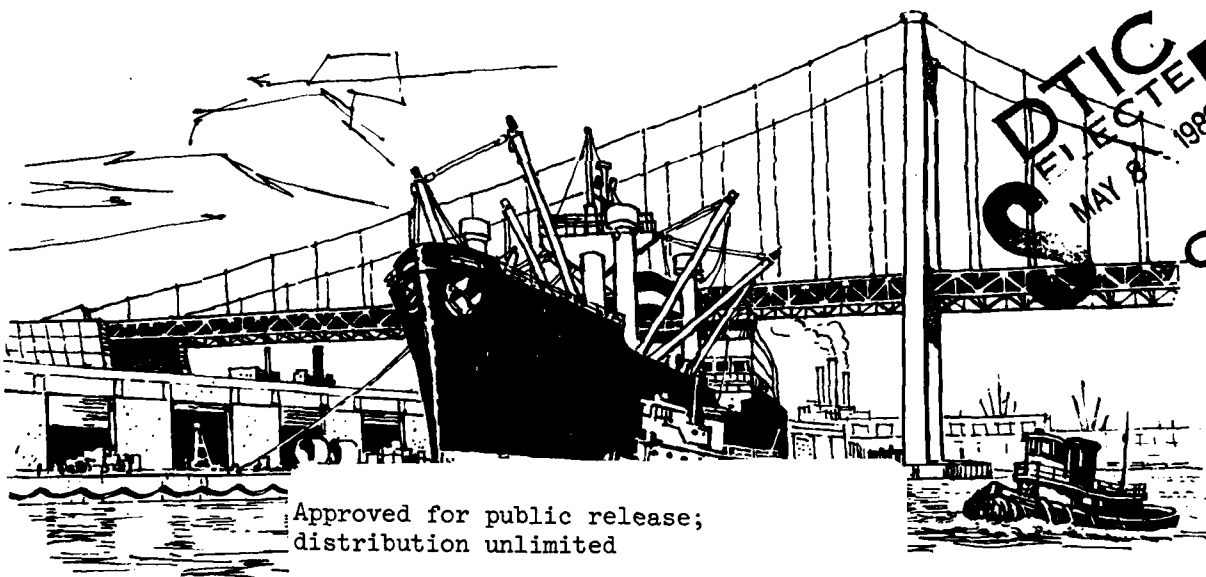
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LEVEL III

LONG RANGE SPOIL DISPOSAL STUDY

PART III

SUB-STUDY 2

NATURE, SOURCE, AND CAUSE OF THE SHOAL

APPENDIX A

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NORTH ATLANTIC DIVISION

DECEMBER 1973

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FACTS ABOUT THE AUTHOR

This report was prepared by Dr. James Neiheisel who received his PhD in Geophysical Sciences from Georgia Institute of Technology and is currently Chief, Geology and Petrography Section of the U. S. Army Corps of Engineers South Atlantic Division Laboratory. Prior to this project, Dr. Neiheisel was active in estuarine and coastline investigations in the Charleston and Brunswick areas along the South Carolina and Georgia Coasts and he has published several papers in national scientific and engineering journals.

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This study of the Delaware River dredging spoil disposal problems was undertaken by the U.S. Army Corps of Engineers, Philadelphia District. Part III, sub-study 2, Appendix A is subtitled "Source and nature of shoaling materials in the Delaware Estuary." This phase of the investigation was undertaken to determine the total composition of the shoal utilizing techniques capable of determining all phases including its amorphous and organic materials as well as, crystalline ⟶

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materials and to compare this with the composition of bottom and suspended sediments from streams draining watershed areas as well as bottom sediments of the bay. Environmental parameters were also evaluated in the water column to estimate the sediments resulting from pollution and eutrophication of the estuary by industry and municipalities. Special tests were conducted to determine the physiochemical and electrophoretic mobility parameters associated with flocculation occuring at Marcus Hook shoal. ⟵

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FOREWORD

1.   The "Long Range Spoil Disposal Study" of the Delaware River was conceived in response to a request of the Chief of Engineers that an overall engineering study of the problems involved in the maintenance of the Delaware River navigation channels and anchorages be made with a view to arriving at improved solutions.

This report is the appendix to Sub-study 2, which is concerned with the nature, source, and cause of the shoaling in the navigation channels and anchorages of Delaware River. The basic concept of this particular phase of the investigation was to determine the total composition of the shoal utilizing techniques capable of determining all phases including the amorphous and organic materials as well as crystalline materials and to compare this with the composition of bottom and suspended sediments from streams draining watershed areas as well as bottom sediments of the bay and continental shelf area in the seaward direction. Environmental parameters were also evaluated in the water column to estimate the sediments resulting from pollution and eutrophication of the estuary by industry and municipalities. Dispersal patterns of diagnostic materials found in the shoal or water column were used as "natural tracers" to delineate source areas as well as nature and direction of transport of the materials. Special tests were conducted to determine the physiochemical and electrophoretic mobility parameters associated with the flocculation occuring at Marcus Hood shoal.

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ABSTRACT

An intensive investigation of the shoals and other bottom sediment locations and suspended sediment of Delaware estuary was conducted by the U.S. Army, Corps of Engineers to determine the cause and source of shoaling in the river estuary. Forty percent of the total shoaling in the Federally maintained man-made channel occurs in the Marcus Hook Range where the average mean grain size is 6 microns and only 2 percent of the sediment ranges up to fine sand-size. Sediment composition approximates 40 percent silt-size quartz, feldspar, and minor mica, 26 percent clay minerals (illite, chlorite, kaolinite, and minor montmorillonite and vermiculite), and 34 percent diatoms, organic matter, anthracite coal, amorphous iron, and minor other materials. Electrophoretic mobility measurements and other physiochemical tests suggest that flocculation is the controlling mechanism at this shoaling site. Approximately 75 percent of the sediment in the major shoals is derived from the upland watershed and it is estimated that the remaining 25 percent is derived from industrial effluents, municipal sewage discharge, and biogeneous materials derived from within the river estuary. Analysis of diatoms suggests that there are but negligible amounts of materials derived from the embayed portion of the estuary.

The organic matter comprises from 3 to 8 percent of the shoal sediments with proteinaceous material a large proportion of the organic matter. Fatty acids and hydrocarbons are also present in significant amounts. Organic matter and sewage accumulate in the bottom sediment because of the highly polluted nature of the surface waters as reflected by the low dissolved oxygen and high fecal coliform count as well as other environmental indicators. Anomalous amounts of diatoms in the bottom sediment of Marcus Hook shoal and nitrogen and phosphorus concentrations of the water column suggest that eutrophication conditions may exist in the estuarine waters.

Anthracite coal mine waste from the Schuylkill River has diminished since pollution abatement measures effected in 1952. Coal in the shoal areas ranges between 3 and 6 percent by weight with a dispersal pattern evident in a seaward direction from a "point" source in the Schuylkill River.

Low temperature, hydrous iron concentrations occurring in the shoals, identified by the sodium dithionite method, appear in part to be related to industrial acid effluents. The highest iron concentration, as 3 percent Fe_2O_3, occurs in the shoal sediments at Marcus Hook; other bottom sediments generally average about half this amount.

Heavy metals in the bottom sediment show marked concentration in shoal areas with Marcus Hook shoal containing more than other shoals. Zinc has anomalous occurrences in the Christina and Schuylkill Rivers and a dispersal pattern is evident in suspended samples of Christina River. Mercury concentrations are highest in the navigation channel in vicinity of Pea Patch Island about 10 miles south of Wilmington. Old dredge spoil samples tested from historic dredge areas correlate well with contemporary heavy metal concentrations except for mercury; this metal appears to abate in quantity after spoiling as a result of the release of some of this metal back into the environment by bacteria action or plants.

A comparison of the electrophoretic mobility measurements and other physiochemical parameters of the shoal sediments reveals that Marcus Hook shoal reflects flocculation while other shoals are less affected. Apparently iron oxide as thin films on quartz surfaces and possibly organic constituents aid in the

flocculation process. X-ray microprobe analysis reveals both high silica and iron with iron limited to thin films. Electron diffraction reveals the iron thin films to be gamma Fe_2O_3 (lepidocrocite) and alpha $Fe_2O_3 \cdot 3H_2O$ (goethite). The quantity of freshly deposited iron oxide is greater in Marcus Hook shoal than elsewhere in the river estuary.

Diagnostic heavy minerals of sand-size reflect upon the long term transport characteristics of the estuary. The river estuary is a typical fluvial Piedmont source since the Piedmont streams from below head of tide discharge approximately 80 percent of the annual input of transparent heavy minerals to the estuary in the distance to the bay at mile 49; this heavy-mineral suite is rich in hornblende and garnet. The heavy-mineral suite of Delaware Bay is a mixed Piedmont and Coast Plain source characterized by high silli-manite; this province extends southward along the Delaware coast in the continental shelf area. Glacially derived heavy minerals along the New Jersey shelf area are rich in pyroxene and impoverished in silli-manite relative to the Delaware Bay heavy-mineral suite and a dispersal pattern into the lower eastern bay area is reflected by the heavy minerals. Using sillimanite as the diagnostic mineral to reflect upon sediment transport, it is apparent that a net sediment transport from the bay via the Delaware submarine channel exists which exceeds the input of sediment around the capes by littoral currents; correlation exists in sus-pended sediment investigations and feldspar dispersal patterns. No apparent mixing of sediment occurs across the capes and the heavy mineral distribution reflected in this investigation correlates with the hydrodynamics and bathymetry in vicinity of the mouth of Delaware Bay.

Pollution parameters verify that the water column over major shoaling areas are a contributing factor to the high organic content of the shoals. Phosphorus and nitrogen concentrations from sewage and industry also are sufficient to cause the eutrophication conditions reflected by large quantities of biogenous diatoms and other organic matter in the shoal sediments.

INTRODUCTION

PURPOSE AND SCOPE

The navigation channel from the capes at the entrance of Delaware Bay to the head of tide at Trenton, N. J. requires the removal of more than 8 million cubic yards of dredge spoil annually. Most of this shoaling occurs in the estuary from vicinity of the C and D canal to Philadelphia; major shoaling sites are Fort Mifflin shoal at Philadelphia, Marcus Hook shoal approximately 14 miles south of Philadelphia, and Pea Patch Island shoal 10 miles south of Wilmington (see Figure 1). The most prolific shoaling area, accounting for about 40 percent of the annual dredging done by the Federal Government in the Delaware estuary, is the Marcus Hook anchorage and navigation channel situated near the mean point of salinity intrusion into the estuary and near major discharge points from tributary rivers as well as municipality sewage discharge and industrial effluents (see Figure 2). This physical setting in relation to source materials and the hydrodynamics of the estuary will be shown to be the reason for the high sedimentation rate at Marcus Hook shoal.

The purpose of this report is to report on the texture and composition of the shoal material which must be dredged from the navigation channels and the bottom sediment from other portions of the estuary and adjacent areas for comparison so that source areas might be delineated by diagnostic materials. In recent years, the recognition of estuaries as traps for toxic heavy metals, toxic insecticides, and toxic pathogens has also made the knowledge of these materials necessary from the ecological factors involved in dredging operations.

In this investigation, the materials contributed from the tributary streams to the watersheds are based on bottom sediment above tidal reach and suspended samples from 1 foot above bottom and 0.2 and 0.8 depth at 20 minute intervals for a period of 1 hour during peak discharge following greater than average runoff from the watershed. This composition data coupled with annual discharge records as maintained by the United States Geological Survey provides the annual watershed input data for quantitative evaluations. Within the estuary, the industrial and municipal wastes as well as local eutrophication effecting diatom blooms constitutes contributions to the active sedimentation. The condition of the water determines how much of these wastes actively precipitate or are altered in their transport. The fecal coliform per 100 ml of suspended sample, dissolved oxygen in mg/liter, nutrient levels, and other parameters will be used to evaluate the relatively high organic content and industrial solids in the shoal areas.

Since the settling of solids in a chemically complex liquid medium of varying hydrodynamic properties during a reversing tidal cycle produces the shoal, special attention in this investigation is also directed to the physiochemical relationships of the flocculation phenomena.

NOMENCLATURE

A glossary of terms is provided to acquaint the reader with nomenclature used. A term that has wide usage but which varies in definition is the term estuary which may be classified from several points of view. The Delaware estuary might be defined by a geomorphologist as a "drowned river-mouth" while oceanographers classification would include the concept of the farthest point inland where seawater is measurably diluted with fresh water.

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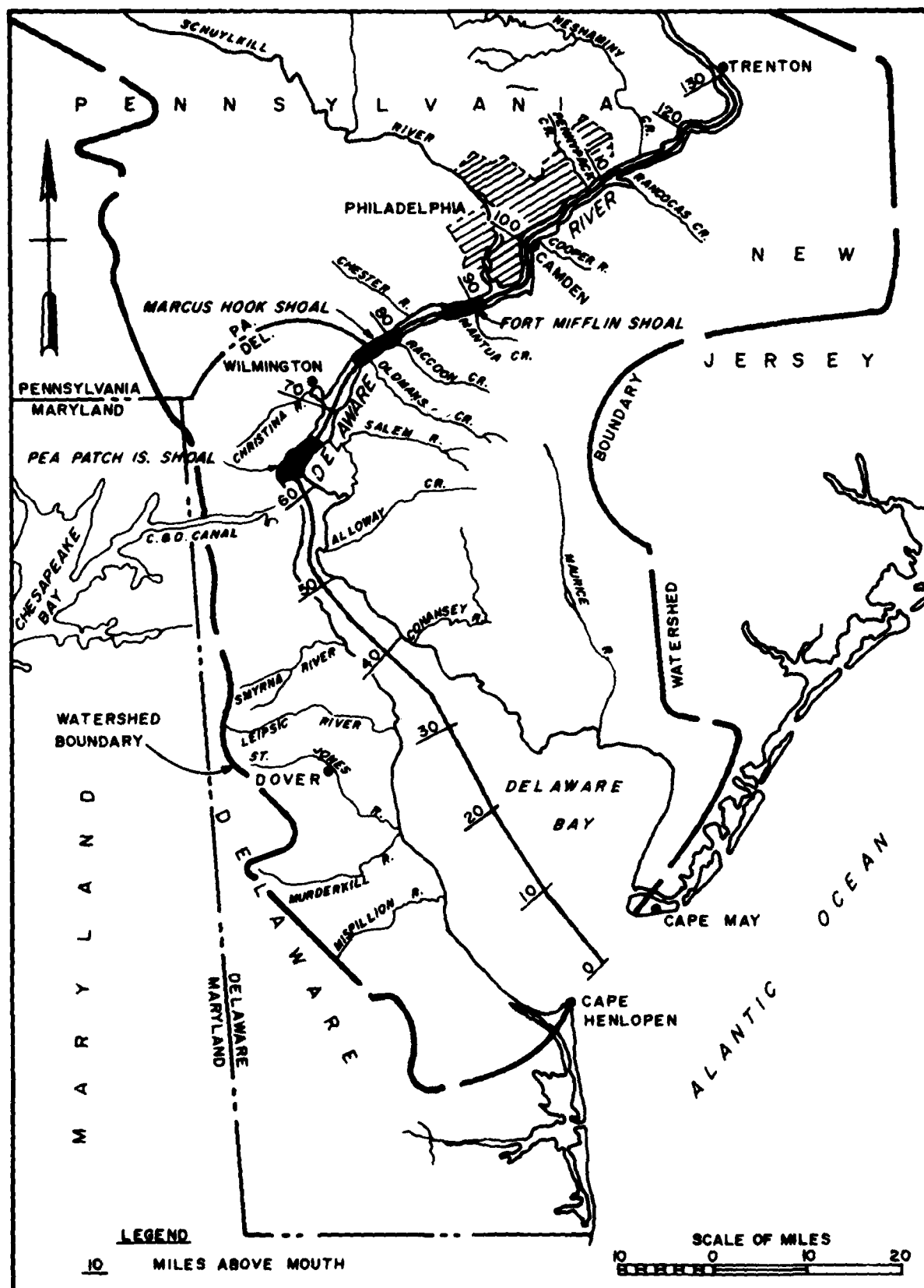
FIGURE I. Delaware Estuary Showing Location Of Major Shoals

2
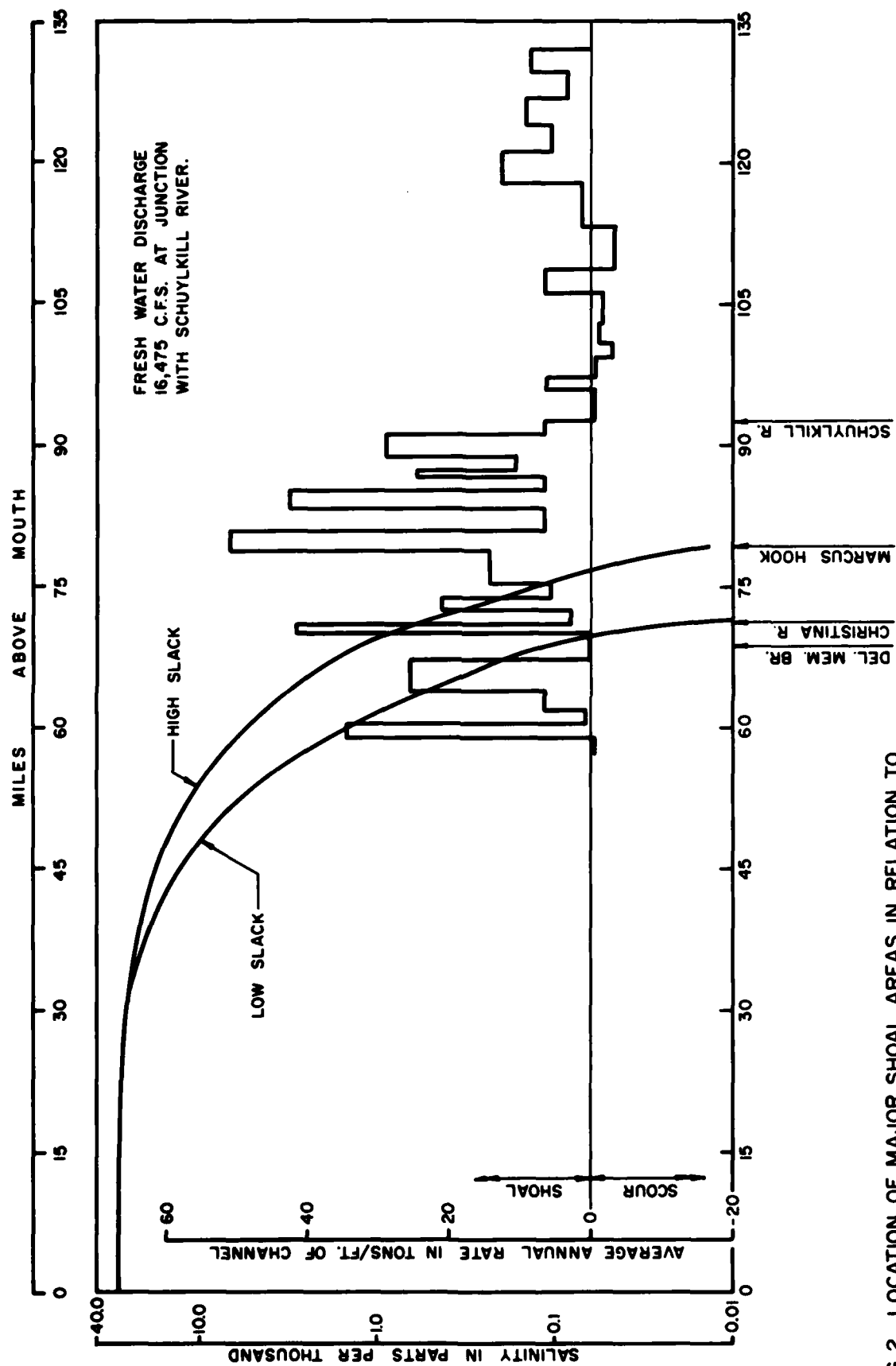
FIG. 2 LOCATION OF MAJOR SHOAL AREAS IN RELATION TO
AVERAGE SALT WATER INTRUSION IN THE DELAWARE RIVER.

3

The classification by Ippen (1966) and others who emphasize tidal dynamics in estuaries will be employed in this investigation; this classification extends the estuary to "head of tide". The Delaware estuary is by definition that portion of the Delaware watershed from the capes at the mouth of the bay to Trenton, New Jersey, a distance of 133 miles. The portion of Delaware River between Trenton and the head of bay is referred to as the "river estuary" to distinguish it from the embayed portion (Delaware Bay) of the estuary.

In heavy mineral investigations of Coastal Plain Formations and estuarine sediments, the concept of "full" versus "stable" heavy-mineral suites is in wide spread use (Owens and Sohl, 1969). A "full" suite contains less stable mineral species such as hornblende and pyroxene while the "stable" suite contains only the minerals highly resistant to chemical weathering. Zircon, rutile, and tourmaline are considered the most resistant of the heavy mineral species. More detail regarding the stability of heavy mineral species is afforded the reader in Annex B.

METHODS OF ANALYSIS

Approximately 140 samples of bottom sediment were obtained by means of a Shipex and harpoon sampler by the Philadelphia District, U. S. Army, Corps of Engineers, from locations in the Delaware estuary and tributary streams shown in Figure 3. In addition, 24 samples from the continental shelf in vicinity of the capes were obtained from the Coastal Engineering Research Center and three beach samples off the Delaware coast were procured from the Geology Department of the University of Delaware. Most of the bottom samples were obtained in the summer of 1969; however, several shoal samples were collected periodically up to March 1972. Suspended samples were also obtained in the vertical water column over a complete tidal cycle from 9 points at 3 locations in the estuary on 15 May and 23 July 1969. At periods of peak stream discharge, following high runoff in the watershed of tributary streams, suspended samples were obtained from 3 depth locations in order to obtain material in suspension that was representative of sediment discharged to the estuary. Measurements of pH and Eh were also obtained in the field during sampling of key shoal areas.

The samples of sediment were frozen in dry ice and shipped to the U. S. Army, Corps of Engineers, South Atlantic Division Laboratory, for analysis. The test methods utilized in this study were especially designed to obtain quantitative data on all significant materials including organic and amorphous materials as well as crystalline materials so that source study evaluations could be effected. Many of the techniques employed are conventional while others were adapted to this type of study for the first time. A brief summary of tests is described in the following paragraphs and details of the test methods are described in Annex D.

A method for determination of amorphous and organic materials embraces the use of differential thermal analysis, thermogravimetric analysis, and the mass spectrometer in conjunction with scanning electron microscopy and analytical chemical techniques (Neiheisel, 1972). Identification of crystalline materials was effected by means of x-ray diffraction and petrographic techniques. Of special significance was the analysis of heavy minerals separated into several magnetic fractions by use of the isody-
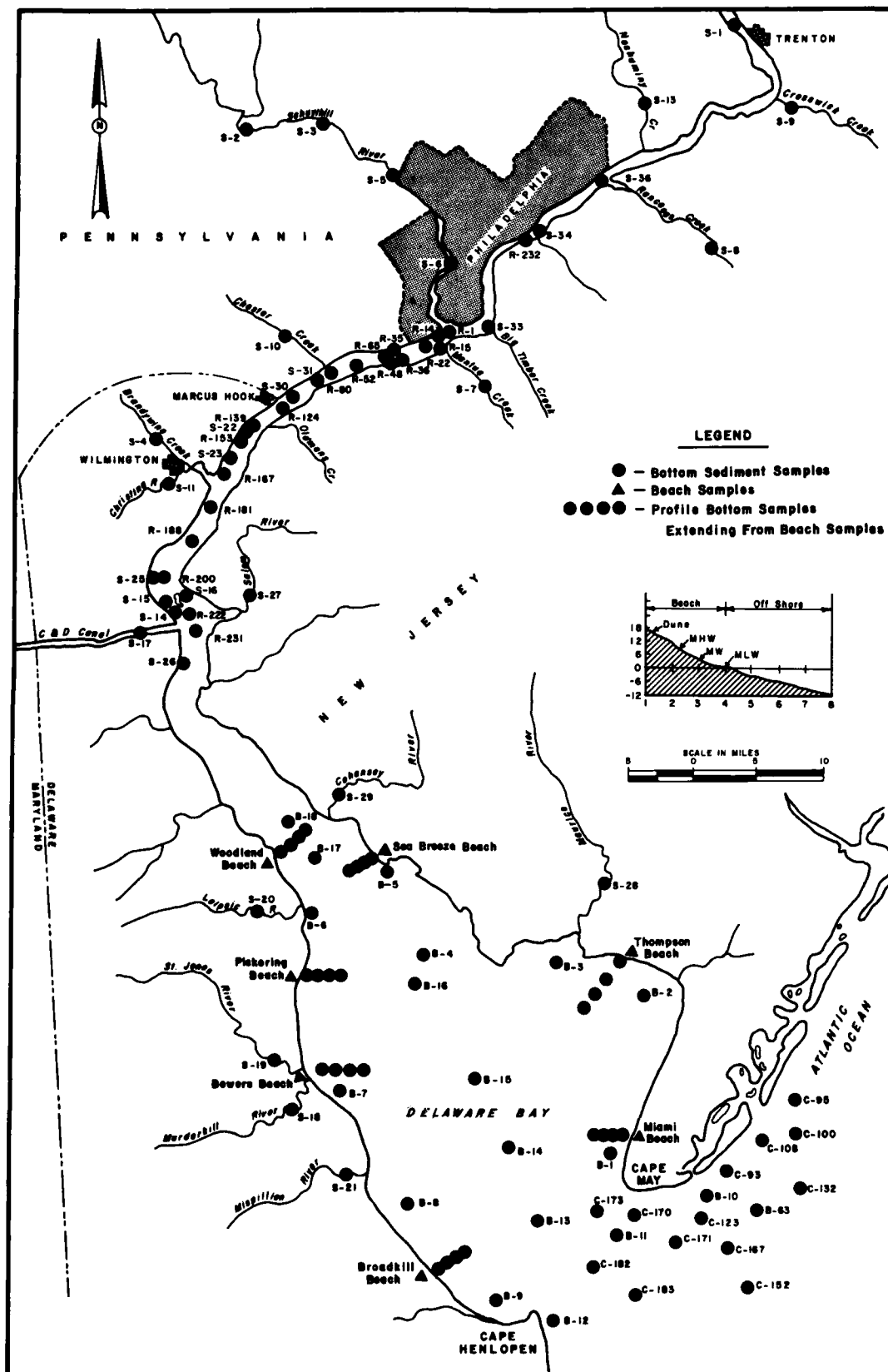
FIGURE 3   LOCATION OF BOTTOM SEDIMENT SAMPLES IN DELAWARE ESTUARY AND VICINITY

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namic magnetic separator and x-ray diffraction analysis of these fractions used as corroborating evidence to the petrographic technique; twelve samples thus analyzed present a high degree of confidence to the heavy minerals as reported in this investigation.

Electron microscopy was used in establishing diatom identification while differential caustic leach and x-ray diffraction of a calcined sample in reference to an aluminum oxide internal standard was used for evaluation of the concentration of diatoms in the sediments.

A combination of electron diffraction and the electron microprobe was instrumental in gaining data of thin films on sediment source material while electrophoretic mobility studies were used to gain an insight into conditions favoring flocculation.

GEOLOGICAL SETTING OF DELAWARE ESTUARY

The Delaware River in its headwaters trends in a NW-SE direction across the Appalachain Highlands and Piedmont crystalline rocks. At the head of tide at Trenton, the Delaware River bends at nearly right angles in a NE-SW direction to parallel the regional trend. Thus, the Delaware River parallels the Fall Line which separates the Piedmont from the Coastal Plain physiographic province. At the head of the embayed portion of the Delaware estuary, the trend is again NW-SE through Coastal Plain sediments to the Atlantic Ocean.

The geologic formations in the regional setting of the Delaware estuary is depicted in Figure 4. The Piedmont crystalline complex is comprised of Pre-Cambrian metamorphic and igneous rocks, Pre-Cambrian-Paleozoic Wissahickan Schist and Baltimore Gneiss, Paleozoic folded and faulted sediments, and Triassic red and grey continental sandstones and shales with intrusions of diabase. The Coastal Plain sediments consist of Cretaceous Formations outcropping near the Fall Line and Eocene, Miocene and Quaternary sediments being predominant toward the coast. Varying thicknesses of Pleistocene sediments blanket most of the Coastal Plain and lower part of the Piedmont provinces.

The rather unique geologic setting of the Delaware River estuary along the Fall Line provides an ideal study area for controlled heavy mineral evaluations. The Piedmont crystalline rocks on the northwest side of the river estuary contribute a "full" heavy-mineral suite while the Coastal Plain sediments older than Pleistocene contain a relatively stable heavy-mineral suite. With evaluation of the heavy-mineral suite in the Delaware River bottom sediment at Trenton and progressively along the river estuary, the influence of the contributing sources is observed in the heavy-mineral suite. Analysis of the bottom sediments of the streams draining these contrasting sources of heavy minerals also provides basis data for evaluation. Stream gaging records by the U. S. Geological Survey on sediment discharge when coupled with the heavy mineral analysis provide a quantitative means of determining the source of heavy minerals through the river estuary.

The embayed portion of the estuary constitutes Delaware Bay which receives discharge from Coastal Plain streams and is contained in a wedge of predominantly clastic sediments tapering from the surface at the Fall Line to 7,000 feet thick at the mouth of Dela-

6

SCHUYLKILL RIVER

OЄ

PIEDMONT CRYSTALLINE ROCKS

A

PHILADELPHIA

P

Th

Tv

Th

Tv

COASTAL PLAIN SEDIMENTS (UNCONSOLIDATED)

Tc

A'
ATLANTIC CITY

N

DELAWARE BAY

SCALE IN MILES

5 0 5 10 15

200
100

SECTION A – A'


```
        A      DELAWARE RIVER                    DIVIDE
  200'
  100'
    0'
        P
```

HORIZONTAL SCALE
5   0   5   10   15 MILES
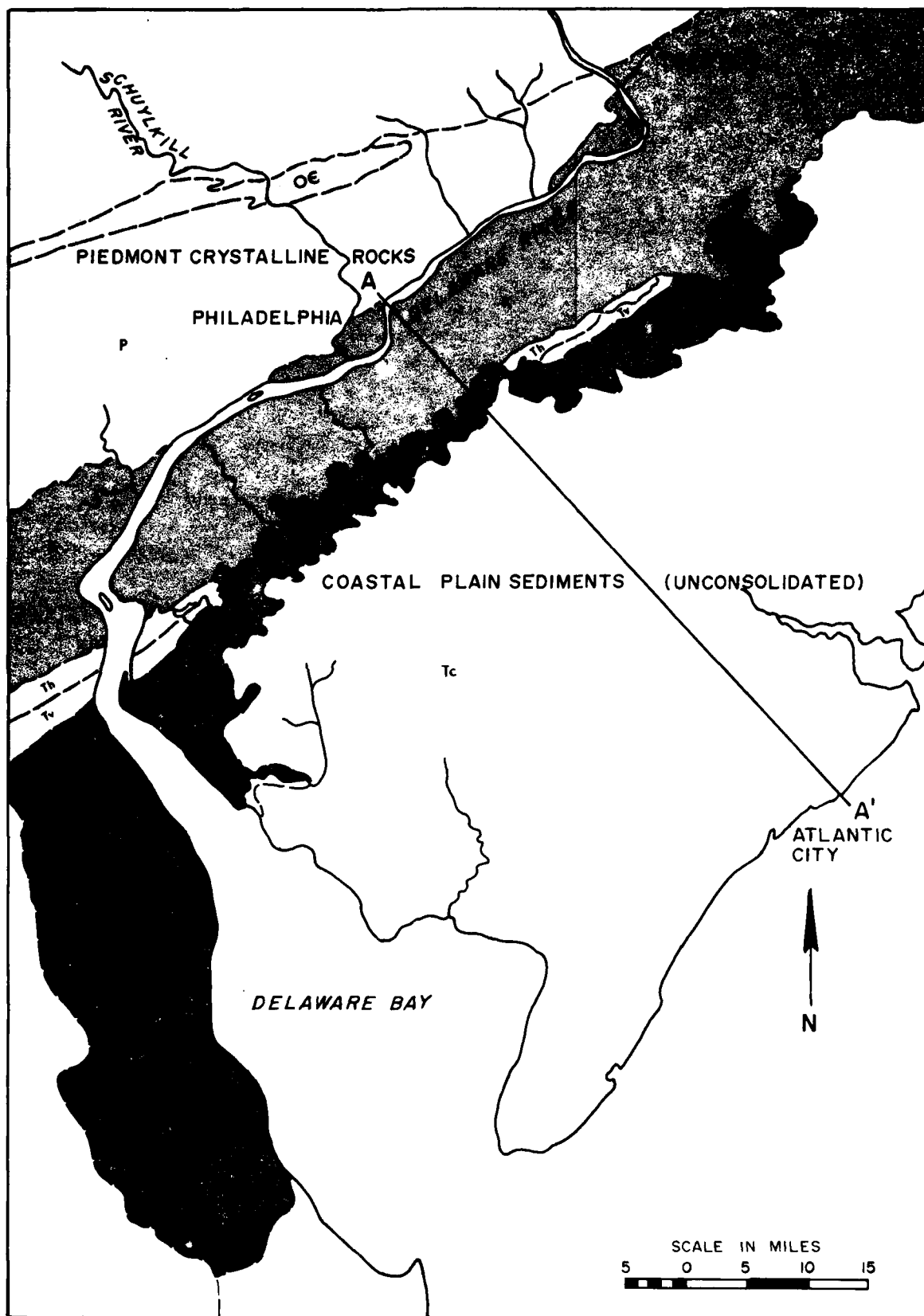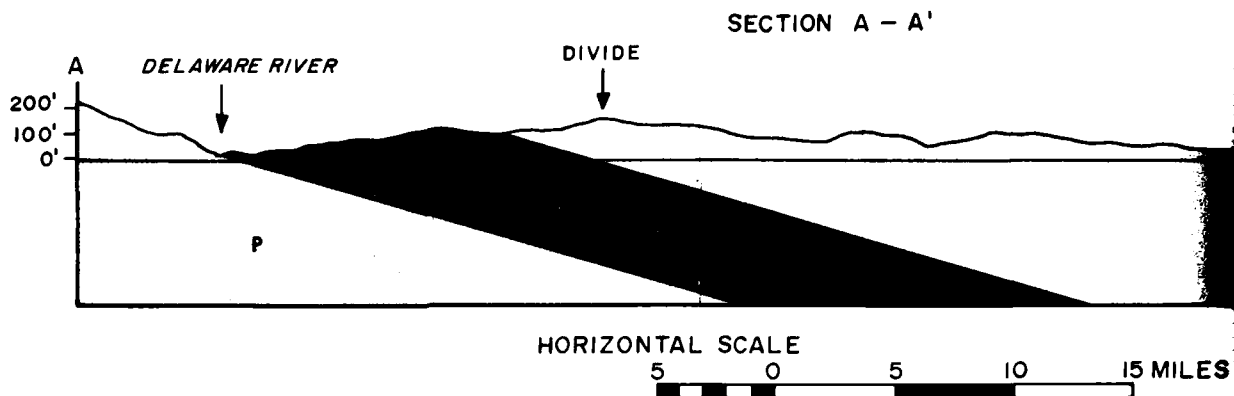
EXPLANATION

TERTIARY

Tc COHANSEY SAND

■ KIRKWOOD FORMATION

Tv VINCETOWN SAND

Th HORNERSTOWN MARL

CRETACEOUS

■ INCLUDES: THE FOLLOWING FORMATIONS
RED BANK SAND, NAVESINK MARL, MOUNT
LAUREL & WENONAH SANDS MARSHALL-
TOWN FM, ENGLISHTOWN, WOODBURY &
MERCHANTVILLE CLAY; NONMARINE
SEDIMENTS SUCH AS MAGOTHY, RARITAN,
PATAPSCO, PATUXENT

TRIASSIC

Tr TRIASSIC S▮
    & IGNEOUS

ORD-CAMB

■ ORDOVICIA▮
    CARBONATE▮

PALEOZOIC

P PALEOZOIC ▮
    SCHIST, GRA▮
    CRYSTALLI▮

NOTE: 1. SECTION A-▮
         PAPER 381 ▮
      2. GEOLOGIC ▮
         MAP OF DEL▮
         ADJACENT ▮

LONG ▮

GENERA▮

OF ▮

U. S.▮

(SOLIDATED)

A'
ATLANTIC
CITY

N

▮ MILES
10   15

3

SECTION A — A'

ATLANTIC CITY

A'

SEA LEVEL

Tc

SCALE

0   5   10   15 MILES

EXPLANATION

TRIASSIC

Tr TRIASSIC SEDIMENTARY FORMATIONS
& IGNEOUS INTRUSION

ORD-CAMB

ORDOVICIAN & CAMBRIAN
CARBONATE FORMATIONS

PALEOZOIC

P PALEOZOIC & PRECAMBRIAN GNEISS,
SCHIST, GRANITE, & OTHER RELATED
CRYSTALLINE ROCKS

NOTE: 1. SECTION A-A AFTER USGS PROFESSIONAL
PAPER 381 PLATE 6.
2. GEOLOGIC MAP AFTER USGS GEOLOGIC
MAP OF DELAWARE RIVER BASIN AND
ADJACENT NEW JERSEY.

ATIONS
MOUNT
HALL-
URY &
NE
ARITAN,

LONG RANGE SPOIL DISPOSAL STUDY

GENERALIZED GEOLOGIC MAP AND SECTION
OF DELAWARE ESTUARY AND VICINITY

U. S. ARMY ENGINEER DISTRICT
PHILADELPHIA

FIGURE 4

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ware Bay and increasing to a maximum thickness of 17,000 feet in the Baltimore Trough. Heavy mineral patterns in the bay are controlled by the hydrodynamics of the bay with sources from the river estuary and the contribution from the tributary streams to the bay as well as erosion of the beaches and marshes around the bay area. Toward the mouth of the bay there exists the complex interaction of the sediments of the continental shelf and coast which are controlled by the bathymetry and hydrodynamics along the coast.

The Delaware estuary location within the physiographic boundaries indicated is a recent geologic event. As Schubel (1971) points out,

positions of the present day estuaries are a consequence of the rise of sea level some 125 meters following the retreat of the last continental glacier approximately 18,000 years ago. Estuaries have had outlines approximately their present configurations for only the past few thousand years, but many of the deeper submerged river valley estuaries such as the Delaware River estuary, have occupied the deeper seaward portions of the same basins for 8,000 to 10,000 years. According to Kraft (1971) the Delaware estuary approximately 7,000 years ago occupied a position of a narrow river valley in the site of the lower end of present Delaware Bay to a bay area extending more than 10 miles onto the present day continental shelf.

RIVER DRAINAGE AREAS AND SEDIMENT DISCHARGE

The entire Delaware drainage basin, excluding the surface area of the bay, measures 12,765 square miles and comprises large parts of the states of New York, New Jersey, Pennsylvania, and Delaware, as well as a few square miles of Maryland. (See Figure 5) U. S.

Geological Survey, Water Resources Data Reports (1969) and U. S. Army, Corps of Engineers Reports (1969) present the following drainage area and annual average tons of sediment discharge for the following streams tributary to the Delaware drainage basin.

Stream and Drainage Area	Drainage Area (Sq.Mi.)	Annual Tons Sediment Discharge	Annual Tons Heavy Minerals	Annual Tons Transparent Heavy Minerals
Delaware R.—Piedmont and at Trenton App. Highlands	6,780	770,000	3,080	1,786
Crosswick Cr.—Coastal Plain	139	9,000	11	3
Neshaminy Cr.—Piedmont	233	45,100	185	94
Rancocas Cr.—Coastal Plain	342	14,300	51	17
Pennypack Cr.—Piedmont	56	12,300	20	8
Cooper River—Coastal Plain	40	2,200	4	2
Schuylkill R.—Piedmont and Valley & Ridge	1,916	231,000	693	243

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Stream and Drainage Area	Drainage Area (Sq.Mi.)	Annual Tons Sediment Discharge	Annual Tons Heavy Minerals	Annual Tons Transparent Heavy Minerals
Mantua Creek—Coastal Plain	51	2,800	8	1
Darby Cr.—Piedmont	79	21,800	200	40
Crum Cr.—Piedmont	38	10,500	95	21
Ridley Cr.—Piedmont	38	10,500	95	21
Chester Creek—Piedmont	67	19,300	116	61
Christina R.—Coastal Plain	284	27,000	137	64
Christina R.—Piedmont	284	27,000	137	64
Salem River—Coastal Plain	112	6,700	7	3
Smyrna River—Coastal Plain	64	11,450	11	4
Cohansey R.—Coastal Plain	106	11,560	22	5
Maurice R.—Coastal Plain	388	11,948	26	18
St. Jones R.—Coastal Plain	90	12,038	12	3
Murderkill R.—Coastal Plain	96	12,134	4	1
Mispillion River—Coastal Plain	126	12,260	23	13

The percent heavy minerals listed is based on the testing of the bottom sediment sand fraction between 74 and 420 micron size (See Table 1 of Annex B). The sand fraction of the sediment discharge is a statistical estimate, based on U. S. Geological Survey (1967) computations that approximately 10 percent of the sediment discharge is sand size material. The annual tons of heavy minerals listed is the product of the percent heavy minerals and the annual tons of sand. The annual tons of transparent heavy minerals is the percentage of transparent heavy minerals (minus mica) listed in Table 1 of Annex B for the heavy minerals times the annual tons

of heavy minerals, this tonnage is an index to the amount of transparent heavy minerals transported to the river estuary and bay by the streams from their respective source areas

The amount of transparent heavy minerals transported to the river estuary by Piedmont streams between Trenton and the bay is estimated as 5 times that delivered annually by the Coastal Plain streams along the same stretch of river. This will be an important aspect in use of heavy minerals as natural indicators of source areas in a later section of this report

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DELAWARE WATERSHED			
REACH	DRAINAGE AREA (SQ. MILES)	SEDIMENT (ANNUAL TONS)	MEAN FRESH WATER DISCHARGE (CFS)
HEADWATERS DEL. RIVER TO TRENTON	6,780	770,000	12,000
TRENTON TO SCHUYLKILL RIVER	3,209	354,500	4,560
SCHUYLKILL RIVER TO CHRISTINA RIVER	1,033	131,900	1,400
CHRISTINA RIVER TO CAPES	1,743	145,600	2,240
TOTAL	12,765	1,402,000	20,200
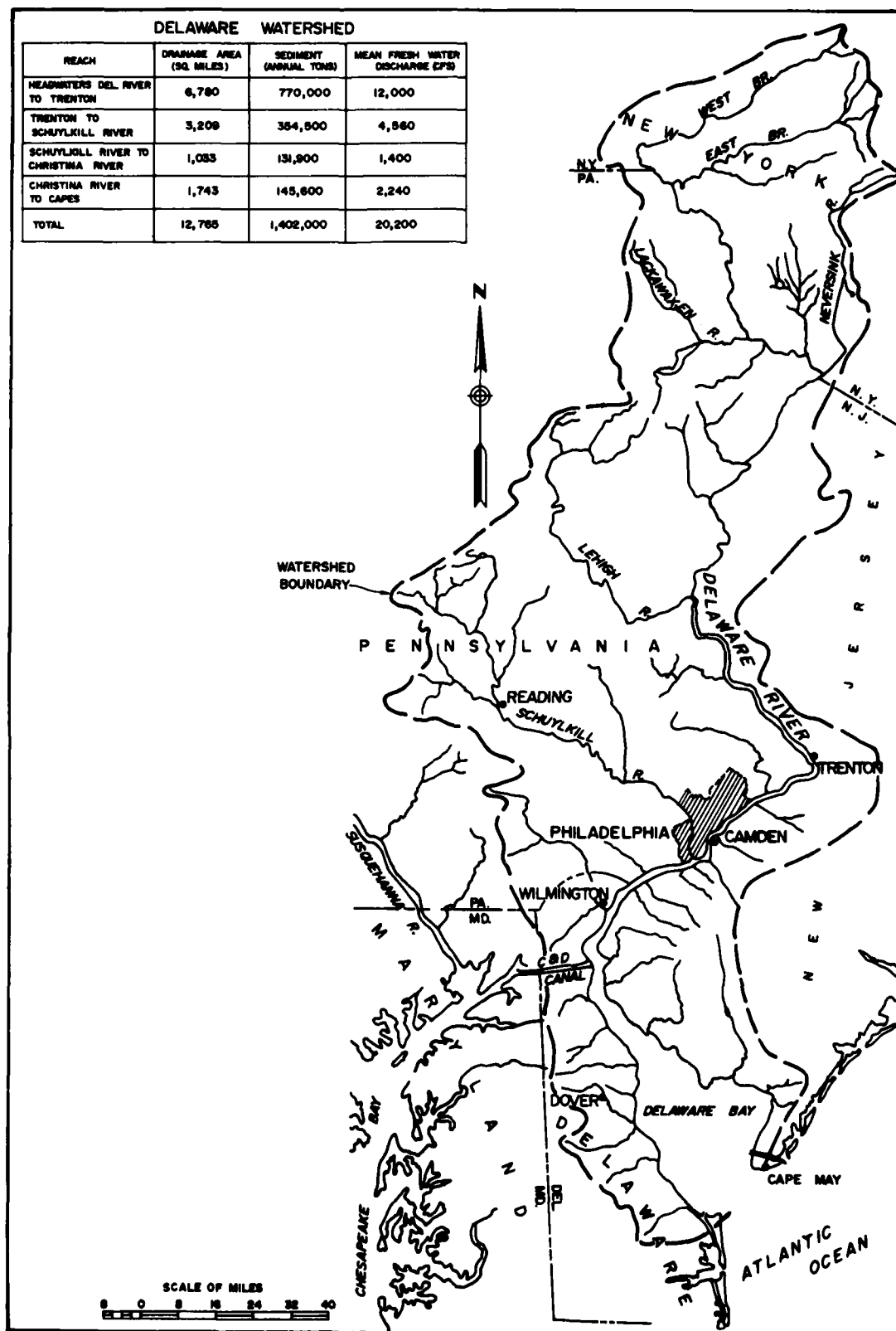
FIGURE 5. DELAWARE RIVER WATERSHED

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ANALYSIS OF DELAWARE ESTUARY BOTTOM SEDIMENTS

SEDIMENT TEXTURE

The bottom sediment samples from the capes to Trenton, New Jersey vary in both texture and composition with sand size and more homogeneous sediments in the bay area and heterogeneous and finer textured organic and inorganic admixtures in the estuary. The sediment was sized by hydrometer and sieve analysis and a cumulative grain size distribution curve made for each sample location. The boundaries of silt and clay are in accordance with current ASTM procedures at 2 microns (0.002 mm); the boundaries between silt and fine sand used were 74 micron (0.074 mm). A sediment description, based on a triangular plot in accordance with Shepard (1953) is depicted in Figure 6. The shoal sediments are sandy silts and silty clays to which the term organic might appropriately be prefixed to describe the relatively abundant organic matter from the watershed and wastes from activities of man along the estuary.

The average composition of bottom sediment for the estuary and bay area is summarized in Table 1 and the composition of individual samples are included in the tables of Annex A. Because of the variation in composition with grain size, the sediment was split at the 44 micron size for more uniform conditions in comparison analysis; materials greater than 44 microns were identified by petrographic techniques and finer than 44 micron size by a variety of techniques including diffraction, differential thermal, mass spectrograph, electron microscopy, and chemical methods. The average sample as reported is the weighted average of these two functions. The average composition of the 3 major shoals of Delaware River are shown graphically in Figure 7.

The major minerals, organic materials, amorphous diatoms and iron oxides and materials important for environmental factors and diagnostic trance constituents will be considered in the following paragraphs.

BIOGENOUS MATERIAL

Introduction

The biogenous fraction of bottom sediment and spoil samples formed by organic processes includes vegetable matter, organic sewage, diatom remains, human and animal ejecta, and other organic materials. Anthracite coal, a fossil fuel derived largely from strip mining in the watershed is also a biogenous material since it was formed from geologic processes which changed vegetation to the fossil fuel. The biogenous material in this study will be categorized into organic matter, anthracite coal, diatoms, and oil and grease. In Marcus Hook shoal, the biogenous material averages 31 percent (see Figure 7) as compared to 21 percent for Fort Mifflin shoal and 18 percent for Pea Patch Island shoal.

Organic Matter

Organic matter in bottom sediments of the Delaware estuary ranges from trace amounts to 8 percent by dry weight with greatest concentration in the organic clayey silts of the shoaling areas. The term organic matter refers to a variety of amorphous organic materials which includes vegetation debris, animal wastes from sewage, and organic chemical effluents from industry and municipalities which have not decomposed and accumulate as part of the bottom sediment in rivers. In this study, organic matter is restricted to those materials which appear as

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Legend

▲ Delaware River (Mile 36 to head of tide)
■ Marcus Hook shoal, Delaware River
✗ Tributary streams
● Delaware Bay (Mouth to mile 36)
+ Beach sands, Delaware Bay(MWH)
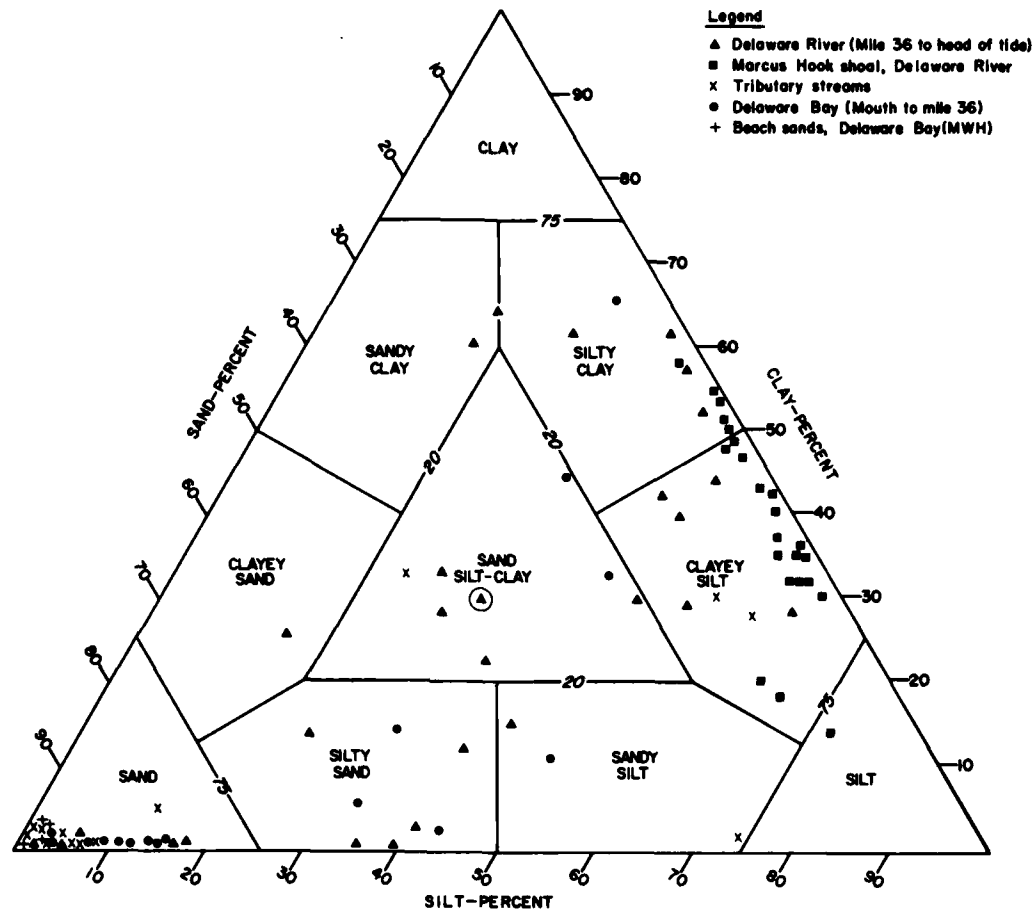
Nomenclature according to Shepard(1953)

Sand sizes: 2.00mm to 0.074 mm
Silt sizes: 0.074 mm to 0.002 mm
Clay sizes: < 0.002 mm
Example of interpretation: The circled ⓐ
near the center of the diagram is 30%
clay, 33% silt, and 37% sand.

FIGURE 6   SAND-SILT-CLAY CONTENT IN DELAWARE ESTUARY AND BAY BOTTOM SEDIMENTS

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TABLE 1

SUMMARY OF AVERAGE BOTTOM SEDIMENT COMPOSITION IN DELAWARE ESTUARY FROM TRENTON, N. J. TO THE CAPES.

Constituents	Delaware River N. of Trenton	Delaware River Trenton to Philadelphia	Schuylkill River	Fort Mifflin Shoal	Schuylkill River to Wilmington	Marcus Hook Shoal	Wilmington to Ship John Light	Pea Patch Island Shoal	Ship John to Capes	Vicinity of Capes
					Average % Composition of Samples					
Quartz	83.8	63.9	60.4	50.8	56.3	24.5	57.3	51.6	83.6	93.5
Feldspar	2.2	8.2	7.8	9.5	7.1	14.1	9.9	11.6	6.1	3.4
Mica	2.4	1.6	1.3	0.5	0.8	0.1	0.7	1.3	1.0	0.2
Clay Minerals	5.2	15.8	5.9	16.6	12.3	26.4	16.5	14.2	4.3	1.4
Heavy Minerals	2.3	2.1	0.8	0.3	1.3	0.1	1.1	1.1	2.8	0.5
Organic Matter	1.5	2.4	5.3	5.9	3.2	8.0	2.2	3.1	0.5	0.3
Coal	1.6	0.5	15.3	5.6	4.7	5.4	3.2	3.0	0.0	0.0
Diatoms	0.1	5.0	1.4	9.2	13.3	18.0	8.0	12.0	0.3	0.1
Amorphous Iron	0.4	0.3	1.4	1.4	0.8	3.1	0.7	1.8	0.1	0.1
Other	0.5	0.2	0.4	0.2	0.2	0.3	0.4	0.3	1.3	0.5
					Average % Clay Fraction					
Illite	50	57	65	53	65	61	65	50	59	72
Chlorite	26	29	18	25	15	18	20	20	26	23
Kaolinite	19	8	11	15	15	13	10	25	8	3
Montmorillonite	5	6	6	7	5	8	5	5	7	2
					Number of Bottom Samples					
Number Samples	4	5	13	6	20	12	11	6	15	3

NOTES: 1. Other includes calcite, shells, glauconite, and miscellaneous rock particles and slag.

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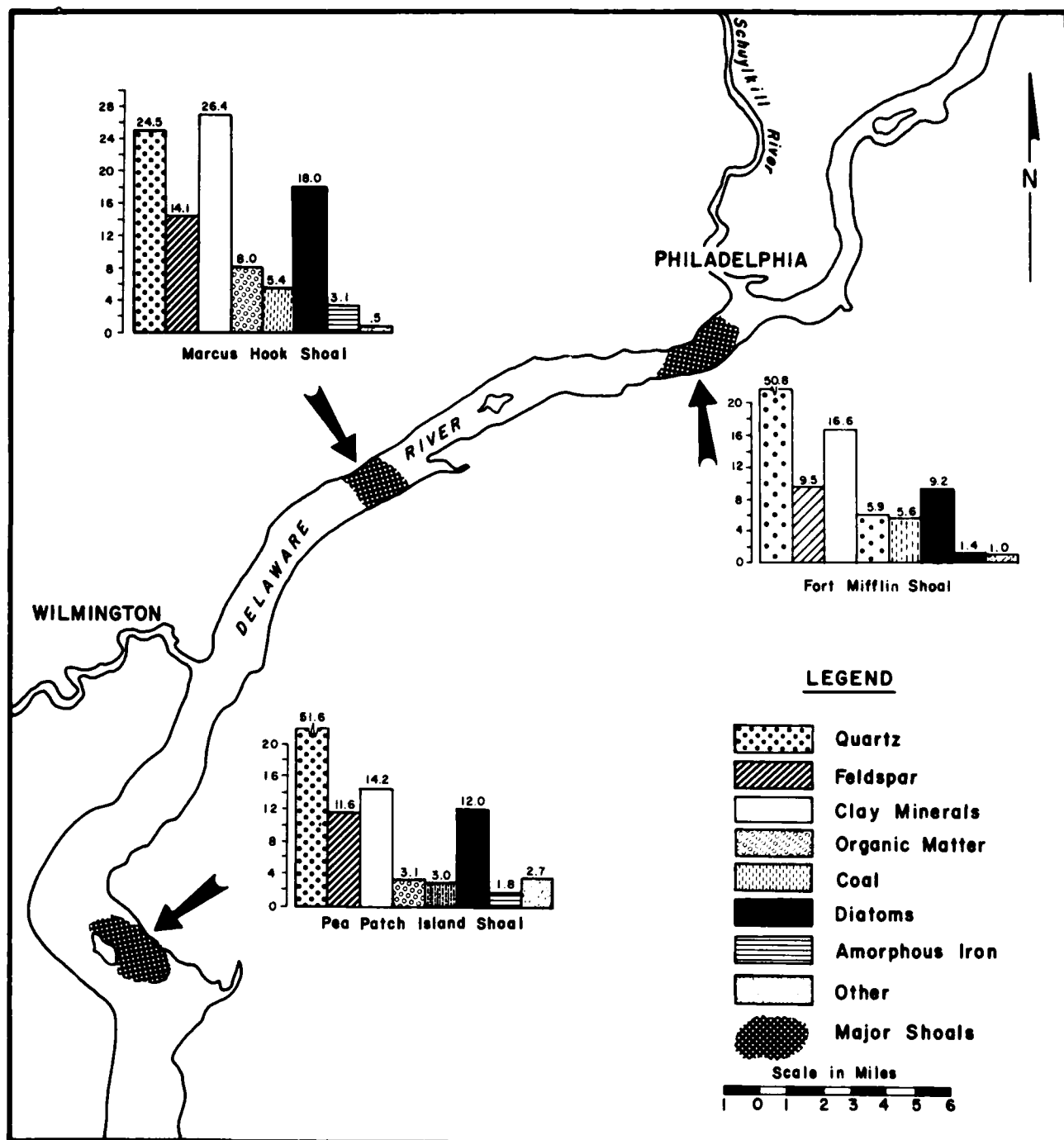
Figure 7. Sediment Composition of Major Shoal Areas in the Delaware River

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an exotherm in the 300° C chart region of the DTA or as obtained by chemical techniques previously cited. As shown in Figure 8, the organic matter tends to increase with decreasing grain size in the shoal sediment of Marcus Hook with greatest concentration in minus 10 and minus 5 micron size range;this concentration of the organic matter as finely divided particles suggests that sewage constituents may comprise a substantial portion of this fraction in the Marcus Hook shoal. Although detailed study by DTA techniques were not accomplished on various size fractions of Pea Patch Island shoal sediments, it was observed that marsh grass and vegetation occurred in the fine sand and silt sizes and constituted the bulk of that material comprising the organic matter in that shoal;it is estimated that

sewage content of this shoal is minor as compared with Marcus Hook shoal and this will be shown as highly likely with analysis of the environmental pollution parameters of the water column in a later section of this report.

Analyses of the organic matter of the bottom sediment of the Delaware River by Reuter (1970) using chromatography techniques disclosed that 80 to 95 percent of the organic matter soluble in acid benezene methanol solution is proteinaceous matter and that the amino acid pattern of this proteinaceous matter in the estuary differs upstream and downstream of the Marcus Hook shoal area. The solvent extractable organic matter, for 6 sample locations depicted in Figure 3, is listed below.

SOLVENT EXTRACTABLE ORGANIC MATTER

Sample No.	Benzene-methanol ppm	n-hexane soluble fraction		n-hexane insoluble fraction	
		ppm	% of total	ppm	% of total
R1	1450	1150	79	300	21
R52	580	278	48	302	52
R124	776	311	40	465	60
R167	1860	1666	90	194	10
R200	2723	1737	64	986	36
R231	1929	815	42	1114	58

The distinctly different spectrum of amino acid is interpreted by Reuter (1970) as reflecting different sources of proteins. Organisms growing in the water such as microorganisms would differ from "organic detritus" from sewage and other sources. The differences in the various amino acids and respective concentrations for different locations (Figure 3) in the bottom sediment of the river estuary is listed for 6 samples as follows:

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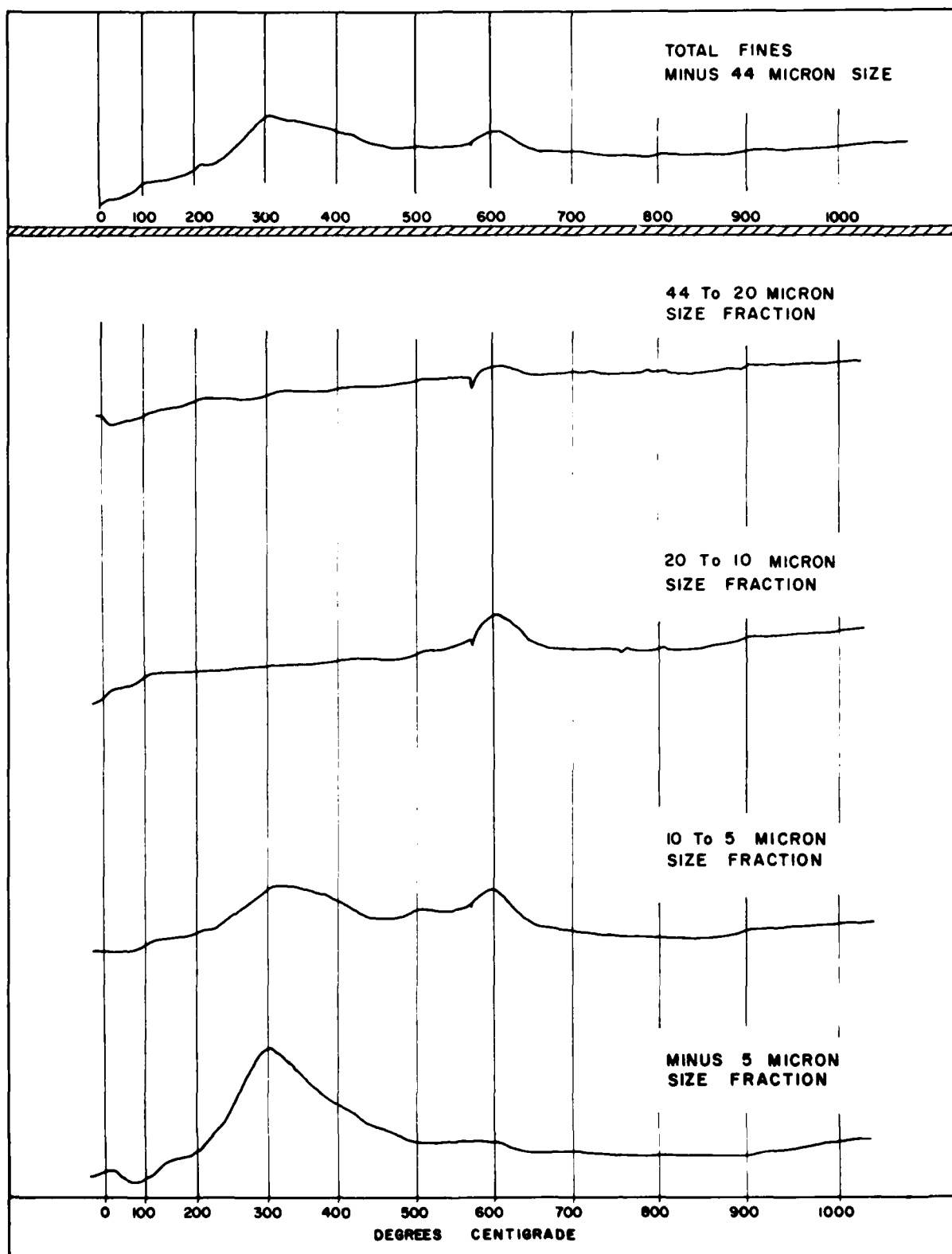
Figure 8. Differential thermal analysis curves of dispersed Marcus Hook shoal sediment for various size fractions.

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AMINO ACIDS IN DELAWARE RIVER BOTTOM SEDIMENT

Sample No.	R-1	R-48	R-65	R-124	R-181	R-200	R-231
Amino Acid				ppm — μ g/g			
Aspartic acid	892	574	1025	1359	1219	2321	1387
Threonine	446	456	555	609	571	1194	792
Serine	421	404	548	546	485	1100	799
Glutamic acid	1187	856	1084	1158	1033	2121	1379
Proline	394	391	531	582	581	1051	755
Glycine	675	515	837	1125	842	1435	1209
Alanine	1045	709	714	832	770	1440	1065
Cystine	146	66	27	n.d.	n.d.	90	47
Valine	605	502	600	684	656	1219	839
Methionine	132	82	35	n.d.	24	77	34
Isoleucine	360	302	357	417	365	754	469
Leucine	626	509	579	619	551	1162	701
Tyrosine	172	378	n.d.	662	672	946	919
Pheuylalanine	301	280	298	419	348	654	414
Lysine	669	531	505	626	573	1131	713
Histidine	235	239	177	152	149	343	158
Arginine	86	93	109	94	94	215	142
Total	8392	6887	7981	9884	8933	17253	11822

Some of the conclusions of Reuter (1970) concerning the foregoing is summarized below:

(a) As regards amino acids, the striking fact is the extraordinary amount of proteinaceous material, as compared to normal sediments, even those with a reducing environment. Instead of several hundred ppm, one finds several thousand ppm, up to amounts ranging between 1 and 2 percent. Samples R1 and R48 are taken from locations where a high amount of sewage outfall would be expected. R1 contains about 8400 ppm and R48 about 6900 ppm.

(b) More interesting than the concentration is the composition of the proteinaceous material in terms of its amino-acid spectrum. Both the ratio of the acidic amino acids (aspartic to glutamic acid) and the sum of the basic amino acids (lysine + histidine + arginine) compare well with each other.

(c) If we take these two samples (R1 and R48) as representative for domestic sewage, we can observe a change in the character of the proteinaceous matter from location R65 on downriver. From here on the ratio of the acidic amino acids changes significantly where R65 seems to have an intermediate character. R124 (Marcus Hook Shoal) and the samples following downriver have a distinctly different spectrum of amino acids, which indicates a different source of proteins, for example from organisms growing in the river itself. Since the process of eutrophication seems to be dominant throughout this part of the river, the organic matter could be a product of microorganisms living in these waters

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in great abundance. This is also indicated by the fact that the amount of proteinaceous matter increases to 10,000 ppm in R124 and to even more than 17,000 ppm in R200.

Semiquantitative analysis of carbohydrates by Reuter (1970) shows glucose, galactose, rhamnose, mannose, arabinose, xylose and ribbose present. The concentrations range in the order of several hundred ppm, not unusual for a recent sediment. The absolute abundances follow somewhat those of the amino acids, with R200 having the highest concentrations. It seems that these sugars are of algal origin and

due to their high nutritional value and relative instability are decomposed rather rapidly. Thus, one does not observe any unusual concentrations comparable to the amino acids.

As regards hydrocarbons and oxygen-containing compounds (e.g. fatty acids), Reuter and others have indicated that the samples which are closest to the domestic sewage source, have the most offensive smell, probably caused by higher fatty acids. Silica gel chromotography of n-hexane soluble fraction of solvent extractable organic matter throws some light on this matter and is listed below.

EXTRACTABLE ORGANIC MATTER

Sample No.	(1) n-hexane ppm	(2) CCl$_4$ ppm	(3) (1) + (2) ppm	(4) benzene ppm	(5) (3) + (4) ppm	(6) methanol ppm	(7) (5) ÷ (6)
R1	50	85	135	250	385	750	0.51
R52	13	31	44	28	72	185	0.39
R124	12	24	36	43	79	204	0.39
R167	516	250	766	294	1060	572	1.85
R200	308	250	558	300	858	818	1.05
R231	28	144	172	83	255	560	0.46

The silica gel chromatography of the n-hexane soluble fraction of the solvent extractable organic matter yields some interesting results. The fraction eluted by n-hexane contains normal and branched alkanes (and possibly alkenes). The carbon tetrachloride fraction contains mostly cyclic alkanes. The sum of columns 1+ 2 is therefore the total alkane fraction. The fraction eluted by benzene is mostly composed of aromatic hydrocarbons. Thus, the sum of columns 1 + 2 + 4 represents the total hydrocarbons. The fraction eluted with methanol contains mostly oxygen-containing compounds, probably predominantly fatty acids. The last column gives the ratio of total hydrocarbons over "fatty acids". It

is interesting to note that this ratio is lowest in the area that is predominantly influenced by domestic sewage outfall; further downriver, in the area of Wilmington, the hydrocarbon fraction increases abruptly, most probably due to contributions from industrial sludges. The fraction eluted from the silica gel column with methanol contains substances, probably fatty acids, of an obnoxious odor, which is the source for the odor of the river bottom sediment. With regard to the quality of the overlying waters these materials have a rather deleterious effect.

Evidence of the organic matter distribution and pollution parameters of the sus-

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pended samples of the water column in a later section will be shown to support the view that the high organic matter in Marcus Hook shoal bottom sediment is probably due to the activity of man and the polluted conditions of the water. The high organic content also may account for abnormal amounts of toxic heavy metals in the shoals.

Organic matter from historic dredge spoil locations from several shoal areas between Schuylkill River and Wilmington Harbor obtained from 1911 to 1966 show values ranging from 4.8 to 14.2 percent of the spoil bank materials (see Table 3). The highest organic matter is from sediment of the mixed Schuylkill River and Chester Range of the Delaware River which are closest to the sewage outfalls of Philadelphia. Organic matter in Marcus Hook shoal sediment prior to 1946 was 4.8 percent but increases to twice that much for the periods between 1946 and 1962 (see Table 3). Organic matter in the spoil from Wilmington Harbor ranges between 7.6 and 13.3 percent from the spoil banks between 1911 and 1966 which is comparable with contemporary sediments from that area.

Some of the differences between the organic content of the historic dredge spoil and contemporary bottom sediment may be largely due to improved dredging methods. The basic report points out that early dredging methods allowed fines to escape at the spoil site as follows:

"Prior to 1955, the method of dredging consisted of the use of hopper dredges on the shoal, and pipeline dredges to rehandle the dredged material ashore. The hopper dredges dumped their loads in basins that were dredged deeper than the surrounding bed of the estuary and the pipeline dredge pumped the accumulated material ashore behind enclosing dikes. In addition, the hopper dredges pumped beyond overflow in the interest of obtaining the so-called economic load. The material that overflowed was finer than that retained in the hoppers. There was also a loss of fines in the dumping process, with the result that the materials rehandled into the disposal area were heavier and coarser than the texture and composition of the shoal itself. Because it was found that these procedures were in effect contributing to the shoaling of the channel, and because it was also found that the texture of the shoal itself was gradually becoming finer, a very important change was made in the dredging process. This was done in two steps: The first involved the use of a so-called sump rehandler; the second involved the provision of facilities on the hopper dredge such that the material was pumped directly ashore. In both cases, the material removed from the shoal was placed in the disposal area totally with no apparent loss of material."

Since much of the organic sewage is associated with the fine suspended sediment, it follows that earlier dredging practices would result in a spoil bank deficient in the actual amount of organic and other fine material dredged from the shoal areas.

The organic matter for various bottom station locations in the Delaware River and upper Bay determined by chemical methods described in an earlier section are listed in Table 2.

Anthracite Coal

A higher concentration of anthracite coal occurs in the Schuylkill River than anywhere in the estuary with dispersal of the coal in a seaward direction from the confluence of the Schuylkill and Delaware Rivers. The primary source of the culm or fissile anthracite coal is from washings of coal in the anthracite coal

TABLE 2

ORGANIC MATTER, ANTHRACITE COAL, CHEMICAL OXYGEN DEMAND,
OIL AND GREASE, PHOSPHATE, AND ARSENIC IN BOTTOM SEDIMENTS,
DELAWARE RIVER

Sample Control Number	Field Sample No.	Organic Matter	Anth. Coal	C.O.D.	Oil and Grease	PO_4	Arsenic
			% on Dry Weight Basis				
RB306	R232	4.5	0.1	7.7	0.053	0.23	0.00044
RB75	R1	0.5	1.9	2.8	0.027	0.15	0.00001
RB88	R14	1.2	1.7	7.5	0.064	0.32	–
RB89	R15	1.0	4.3	11.2	0.100	0.34	0.00029
RB96	R22	0.4	4.4	9.2	0.096	0.26	0.00017
RB109	R35	1.2	3.3	8.1	0.078	0.24	0.00061
RB110	R36	4.4	6.1	13.4	0.028	0.65	0.00272
RB122	R48	0.4	1.5	2.7	0.030	0.18	0.00006
RB126	R52	1.8	2.6	5.0	0.025	0.21	0.00020
RB139	R65	4.4	8.3	18.9	0.135	0.20	0.00067
RB154	R80	1.0	1.0	4.9	0.060	0.22	–
RB198	R124	2.6	2.2	4.5	0.052	0.22	0.00066
RB306	R139	2.4	1.1	5.2	0.118	0.35	0.00229
RB227	R153	2.3	1.5	5.5	0.046	0.20	0.00091
RB241	R167	7.8	4.7	15.4	0.167	0.30	0.00405
RB255	R181	1.4	0.3	7.2	0.104	0.26	0.00077
RB304	R188	2.5	–	10.1	0.121	0.44	0.00392
RB268	R200	1.2	0.5	4.5	0.092	0.28	0.00101
RB294	R222	0.7	–	7.1	0.071	0.26	0.00085
RB299	R231	1.0	–	8.7	0.065	0.29	0.00113
BB37	B-2	0.4	Tr	2.0	0.055	0.20	–
BB53	B-18	2.8	Tr	2.4	0.029	0.13	0.00017

TABLE 3
AVERAGE TEXTURE AND COMPOSITION OF HISTORIC DREDGE SPOIL SAMPLES, DELAWARE RIVER.

Disposal Area and Source	Darby Creek (Chester Range & Schuylkill River)		Oldmans Creek (Marcus Hook)			Edgemoor (Wilmington Harbor)			Pigeon Point (Wilmington Harbor)		
Sample Dates	1955-59	1959-66	Pre 1946	1946-58	1958-62	1911-44	1944-58	1958-67	1948-55	1955-58	1958-66
Texture											
% Sand	2	2	–	23	–	2	2	2	12	6	11
% Silt	66	66	–	60	–	63	73	60	67	62	65
% Clay	32	32	–	17	–	35	25	38	21	32	24
% Average Composition of Total Sample											
Quartz	26.2	31.8	59.8	30.5	43.5	41.0	44.4	33.2	39.1	33.5	33.6
Feldspar	5.4	7.1	2.0	9.1	6.6	3.2	4.1	3.3	9.3	10.4	8.0
Organic Matter	14.2	11.5	4.8	10.3	9.3	13.3	11.8	10.2	9.1	7.8	7.6
Coal	2.5	2.3	1.0	1.8	2.3	2.5	1.7	2.0	1.7	1.5	2.2
Diatoms	13.2	12.5	1.0	9.7	9.0	8.0	7.0	9.5	7.0	15.3	15.0
Clay Minerals	32.3	29.4	29.0	33.0	24.8	25.8	26.4	36.8	29.6	26.4	29.6
Fe$_2$O$_3$	5.4	4.2	2.0	4.8	3.8	5.5	3.8	4.2	3.4	4.4	3.4
PO$_4$	0.8	0.9	0.3	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4
Oil & Grease	–	0.3	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2
% Clay Mineral Fraction											
Illite	58	58	62	55	56	47	54	46	56	47	56
Chlorite	26	26	22	31	24	36	35	31	24	38	22
Kaolinite	13	13	11	11	16	14	8	20	15	12	18
Montmorillonite	3	3	5	3	4	3	3	3	5	3	4
Arsenic and Heavy Metals in mg/1000g of dry solids											
Mercury	0.6	0.6	1.7	0.9	0.8	1.4	1.4	1.1	1.0	1.0	0.7
Lead	330	240	80	200	230	260	200	270	180	180	180
Nickel	85	70	15	53	72	70	45	62	58	50	45
Copper	140	90	40	60	60	110	90	60	80	60	50
Zinc	1200	710	2150	280	440	1000	640	690	430	480	2500
Cadmium	10	6	2	1	3	8	2	2	5	7	1
Arsenic	29	22	20	25	26	54	25	25	26	20	22

fields in the upper watershed of the Schuylkill River. A survey of the deleterious nature of the culms published in the U. S. House Document 529, 79th Congress (1946) indicated that this material required the dredging of 1,200,000 cubic yards of mine waste per year from the Delaware and Schuylkill Rivers, put a heavy load on water-purification plants of Philadelphia, caused obstructions of the upper river channels causing flood damage, and added to the silting problems along the Schuylkill River. In 1952, a large culm removal program was initiated in the pools behind the locks and dams of the Schuylkill River navigation project. Other cleanup projects effected at the same time included abatement of the discharge of coal mine washings into the streams, and construction works to prevent erosion of accumulated wastes into streams. The samples obtained from the Schuylkill River during 1972 and the Delaware River to Marcus Hook shoal between 1969 and 1972 are compared with the 1946 survey data in the following tabulation:

Location	Per Cent Anthracite Coal Mine Waste	
Schuylkill River	1946	1972
Fairmount Dam to University Avenue Bridge	53.0	43.4
University Avenue Bridge to Passyunk Avenue Bridge	53.0	29.9
Passyunk Avenue Bridge to mouth of Delaware River	42.0	15.3
Delair Bridge to lower end of Philadelphia Hbr.	12.0	1.1
Mouth of Schuylkill River to Marcus Hook Shoal	5.0	3.4

NOTE: Percentages expressed in percent dry weight.

The analysis of the contemporary Schuylkill River samples was in accordance with the chemical techniques outlined in the earlier survey (U. S. House Document 529, 79th Congress, 1946). Analysis of the anthracite coal in the Delaware River between the mouth of the Schuylkill River to Marcus Hook shoal approximately 12 miles south of Philadelphia was in accordance with the combined DTA, TGA, and mass spectrograph technique for the silt and clay-size sediment fraction and microscopic examination for the sand-size materials (Nei-

heisel, 1972) and results are listed in Table 2. The relative abundance of the anthracite coal in the various size fractions of Marcus Hook shoal is shown in the differential thermal analysis curves, depicted in Figure 8, to be contained predominantly in the silt fraction of the sediment. In this figure, the area of the 600 degree centigrade exotherm reflects the quantity of anthracite coal, the weight which is determined by thermogravimetric analysis (Neiheisel, 1972). The 300 degree centigrade exotherm reflects the organic matter (largely sewage) which occurs

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most abundantly in the less than 5 micron fraction (see Figure 8).

A comparison of the contemporary and 1946 anthracite coal surveys are depicted graphically in Figure 9. The local occurence of anthracite coal (1.1%) above the confluence of the Schuylkill River to Delair Bridge is due to flood currents effecting mixing. In the seaward direction from the confluence of the Schuylkill and Delaware Rivers. a dispersal pattern showing a progressive decrease is evident; local anomalies such as occur at station locations R-65 (8.1 per cent coal) and R-167 (4.7 percent coal) are attributed to runoff from fossil fuel plant consumers' coal piles located along the river banks. In the Schuylkill River a rather large anomaly occurs at the station location nearest Fairmount Dam (see Figure 9); the 63.8 percent coal found here is probably from a nearby source since dispersal to 13.2 and 12.7 percent is effected within a quarter mile from this point. In the central stretch of Schuylkill River between the University Avenue Bridge and Passyunk Avenue Bridge. anomalous amounts of coal in the bottom sediment ranging from 38.8 to 58.7 percent is probably due to runoff from coal piles along the bank; north and south of this location the coal ranges between 10 and 18 percent of the bottom sediment (see Figure 9).

Analysis of historic dredge spoil samples from shoal material dredged from the Schuylkill River and Delaware River. Marcus Hook shoal. and Wilmington Harbor from 1911 to 1966 reveals very little change for these fine grained sediments (see Table 3). The coal analysis was conducted on dry spoil sample by the same technique used in 1946 survey previously cited; coal values range from 1.0 to 2.5 percent for the fines with highest values in the Wilmington Harbor spoil and the mixed Schuylkill River and Delaware River spoil (1955-59); spoil prior to the cleanup effected in 1952. however. was not

available from the mixed Schuylkill and Delaware River spoil area for comparison.

From the foregoing. it is apparent that the anthracite coal has been reduced considerably since the 1946 survey and that the cleanup effected in 1952 has been successful in curbing pollution from culm emanating from the Schuylkill River watershed. Local stockpiles from industry located along the river banks. however. may be responsible for local anomalies found in the sediment; dispersal patterns reveal that the anomalous occurrences previously cited constitute but a small portion of the river bottom sediments.

Diatoms

Microscope opaline diatom tests comprise *the third most* abundant type of materials in the shoaling regions of the estuary. This biogenous amorphous material is invisible to x-rays but readily observed by their morphological structures on scanning electron micrographs. Quantitative evaluation of amounts of the diatoms was by special techniques designed for this investigation (Neiheisel. 1972) and the application of techniques from methods of Hashimoto and Jackson (1960) and Follett. et al. (1966). and Goldberg (1958) which are described in detail in Annex D. A graphic display of the differential caustic leach method and x-ray diffraction method is depicted in Figure 10. The differential caustic leach method employed dissolution of the tests in 0.5 N sodium hydroxide solution during a 2½ minute boil and determination of the amount of silica dissolved versus that available in total sample; comparison was made to a standard curve made from injecting known amounts of diatoms to prototype sediment essentially free of biogenous silica. The x-ray diffraction method by contrast. converts the opaline silica to cristobalite by heating the sample in a porcelain crucible at 1000°C for 4 hours. In this method.

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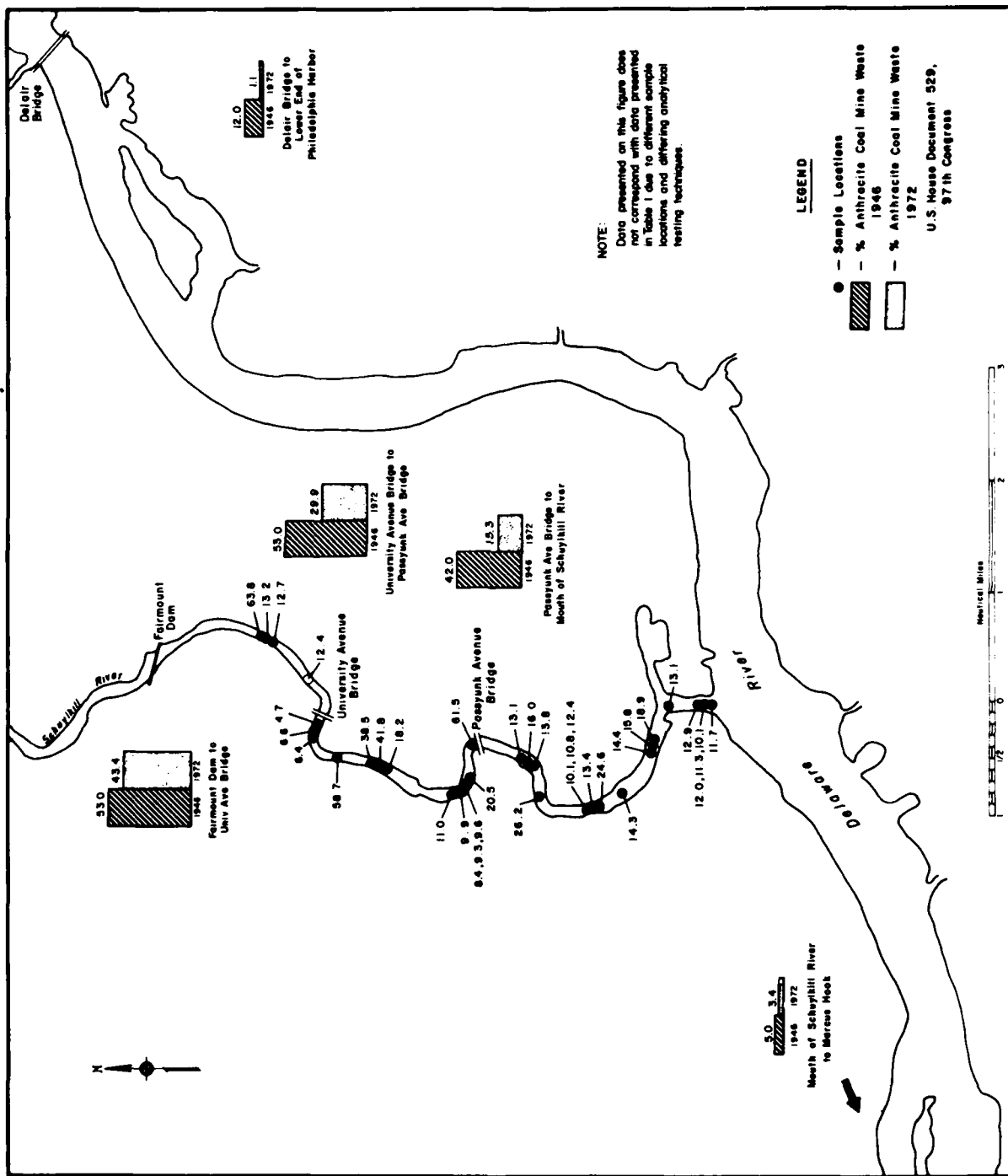
Figure 9. Comparison of Anthracite Mine Waste Concentration in Sediment of Schuylkill River and Delaware River Since 1946 Survey.

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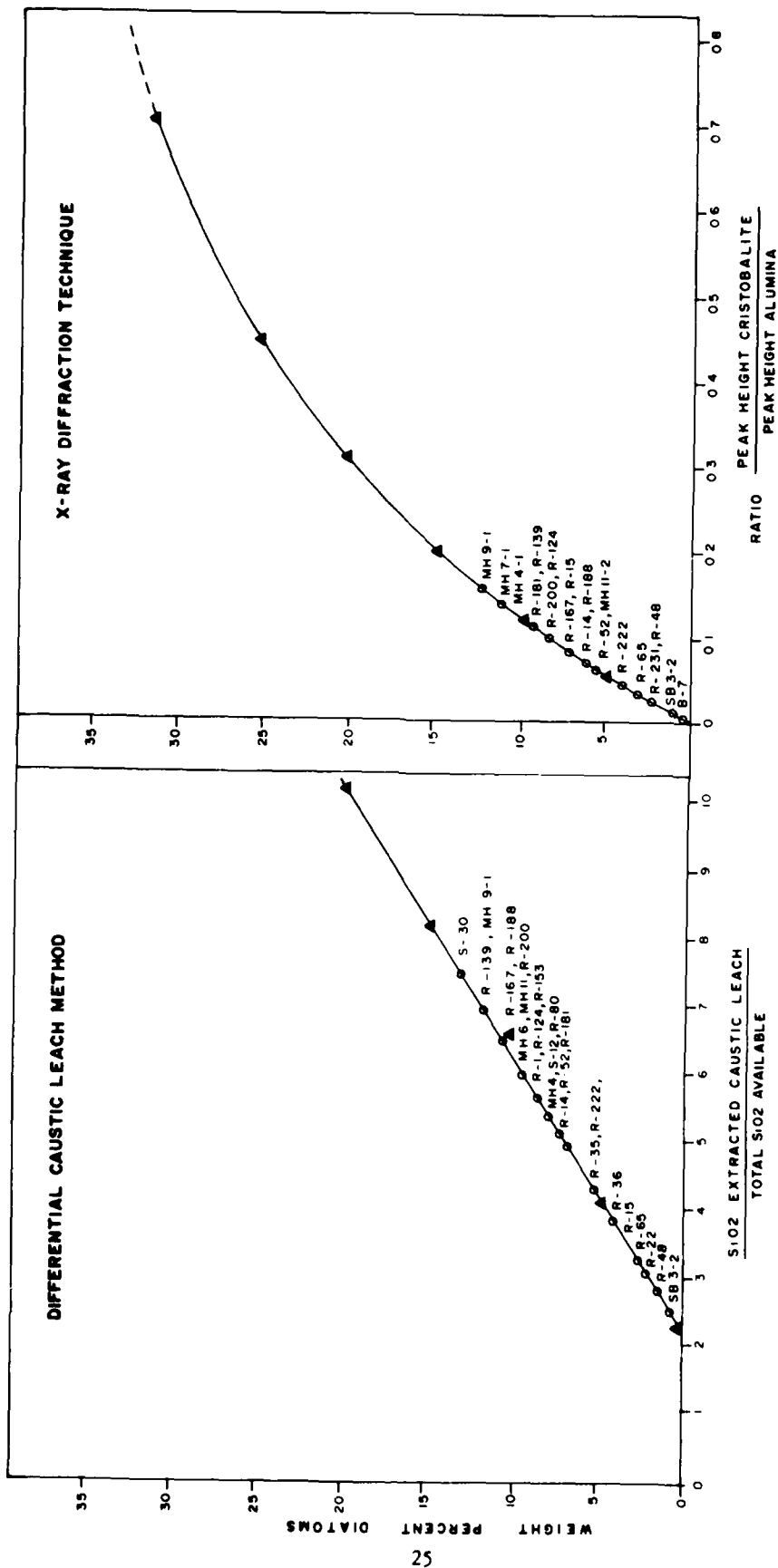
FIGURE 10. DETERMINATION OF DIATOM CONCENTRATION IN FINES OF DELAWARE RIVER SEDIMENT BY DIFFERENTIAL CAUSTIC LEACH AND X-RAY DIFFRACTION TECHIQUES.

the cristobalite peak at 4.04A on the diffractogram was divided by the alumina peak height at 3.47A and the ratio of the cristobalite to the internal indicator (aluminum oxide) compared to a standard curve for determination of diatom content.

The percentage distribution of diatoms in the sediment is shown in Table 1 for stretches of the estuary and is shown for individual sample locations in the tables of Annex A. The highest concentrations of diatoms occurs from south of Philadelphia to mile 60 with maximum amount at Marcus Hook shoal; at Marcus Hook, the diatom concentration ranges to 18 percent. Diatom distribution in the tributary streams is meager and confined to fresh water species and diatom accumulation in the bay is more on the order of trace amounts in the sandy regions near the capes to as much as several percent in the silty and clayey silt portions of the bay area.

Studies of diatom distribution in the various size fractions from Marcus Hook shoal disclose a size range from 74 to 5 microns with optimum concentration at 20 microns. Experiments with diatom volume accumulation in relation to coexisting prototype sediment as observed in controlled settling tube studies of known sediment quantities and several days consolidation has revealed that the volume percent due to diatoms is approximately 18 percent greater than the weight percent. This is attributed to the low specific gravity of diatoms (2.0) and air voids in the opaline test.

In order to obtain information relating to the source of the diatoms found in greater abundance in the shoal areas, several sample locations, situated geographically in fresh water (Schuylkill River), marine water (Delaware Bay), and brackish water (estuary shoal locations), were examined microscopically in the 44 to 74 micron size for diatom contrast and

classification (see Figure 11). Although biased in the restricted size range, the 150 to 225 point count performed on each of the samples provided the contrast of diatom genera listed in Table 4. The diatom suites from these contrasting geographic and ecological locations reveal that diatom differences diagnostic of source areas are apparent. Marcus Hook shoal contains a predominance(54%)of *Coscinodiscus* species (see Figure 12); this diatom is absent in the fresh water location and poorly represented in the marine locations of the bay (see Table 4). Three of the prevalent diatom genera in the 10 to 20 micron fraction of Marcus Hook shoal sediment is shown in the scanning electron micrograph of Figure 13. The diatom classification, as listed in Table 4, was initially compiled by William H. Abbott during the summer of 1969 and later verified by Dr. Ruth Patrick of the National Academy of Science and Dr. K. E. Lohman of the Smithsonian Institute.

According to Patrick (1967), a number of factors affected diatom populations in estuaries including temperature, salinity, turbulence, nutrients, light, etc; the effects of pollution, however, add another variable which, because of imbalanced mineral nutrients, generally favor fewer species but greater population of the species adapted to the pollution. In the distribution of nutrients in the estuary, phosphorus is present in greater abundance in the Marcus Hook shoal area which correlates with the highest diatom occurence in the shoals (see Figure 14); this distribution will be shown to be more meaningful in the analysis of the environmental aspects as reflected in the suspended samples of the estuary which will be considered in later sections of this report.

The diatom occurences in historic dredge spoil samples ranging from 1911 to 1966 is listed in Table 3 for source areas in Chester Range, Schuylkill River, Marcus Hook, and
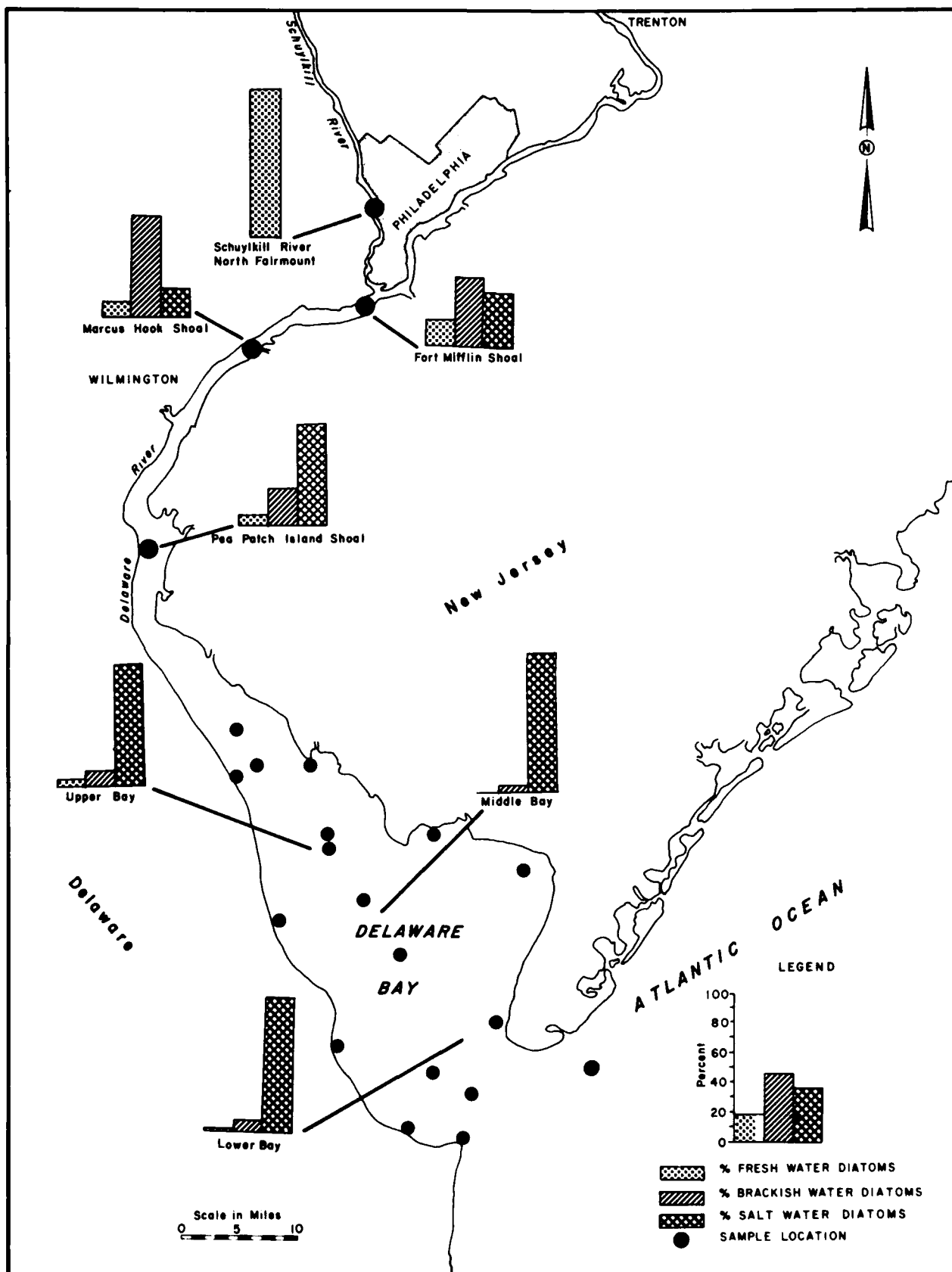
FIGURE 11. Distribution of fresh, brackish, and salt water diatoms in silt-size and fine sand-size of Delaware estuary

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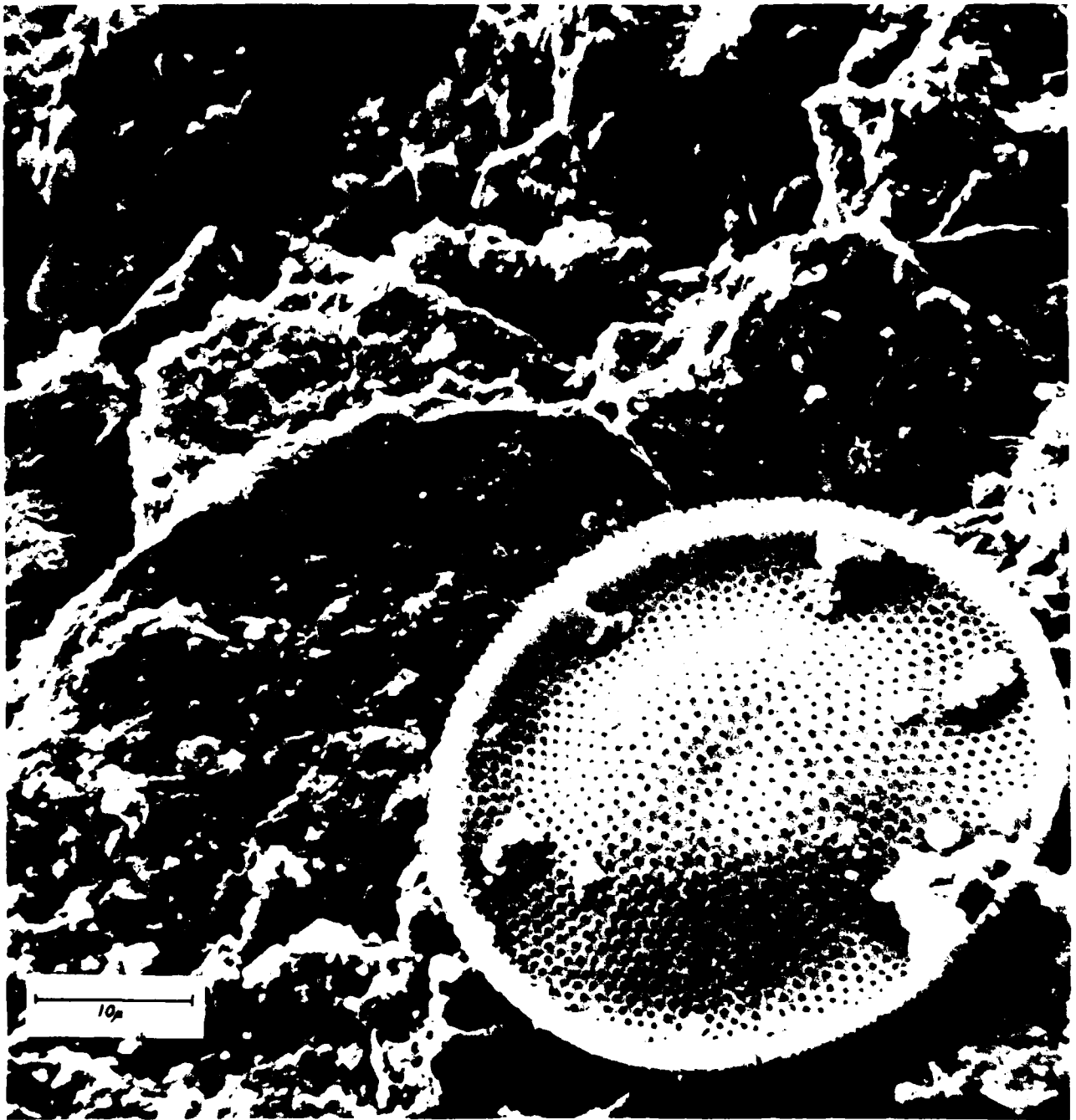
Figure 12. Scanning electron micrograph (2420X) of *Coscinodiscus* sp., the most abundant diatom variety in Marcus Hook shoal.

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TABLE 4

RELATIVE DISTRIBUTION OF DIATOM SPECIES IN THE 44 TO 74 MICRON SIZE SEDIMENT OF DELAWARE ESTUARY AND VICINITY

Diatom Classification	% Schuylkill River	% Ft. Mifflin Shoal	% Marcus Hook Shoal	% Pea Patch Shoal	% Upper Bay	% Middle Bay	% Lower Bay
Triceratium favus Ehrenberg	–	3.9	6.6	10.4	0.6	15.8	11.5
Coscinodiscus sp.	–	24.6	53.0	11.6	–	–	2.6
Aulacodiscus argus	–	–	1.3	0.6	–	–	0.6
Biddulphia c.f. B rhombus	–	0.6	–	–	–	–	0.6
Actinophychus c.f. A senarius	–	0.6	1.3	1.2	1.9	–	9.6
Paralia of P sulcata	–	10.9	12.5	28.8	64.8	84.2	45.9
Surirella sp.	8.5	–	0.4	–	–	–	–
Diploneis sp.	0.4	–	–	–	0.6	–	–
Camplyodiscus sp.	–	–	–	–	–	–	0.6
Cymbella sp.	2.5	3.3	–	0.6	1.2	–	–
Cymatopleura c.f. C Solea	5.2	–	–	–	–	–	–
Pinnularia sp.	11.1	9.9	3.1	1.8	1.2	–	1.2
Navicula sp.	6.7	–	0.4	–	0.6	–	–
Fragilaria sp.	23.1	–	–	–	–	–	–
Epithemia sp.	2.6	4.6	2.2	3.0	–	–	–
Nitzschia sp.	16.7	–	–	–	0.6	–	–
Cymatopleura sp.	0.7	–	–	–	–	–	–
Navicula c.f. N lyra	1.5	–	–	–	–	–	0.6
Unidentified diatoms	21.0	41.6	19.2	42.0	28.5	–	26.8
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

NOTE: Diatom count, for locations indicated is based on 150 to 225 point count. Material between 44 and 74 micron size was mounted in diaphane and point count performed by means of the petrographic microscope.

29

10μ

Figure 18. Diatoms in large micron fraction of a sample from Marquette Bank shoal. Coscinodiscus sp., Lower Left; A. ... Lower Right; Cyclotella sp.; Lower Right.
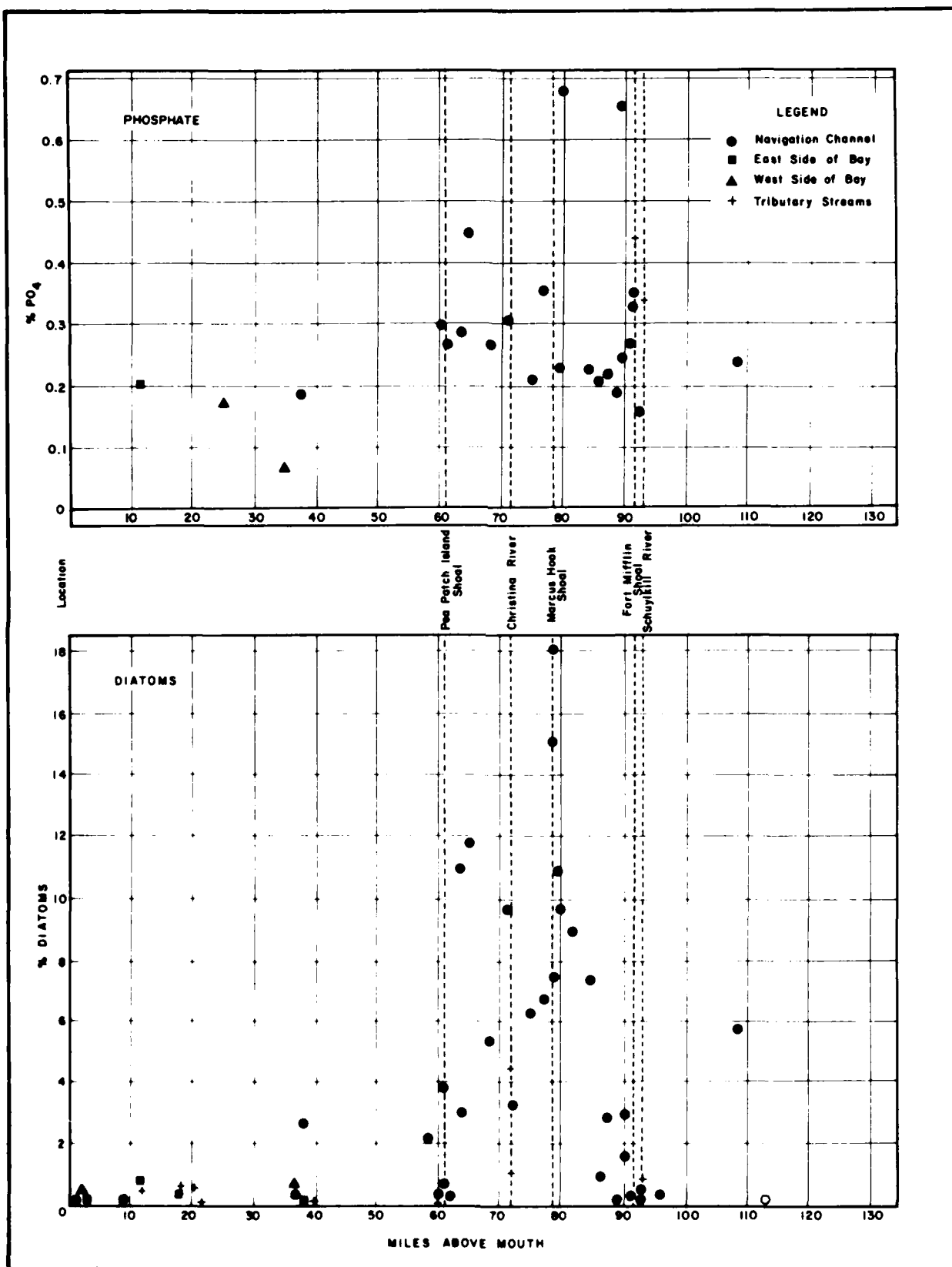
FIGURE 14 Diatom and phosphate concentration in the bottom sediment of Delaware estuary

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Wilmington Harbor. From this table, it appears that diatom occurence prior to 1946 was several times less than contemporary samples. This in part is probably a result of decrease in anthracite coal silting effected by pollution control measures taken after that time and also the gradual increase of nutrients from sewage and industrial effluents generating eutrophication conditions in the estuary between Philadelphia and Marcus Hook shoal area. Improved dredging methods, previously cited, may also contribute significantly to the apparent differences in diatom concentrations over the years. Earlier (pre-1955) dredging practices allowed the suspension and escape of significant quantities of the finer portions of the dredged material during the dredging cycle, particularly the dumping, rehandling and land disposal portion of the cycle. Since diatoms are associated with the silt size of the dredged materials and have a relatively low specific gravity, it is reasonable to conclude that substantial quantities of the diatoms did not reach or were not retained in disposal areas when the earlier dredging practices were employed.

Diatom occurrence in nearby Chesapeake Bay as reported by Biggs (1967) constitutes 10 to 20 percent of the silt-size fraction; his observations are based on optical methods and at best an approximation on volume representation, however, this is generally in similar proportions as that found in Delaware estuaries above mile 49.

The diatom production in the estuary and contribution to the shoals has been computed by more than one method which are described in detail in the main report. The percentages of diatoms found in the samples were used in both methods with maximum and minimum diatom production values respectively as follows:

a. Using an areal basis, the diatom accu-
mulation to an individual shoal is divided into the total area of the shoal and this value is then applied to shore to shore production within a given reach of the estuary to arrive at a total production rate of 2,300,000 tons per year in the shoaling reaches of the estuary.

b. Using only the diatom content of samples from the navigation channel and anchorages gave a minimum production of 743,100 tons per year. However, this method assumes that all diatoms produced in the estuary are transported to the channels and anchorages and that none remain in the areas where they were produced.

Neither of the foregoing methods are entirely valid, however, within the framework of existing data it is reasonable to conclude that the average annual production lies somewhere between the two extremes. The average production of diatoms within the shoaling reaches of Delaware estuary is thus approximately on the order of 1,500,000 tons per year.

Oil and Grease and C.O.D.

In addition to the biogenous materials listed in foregoing paragraphs, special chemical tests were performed for oil and grease and chemical oxygen demand (see Table 2). These chemical parameters are mostly of interest in the analysis of environmental factors which will be considered in a later section.

The oil and grease determined by the hexane extraction technique ranges between 0.027 and 0.167 percent of the sediment. Highest values occur in the Delaware River in proximity to Wilmington and correlates with the higher

values of hydrocarbons reported by Reuter (1970) for this portion of the estuary.

The chemical oxygen demand (C.O.D.) was performed to reflect upon the reducing power of the organic materials. This test for the materials containing appreciable anthracite coal, however, generates high values and reflects this condition but masks the value for which it is mainly intended (see Table 2).

AMORPHOUS HYDROUS IRON COMPOUNDS

The amorphous and low temperature iron compounds were extracted from the fines by the sodium dithionite method described by Jackson (1968). This iron, expressed as Fe_2O_3, does not include the iron in high temperature oxides, clay minerals, or ferromagnesian silicates. Both low temperature sedimentary iron minerals and ferric hydroxide precipitated in the estuary from acid discharge effluents are obtained by the dithionite method. The amount of amorphous iron from industry and watershed source in this study is based on contrast analysis and laboratory model observation.

The highest natural concentration of amorphous iron tributary to the Delaware estuary is the Schuylkill River since it drains not only Triassic Red Beds rich in hematite but also receives ferric sulfate from pyrite oxidation of anthracite coal field mine waste from a source in the upper part of the watershed. This river is, however, virtually free of acid waste discharge from industry. Average iron found by the dithionite method in analysis of sediment from Fairmount Dam on the Schuylkill River in vicinity of Philadelphia averages 1.8 percent Fe_2O_3. By comparison, the highest iron concentration of the estuary occurs in Marcus Hook; 3.1 percent ferric oxide found here is considerably higher than the 0.3 to 1.8 percent

range of other locations (see Table 1).Amorphous iron in the bay does not generally exceed trace amounts (see Table 2).The distribution in the estuary is depicted in Figure 15.

Laboratory studies by Trieff and Zemaitis (1968) and prototype investigations by Kaplovsky (1952) reveal that ferric hydroxide precipitates from acid discharge effluents from industry when the pH has been reduced in acidity to 3.5 by waters of the estuary. The precipitation occurs in most cases within 3000 yards of the outfall. Kaplovsky (1952) using the pyridine iron method on bottom sediment near Wilmington and in older dredge spoil material found that in the ten year period prior to 1952 the ferric oxide content had increased on the average from 0.7 to 1.7 percent. A similar investigation on contemporary bottom samples from north of Philadelphia to Pea Patch Island and older dredge spoil samples from Wilmington and Marcus Hook shoal areas utilizing the dithionite iron method reveals generally higher ferric iron in most dredge spoil samples except those prior to 1946 from Marcus Hook (see Table 3). Some of the higher iron concentrations may be related to peak productions reached during World War II.

Windom (1972) in a study of the dredged bottom sediments from Savannah River reports that in sediment to be dredged there exists a large concentration of reduced iron which when dredged and thrown into suspension is immediately oxidized forming iron hydroxide. The iron hydroxide, according to Windom (1972) has the capacity of scavenging other metals out of solution and precipitating them along with the iron so they accumulate in the sediment of the spoil bank.

Oxidation of ferromagnesian minerals and other high temperature materials in the spoil bank also add to the iron content available for
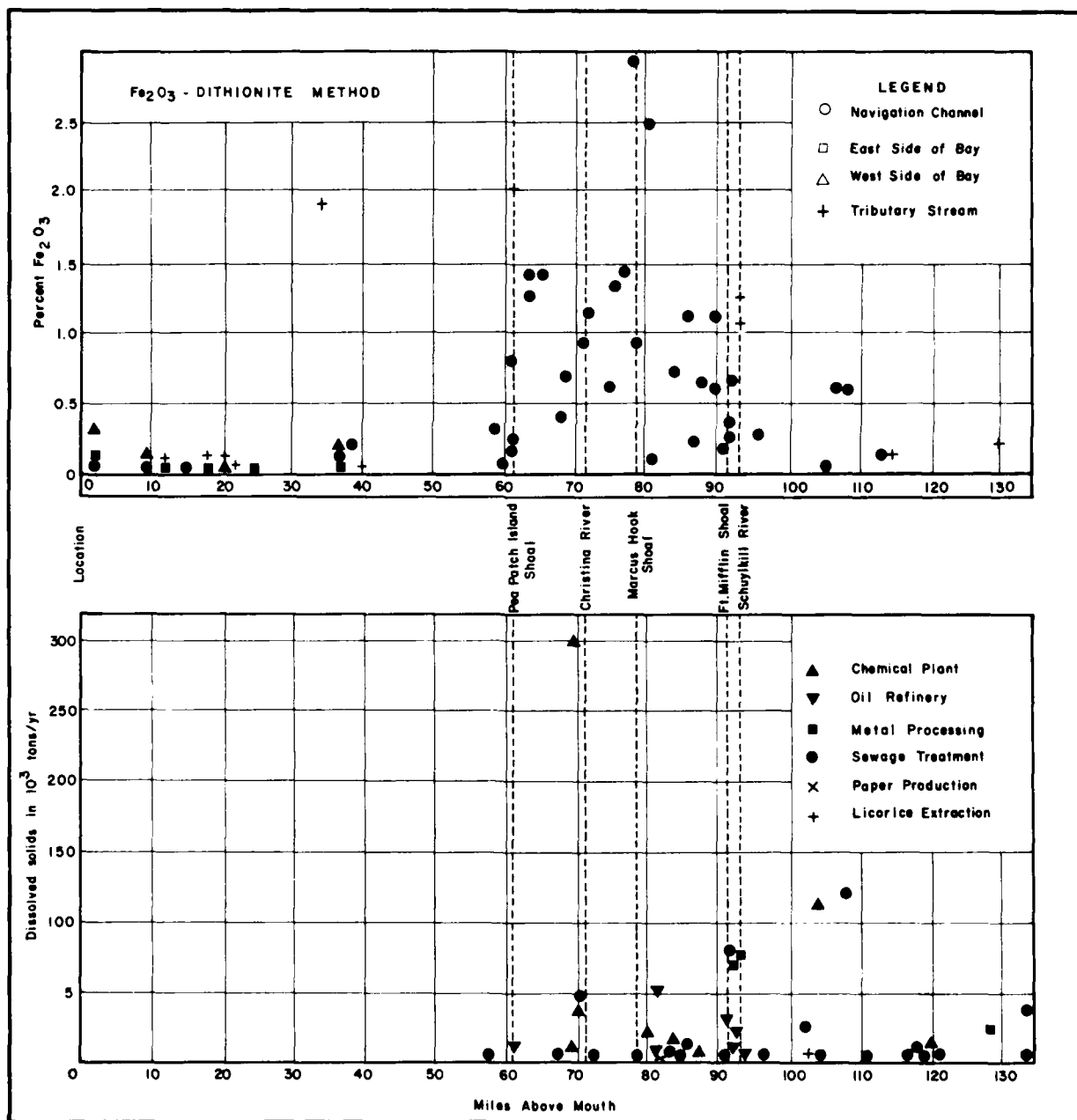
FIGURE 15. Ferric oxide in bottom sediment and dissolved solids from industrial plants along the Delaware River.

detection by the sodium dithionite method. Thus, the ferric oxide of dredge spoil samples may not be a similar measure of ferric oxide as obtained by field sampling methods of fresh bottom samples. It is generally concluded from this investigation that Fe_2O_3 increases in the spoil banks after removal from the shoaling site.

CLAY MINERALS

The clay minerals comprise between 6 and 27 percent of the bottom sediment of the Delaware River with highest concentration in the shoal areas (see Table 1). The clay-mineral suite in the bottom sediments of the Delaware River between Trenton and the bays, in order of abundance, consists of illite (50-65%), chlorite (15-30%), kaolinite (10-25%) and montmorillonite and vermiculite (5-8%). Kaolinite locally in bottom sediment of streams draining the Piedmont physiographic province and Pea Patch Island shoal exceeds chlorite (see Table 1). In the Delaware Bay area between Ship John and the capes, illite is most abundant (59-72%) and chlorite (23-26%) exceeds kaolinite (3-8%) while there are but minor occurrences (2-7%) of vermiculite and montmorillonite. Corroborative evidence of the clay-mineral suite reported above in 1968 and 1969 in unpublished reports of this investigation for the U. S. Army Corps of Engineers, Philadelphia District, is cited by Oostdam (1971), Jordan (1968), and Strom (1972). Hathaway (1972), and personal communication with Hathaway (1969) also reflects this same general ratio of clay minerals in the Delaware Bay area.

Clay mineral composition, based on x-ray diffraction techniques, is listed for each bottom sample location in the tables of Annex A. More details of the clay minerals relevant to source areas and transport characteristics will be presented in a later section of this investigation.

QUARTZ AND FELDSPAR

Quartz and feldspar comprise the major portion of the sand and silt-size bottom sediments of the tributary streams, estuary, and bay. Quartz on the average comprises between 25 and 94 percent of the bottom sediment with least representation in the shoals (see Table 1). Fresh to slightly weathered feldspar comprises from 2 to 14% of the average bottom sediment; feldspar occurs in both sand and silt-size with the smaller particles probably originating from rock flour due to the pulverizing action of the continental glacier which occupied the region during the Pleistocene. The distribution of both feldspar and quartz in individual bottom sediment locations is listed in the tables of Annex A.

Special tests conducted for investigation of the distribution of quartz and feldspar in the various size fractions of the clayey silts comprising the major shoal areas was conducted using x-ray diffraction analysis. The results are tabulated below and the x-ray diffractograms depicted in the figures of Annex A.

DISTRIBUTION OF QUARTZ AND FELDSPAR IN SHOAL SEDIMENTS

Size Range in Microns	44-20	20-10	10-5	5-2	2-1	< 1
			PERCENT DRY WEIGHT			
			FORT MIFFLIN SHOAL AREA			
Quartz	81.0	85.0	68.0	3.0	Tr	Tr
Feldspar	12.0	15.0	15.0	5.0	2	Tr
			MARCUS HOOK SHOAL AREA			
Quartz	79.0	64.0	50.0	17.0	Tr	Tr
Feldspar	10.0	18.0	10.0	5.0	3	Tr
			PEA PATCH ISLAND SHOAL AREA			
Quartz	64.0	55.0	49.0	15.0	2	Tr
Feldspar	20.0	15.0	9.0	3.0	Tr	Tr

From the distribution of quartz and feldspar in the various size fractions of the shoal sediment it is apparent that these materials are markedly uniform in the larger silt-size range between 44 and 5 micron size with quartz ranging between 9 and 20 percent; between 5 and 2 micron size the quartz ranges between 3 and 17 percent and feldspar ranges between 3 and 5 percent. In the clay-size range below 2 micron size, both quartz and feldspar comprise but negligible amounts; the clay minerals dominate the clay size although scanning electron micrographs reveal occurences of diatom fragments and other biogenous materials in this size range.

The sand-size feldspar is present in greatest abundance in bottom sediments of Piedmont streams where it ranges up to 30 percent because of the available source in the crystalline rocks of the region. Feldspar in the sand-size Coastal Plain sediments seldom exceed 5% feldspar and more generally average about 2 percent. Field and Pilkey (1969) also report that in the southeastern United States, rivers with headwaters in the Piedmont metamorphic province consistently contain 3 to 6 times as much feldspar as rivers with headwaters in the Coastal Plain.

A plot of feldspar abundance in the 0.250-0.364 millimeter size fraction versus feldspar in the 0.125-0.177 millimeter size fraction for the bay and continental shelf shows a marked difference (see Figure 16). The paucity of feldspar on the east side of the bay (2 to 6% of the sand fractions) appears to reflect the Coastal Plain source sediments while the higher feldspar content of the west side of the bay (12 to 22% of the sand fraction) appears to reflect the rich Piedmont source.

The sands of the continental shelf and coastal sands contain a feldspar content which is on the average, higher than the Coastal Plain source sediments but generally less than the fluvial Piedmont source sands (see Figure 16). Investigations by Shepard and Cohee (1936) of sediment samples on the continental shelf off the New Jersey coast show a range between 10 and
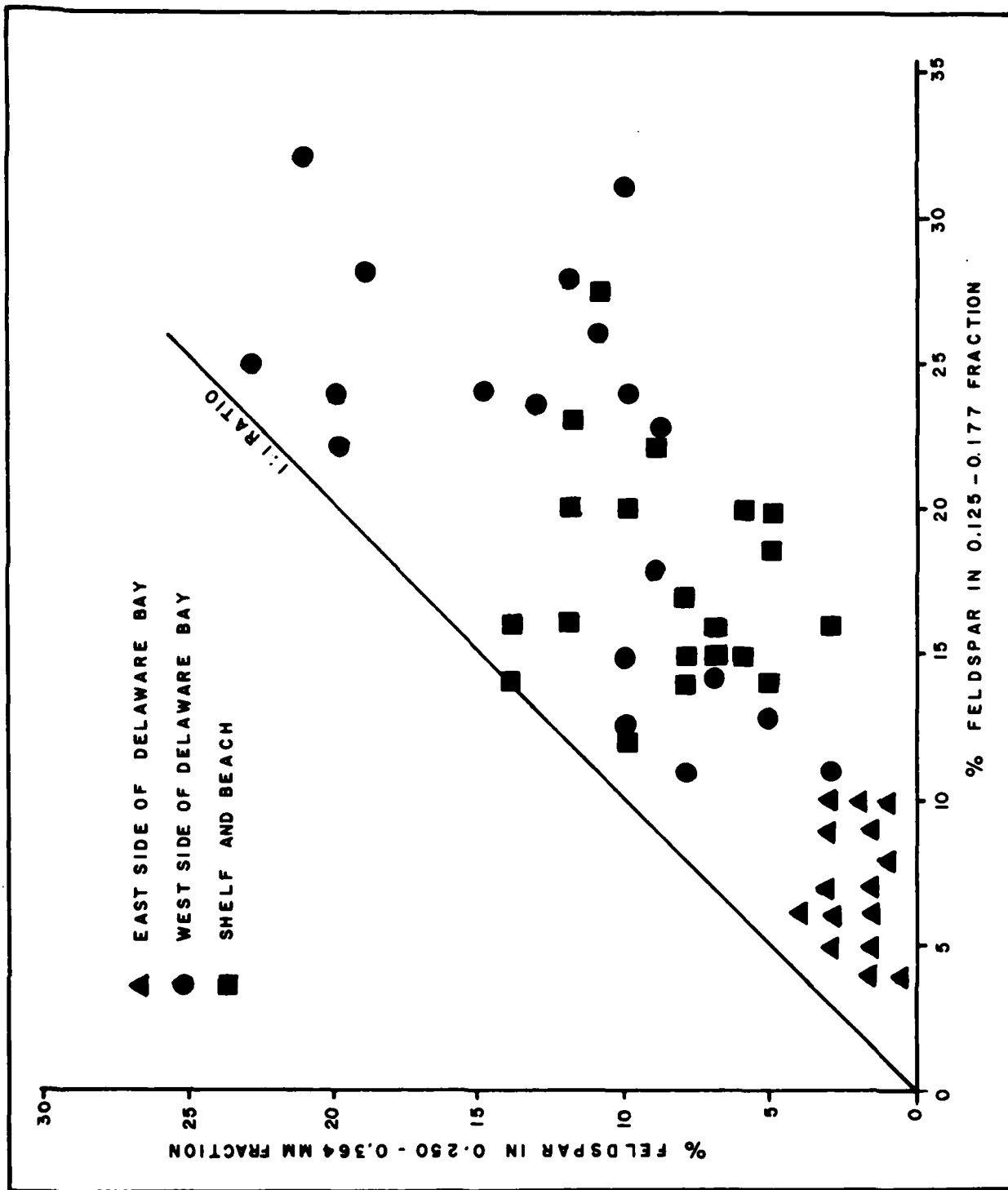
Figure 16. Plot of feldspar abundance in two size fractions of sand from Delaware bay and shelf areas.

20 percent of the sand. McMaster (1954) indicates a similar distribution for New Jersey coastal sands; one offshore New Jersey coastal sand in the investigation area contained 12 percent feldspar while in beach sands along the New Jersey coast feldspar content ranged from 2 to 21 percent of the sand. Milliman, et al (1972) show a rich distribution of feldspar in "apron like" patterns from major estuaries of the northern estuaries. This distribution of feldspar will be cited in a later section in relation to net direction of sediment transport from source areas.

Quartz particles were found by microprobe and electron diffraction analysis to have thin films of iron oxide, especially on the silt size particles of Marcus Hook shoal sediment which is the site of higher iron accumulation. This will be considered in a later section relating to physiochemical factors and the flocculation phenomena.

MICA

Mica seldom exceeds more than a few percent of the sand fraction in the estuary (see Table 1). Mica is virtually absent in the beach sands of the bay or bottom sediments of the capes because of high energy zones allowing the flat particles to be winnowed out and rafted to low energy zones for deposition with finer-sized sediments.

DETRITAL HEAVY MINERALS

Detrital heavy minerals, of greater than 3.0 density, comprise from trace amounts to 18% of the bottom sediment greater than 44 microns in size with a general average of approximately 2% (see Table 1). The heavy minerals contain an opaque and transparent fraction with the transparent fraction generally predominant except for local anomalies. The opaque fraction consists of magnetite, ilmenite, leucoxene, hematite, and industrial slag while the transparent heavy-minerals include the micas, amphiboles (hornblende, actinolite, and tremolite), garnet, zircon, sillimanite, kyanite, staurolite, tourmaline, pyroxenes (hypersthene, diopside, augite, etc.), epidote, chloritoid, and minor others. The transparent heavy mineral species, exclusive of mica, are useful as "natural tracers" to reflect on the "net transport" direction of sand-size sediment from the source areas to depositional sites. The percent of heavy-mineral species in each bottom sediment sample is listed in the tables of Annex B. The dispersal patterns of the transported heavy-minerals (exclusive of mica) will be discussed in detail in a later section of this report.

OTHER MATERIALS

Rock particles, calcite, glauconite, industrial slag, heavy metals, insecticides, and other materials of minor or highly local nature occur in the bottom sediment. Rock fragments ranging from pebble to sand-size occur locally in the tributary streams of the Piedmont and in the upper estuary where the river cuts through the Cretaceous sands to bedrock near the Fall Line. The greatest occurence of rock fragments is in Neshaminy Creek which drains the Piedmont (see Table 1 of Annex A). Industrial slag also occurs locally and ranges up to several percent in Salem River near an industrial source to trace amounts in the upper portion of the estuary. Glauconite is generally absent or occurs in trace amounts in most sample locations but does comprise as much as 9 percent of the sand fraction of the Salem River samples and 5 percent of the sand fraction at Pea Patch Island shoal.

The carbonate shell content ranges to significant proportions in a few samples in the bay area but is virtually absent in the river areas sampled (see Table 1 of Annex A). Foramin-

ifera also occurs in the bay bottom sediments but seldom exceeds more than 1 percent in the samples tested.

Other minor materials such as the heavy metals, arsenic, phosphorus, and DDT are considered toxic or indicators of pollutants.

These will be considered in this context since their minor representation in the sediment is considerably out of proportion to their importance as environmental hazards and the consideration necessary in relation to dredging operations.

ANALYSIS OF HEAVY MINERAL DISTRIBUTION PATTERNS IN DELAWARE VALLEY

INTRODUCTION

The systematic analysis of more than 140 bottom sediment samples for the transparent heavy minerals (between 74 and 420 micron size), in station locations from Trenton to the vicinity of the capes, has established data reflecting upon source and transport characteristics of sand-size sediments in the estuary and at the interface with continental shelf sediments. Definite heavy mineral provinces were found in this investigation to exist in the estuary. The river estuary is dominated by a fluvial Piedmont source with a "full" heavy-mineral suite characterized by hornblende and garnet while the major portion of the embayed estuary has a large mixed fluvial Piedmont and Coastal Plain heavy mineral suite described as the Delaware Bay province and characterized by sillimanite and generally "full" heavy mineral suite. A smaller heavy mineral province occurs in the lower eastern and lower central bay as a result of the mixing of the bay and continental shelf sands

in the lower eastern bay area in vicinity of the capes.

HEAVY MINERALS OF GEOLOGIC FORMATIONS

The heavy minerals in the Coastal Plain Formations of Delaware and New Jersey have been investigated by Owens and Sohl (1969), Jordan (1964), Groot (1955) and others. The investigators generally recognize the restricted or "stable" heavy mineral-suite of the Coastal Plain sediments older than Quaternary and the "full" heavy-mineral suite of the Pleistocene. The extensive investigation of the heavy minerals of the Cretaceous, Pleistocene, and Recent Formations of Delaware and New Jersey, by Groot (1955), are listed in Table 5 and depicted graphically in Figure 17 along with the investigation of New Jersey Coastal Plain Formations by Owens and Sohl (1969). Jordon's (1964) analyses of 75 samples of the Pleistocene Columbia Formation of Delaware are listed below for transparent heavy minerals between 62 and 500 micron size.

HEAVY MINERALS OF PLEISTOCENE FORMATIONS IN DELAWARE

	Percent transparent heavy mineral fraction		
	Min	Max	Avg
Amphibole (hornblende)	0.0	69.0	13.8
Andalusite	0.0	2.0	0.4
Chloritoid	0.0	4.0	1.0
Epidote	3.0	45.0	17.6
Garnet	0.0	11.0	1.6
Kyanite	0.0	7.0	2.1
Pyroxene	0.0	6.0	0.5
Rutile	0.0	8.0	3.7
Sillimanite	1.0	30.0	12.7
Staurolite	0.0	23.0	4.3
Tourmaline	0.0	25.0	5.8
Zircon	3.0	62.0	33.6
Altered	0.0	7.0	1.9
Unidentified	0.0	4.0	1.5
Apatite, Sphene, Monazite, Spinel			Trace

The Pleistocene heavy mineral suite of Jordan (1964) shows a varied suite of heavy minerals in which zircon, epidote, amphibole (mostly hornblende), and sillimanite are the most abundant species. In his analysis Jordan (1964) showed that zircon and hornblende averaged 34 and 14 percent, respectively, but were the minerals which had major variations ranging from extreme zero to values in excess of 60 percent. Sillimanite in the Pleistocene sands ranges between 1 and 30 percent with an average of 12.7 percent for 75 samples; this is somewhat higher than that reported by Groot (1955) who shows a range between 1 and 22 percent and an average of eight percent sillimanite (see Table 5). The heavy mineral suite described by Jordan (1964) generally resembles that indicated by the 25 samples from Delaware Pleistocene sands published by Groot (1955); notable differences are higher zircon and less hornblende and greater consistency of the suite by Groot (1955).

The Piedmont crystalline rocks are comprised of gneiss and schist formations with a relatively abundant source of hornblende and garnet. The Paleozoic-Pre-Cambrian Wissahickon Schist is an especially abundant source of garnet. Diabase sills locally constitute a source of pyroxene. Hornblende is especially rich in gneiss outcrops. Dryden and Dryden (1946) cite pink zircon as characteristic of the Wissahickon Schist of southeastern Pennsylvania and Moxley (1970) reports this mineral in samples on the Delaware side of the estuary.

Of special importance is the relatively "clean" surface of Piedmont rocks, free of Pleistocene blanket deposits, between Trenton and the state of Delaware on the Piedmont drainage area considered in this investigation.
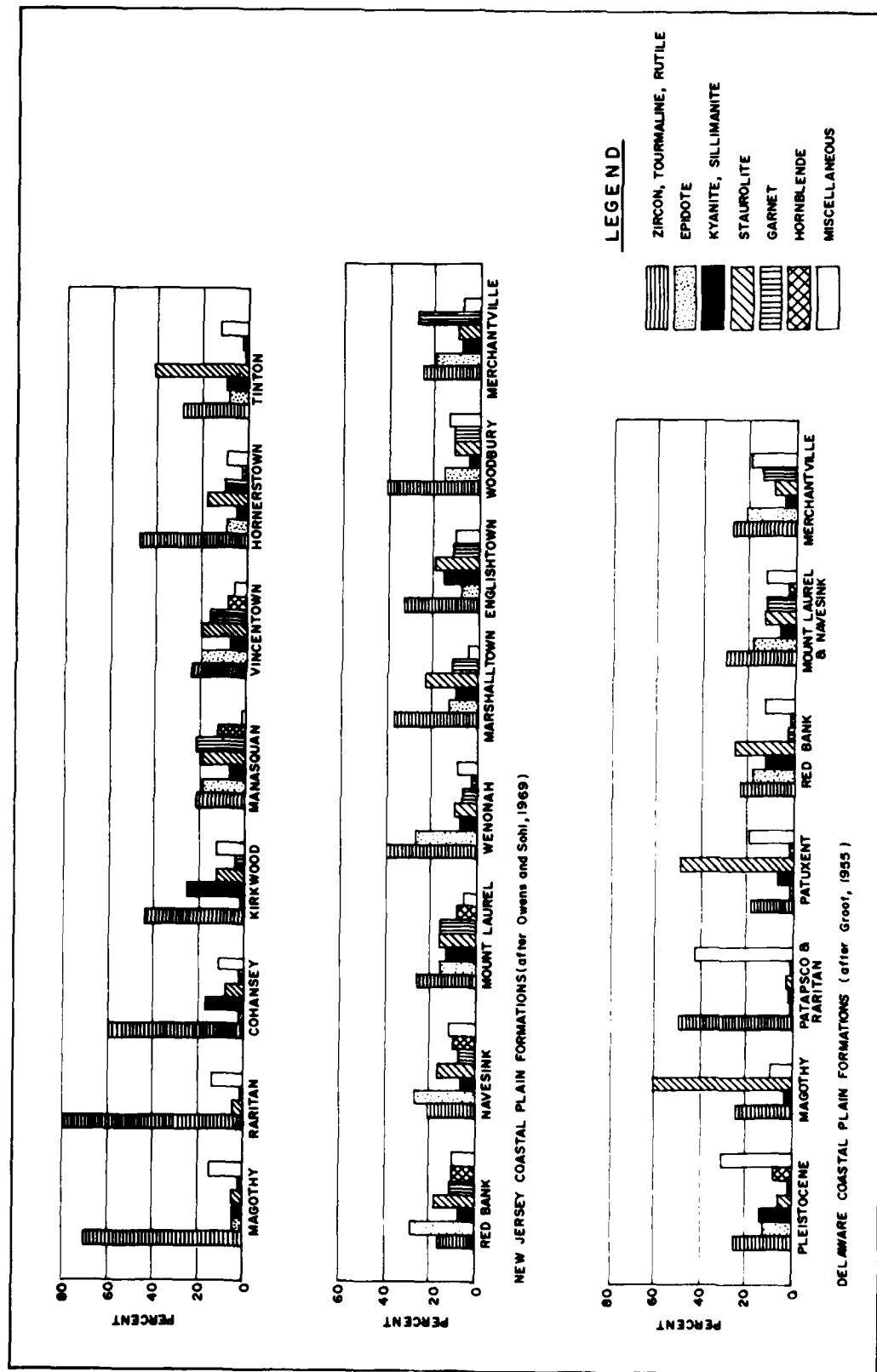
FIGURE 17: Bar graph diagram of sand-size transparent heavy mineral distribution in New Jersey and Delaware Coastal Plain Formations contributing to the heavy mineral suite of the Delaware Estuary and Bay.

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TABLE 5

CONCENTRATION AND SIGNIFICANT HEAVY MINERAL FRACTIONS OF THE HEAVY-MINERAL SUITES OF CRETACEOUS, PLEISTOCENE, AND RECENT FORMATIONS OF DELAWARE

% Heavy Minerals in Sand Fraction – Range and Average (Heavy Mineral row)

% Mineral Species in Transparent Heavy Mineral Fraction – Range and Average (remaining rows)

Heavy Mineral Species	Recent Fm Delaware	Pleistocene Fm Delaware	Upper Cretaceous Fms — Red Bank Delaware	Upper Cretaceous Fms — Mount Laurel Naveskin Delaware-New Jersey	Upper Cretaceous Fms — Wenonah Delaware	Upper Cretaceous Fms — Merchantville Del	Upper and Lower Cretaceous Fms — Patapsco-Raritan N.J.	Patapsco-Raritan Del.	Patapsco-Raritan N.J.	Magothy Delaware	Patuxent Delaware	Englishtown New Jersey
Heavy Mineral	—		1-2 / 1	Tr-5 / 2	Tr-2 / 1	Tr-3 / 1	—	Tr-3 / Tr	— / —	1-13 / 2	Tr-3 / 2	—
Hornblende	1-39 / 10	1-37 / 8	1-2 / 1	1-5 / 2	Tr-1 / 1	Tr-1 / Tr	—	Tr-1 / 1	— / —	Tr-1 / Tr	Tr-2 / 1	Tr-1 / 1
Staurolite	1-17 / 7	2-22 / 8	20-34 / 26	24-29 / 26	4-14 / 11	6-20 / 9	7	1-14 / 3	9-16 / 12	22-80 / 59	24-83 / 50	19-20 / 19
Garnet	1-17 / 3	1-6 / 2	1-4 / 2	2-22 / 12	1-11 / 3	2-18 / 14	8	Tr-1 / Tr	Tr / Tr	Tr-1 / Tr	Tr-1 / Tr	— / —
Zircon	1-40 / 10	1-52 / 16	1-7 / 5	3-22 / 12	2-16 / 10	2-19 / 10	14	17-48 / 33	16-18 / 17	1-24 / 9	1-2 / 1	5-12 / 8
Epidote	3-21 / 9	1-25 / 13	15-25 / 19	13-26 / 19	15-38 / 24	10-28 / 22	18	1-2 / 1	1-2 / 2	Tr-1 / Tr	1-2 / 1	Tr-3 / 1
Tourmaline	1-18 / 7	1-11 / 5	6-16 / 10	4-10 / 7	5-16 / 10	3-12 / 8	13	4-19 / 9	4-15 / 10	3-27 / 12	3-28 / 13	12-20 / 16
Sillimanite	1-17 / 7	1-22 / 8	2-9 / 5	4-5 / 4	1-7 / 3	1-5 / 2	—	Tr-1 / 1	— / —	Tr-1 / 1	Tr-1 / 1	11-12 / 11
Kyanite	1-6 / 3	1-11 / 6	3-10 / 7	4-6 / 5	1-5 / 3	1-7 / 2	2	Tr-1 / 1	Tr-3 / 2	1-7 / 3	1-17 / 6	7-8 / 7
Rutile	1-5 / 3	1-12 / 5	5-12 / 8	4-12 / 8	6-16 / 11	4-14 / 10	9	4-21 / 12	1-6 / 4	1-14 / 4	1-18 / 5	10-12 / 11
Hypersthene	1-3 / 2	1-12 / 4	—	—	—	—	—	—	—	—	—	—
Clinopyroxene	1-5 / 2	1-16 / 3	—	—	—	—	—	—	—	—	—	—
Chloritoid	1-2 / 1	1-5 / 2	2-7 / 4	1-12 / 6	7-15 / 10	4-15 / 10	22	—	—	Tr-1 / Tr	—	—

NOTES: Heavy mineral fractions of key minerals in the Cretaceous, Pleistocene, and Recent formations of Delaware and New Jersey Coastal Plain Formation compiled from data by Groot (1955).

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PREVIOUS HEAVY MINERAL INVESTIGATIONS IN DELAWARE ESTUARY

Although knowledge of the heavy minerals of the Coastal Plain formations of Delaware and New Jersey is abundant and based on several investigations and the heavy minerals of the New Jersey coastal area and continental shelf sands are generally well known, the analysis of heavy minerals in bottom sediment between Trenton and the vicinity of the capes prior to this investigation was limited to one core sample in the Delaware River south of Wilmington described in an excellent manner by Jordan and Groot (1962). Several heavy mineral samples of a reconnaissance nature were reported for the Delaware Bay during the progress stages of this investigation by Strom (1972) and Moxley (1970) and, although limited in scope, provide corroborative evidence of heavy mineral types.

The heavy minerals in this investigation were studied in three phases: (1)Delaware River from Trenton to the bay and tributaries from both the Coastal Plain and Piedmont sources. (2) Delaware Bay to the capes including beach profile and bottom sediments. and (3) the coastal offshore areas of the continental shelf fronting the Delaware capes. Special attention was given the quantities of sediments being considered from the various sources and the hydrodynamic agencies which affect transport of the sediment

HEAVY MINERAL SUITE OF DELAWARE RIVER

The heterogeneous nature of the Piedmont crystalline rock and variability of heavy minerals within formations of Coastal Plain sediment points out the need for a measure of quantity and composition of each heavy mineral

suite from discharge points of rivers tributary to the Delaware River as well as at regular intervals along the Delaware River between Trenton and the bay. Heavy minerals analysis of bottom sediment from streams draining the major Piedmont and Coastal Plain is listed in Tables of Annex B, summarized in Table 6 and depicted graphically in Figure 18. In an earlier section, it was demonstrated from U. S. Geological Survey (1967) sediment discharge data and heavy mineral concentration data that the Piedmont streams between Trenton and the capes annually deliver approximately five times the annual tonnage of heavy minerals to the river estuary as compared to the streams draining the Coastal Plain sediments. The heavy mineral content of the Piedmont streams ranges between 3 to 6 percent while Coastal Plain streams contain between 2 and 4 percent heavy concentration in the sand fraction of estimated sediment discharge; this data and percent opaque versus transparent heavy minerals is listed in Table 1 of Annex B.

The Piedmont streams discharging into the river estuary between Trenton and the bay contribute a high ratio of garnet and hornblende (see Figure 18). Analysis of the changes occurring in the heavy mineral suite for the 70 mile distance of the river estuary between Trenton and Ship John Light at the head of the bay is summarized as follows:

(a) Hornblende increases from 27 to 44 percent in a seaward direction as a result of Piedmont source sediments rich in this mineral effecting this increase. Chester Creek, for example, contains a heavy mineral suite in which hornblende comprises 51 percent of the transparent heavy mineral fraction (see Table 1, Annex B)

TABLE 6

SUMMARY OF HEAVY MINERAL DISTRIBUTION IN DELAWARE ESTUARY, DELAWARE BAY, AND CONTINENTAL SHELF

Heavy Mineral Species	Delaware River Tributaries				Delaware Estuary		Delaware Bay			Vicinity of Capes		Continental Shelf	
	Delaware R. North of Trenton	Schuylkill River	Piedmont Tributaries	Coastal Plain Rivers	North of Philadelphia	South of Philadelphia	Average Total Bay	Delaware West Side of Bay	New Jersey East Side of Bay	Delaware Bay near Cape May	Delaware Bay near Cape Henlopen	New Jersey Coastal Shelf	Delaware Coastal Shelf
	% Heavy Minerals in Sand Fraction – Range and Average												
H.M. Suite	3-6 / 4	2-5 / 3	3-15 / 9	Tr-5 / 2	1-3 / 2	Tr-7 / 3	Tr-18 / 3	Tr-18 / 4	1-6 / 3	1-4 / 2	1-5 / 2	Tr-8 / 2	1-3 / 2
	% Mineral Species in Transparent Heavy-Mineral Fraction–Range and Average												
Hornblende	24-36 / 27	33-45 / 37	29-54 / 40	2-28 / 10	24-52 / 37	28-51 / 38	5-59 / 28	8-46 / 28	5-59 / 23	31-53 / 42	13-55 / 31	21-55 / 34	27-30 / 28
Staurolite	1-8 / 3	Tr-2 / 1	Tr-8 / 5	4-37 / 17	3-10 / 7	1-8 / 4	Tr-26 / 7	Tr-21 / 6	3-26 / 9	Tr-12 / 5	2-23 / 13	3-18 / 8	6-16 / 11
Garnet	6-15 / 8	7-12 / 9	9-49 / 22	3-11 / 6	16-38 / 22	6-16 / 12	2-34 / 12	3-34 / 14	2-20 / 8	6-22 / 14	6-24 / 18	12-27 / 19	10-19 / 16
Zircon	6-32 / 26	8-14 / 11	1-11 / –	18-59 / 31	6-22 / 12	8-33 / 16	5-50 / 20	6-50 / 25	5-48 / 23	6-12 / 9	8-15 / 11	9-25 / 15	5-15 / 12
Epidote	9-15 / 10	9-14 / 11	Tr-11 / 4	2-14 / 5	2-5 / 4	1-8 / 4	1-20 / 7	5-14 / 7	1-20 / 7	5-7 / 7	6-9 / 8	3-7 / 5	5-8 / 6
Tourmaline	2-3 / 2	4-6 / 6	Tr-6 / 2	2-9 / 4	2-4 / 3	1-4 / 3	1-7 / 3	1-5 / 3	1-7 / 4	2-7 / 3	1-5 / 3	2-5 / 3	2-5 / 4
Sillimanite	4-8 / 7	4-10 / 7	3-13 / 8	6-16 / 11	3-9 / 6	6-12 / 8	3-34 / 10	3-34 / 11	5-20 / 13	5-13 / 8	6-8 / 7	2-7 / 3	2-13 / 8
Kyanite	Tr-1 / 1	3-6 / 5	Tr-5 / 3	2-7 / 4	1-2 / 2	1-5 / 3	Tr-4 / 2	Tr-3 / 1	1-4 / 2	Tr-5 / 2	1-4 / 3	1-6 / 2	2-3 / 3
Rutile	2-5 / 4	1-4 / 3	1-3 / 2	2-7 / 4	1-3 / 2	1-4 / 2	1-6 / 2	1-4 / 2	1-6 / 3	Tr-1 / 1	Tr-2 / 1	1-4 / 2	2-3 / 2
No. Samples	4	13	4	10	4	20	43	16	13	4	4	15	4

NOTES: 1 Delaware River N. of Trenton based on 4 bottom samples; Schuylkill River based on 13 samples from Fairmount Dam; Piedmont tributary streams comprise the Schuylkill River, Neshaminy Creek, Chester River and Brandywine Creek with each river given equal weight distribution; Coastal Plain tributary streams comprise Mantua Creek, Rancocas Creek, Crosswick Creek, Murderkill River, St. Jones River, Mispillion River, Salem River, Maurice River, Cohansey River and C&D Canal.

2 Delaware River samples North of Philadelphia comprised of 4 sample locations and other locations South of Philadelphia to St. Johns Light comprised of 20 samples.

3 Delaware Bay based upon 43 samples (28 along profiles of nearshore locations) over entire bay. Delaware side of bay includes profile locations and B6 thru B9 (20 samples). New Jersey side of bay includes profiles and B-1 thru B-5 (17 samples)

4 West side of bay (vicinity of capes) includes field samples B-8, B-9, B-12, B-13, and east side of bay includes field samples B-1, B-10, B-11, and B-14.

5 New Jersey continentals shelf samples include locations C-93, C-95, C-100, C-108, C-123, C-132, C-152, C-167, C-170, C-171, and C-183 while Delaware continental shelf locations include C-182, C-183, B-12, and average of 3 Rehoboth Beach samples.
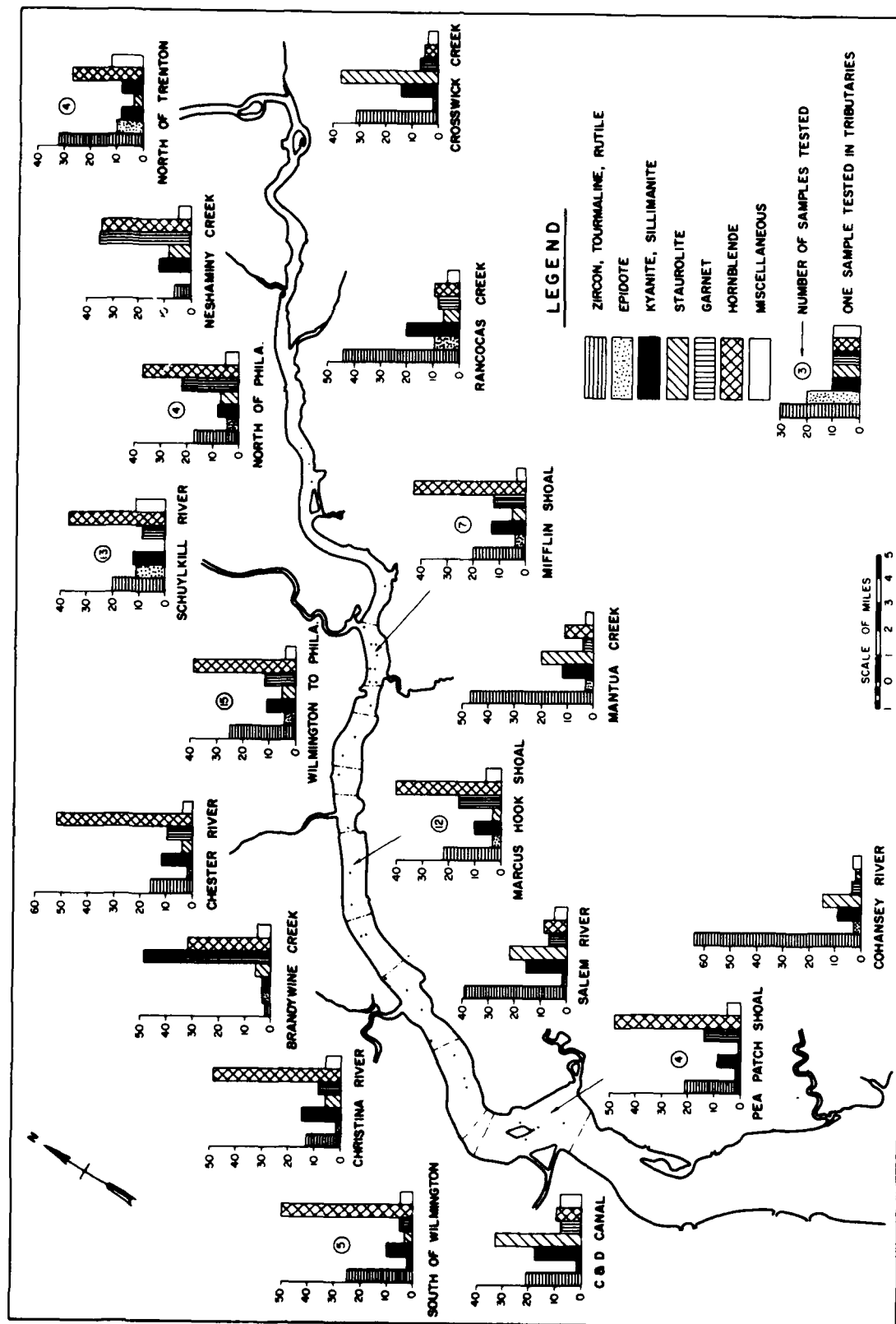
FIGURE 18. Composition of transparent heavy-mineral fraction of Delaware River and Tributaries

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(b) Garnet increases from 8 to 12 percent in a seaward direction with the Piedmont source streams effecting this increase. Brandywine Creek which discharges into the Christina River at Wilmington harbor, contains 50 percent garnet in its transparent heavy-mineral suite which is a maximum garnet source area.

(c) Zircon decreases from 26 to 16 percent and rutile decreases from 4 to 1 percent in a seaward direction. Despite the relatively high proportion of these stable minerals contributed to Coastal Plain streams, the higher quantity of Piedmont source heavy minerals effects a lower ratio in the river estuary sediment than exists at Trenton. Zircon, for example, averages 31 percent of the heavy-mineral suite of the Coastal Plain streams and 7 percent of the Piedmont streams for the distance from Trenton to the bay (see Table 6).

(d) Tourmaline, also one of the most stable heavy minerals, increases from 2 to 3 percent in a seaward direction. This increase is attributed to the 6 percent average tourmaline in the heavy-mineral suite of the Schuylkill River which drains a relatively dense igneous rock source area; this same mineral comprises 4 percent of the Coastal Plain and 2 percent of other Piedmont heavy mineral fractions (see Table 6).

(e) Staurolite tends to increase from 3 to 4 percent in a seaward direction from local source-rich Coastal Plain sediment. This mineral fluctuates most in the source region. Staurolite, for example, is especially abundant in the Crosswick Creek (37 percent) which probably drains the Red Bank Formation rich in this mineral. Staurolite is less abundant farther south in the Coastal Plain streams, possibly being diluted by Pleistocene "blanket" deposits which become thicker and increasingly more abundant toward the embayed portion of the estuary (see Figure 18).

(f) Sillimanite is one of the more consistent heavy minerals in the river estuary with averages ranging between 7 and 11 percent (see Table 6). The sillimanite increases from 7 to 8 percent in the seaward direction with the increase a result of the Pleistocene sands toward the bay.

(g) Epidote decreases from 10 to 2 percent in a seaward direction. Except for local contributions from Schuylkill River, this mineral is impoverished in other sources.

(h) Kyanite increases from 1 percent to 3 percent in a seaward direction with largest input from the Schuylkill River (see Table 6).

The heavy mineral suite from Trenton to the null point in vicinity of mile 49 defines the province existing to the bay area. This province is characterized by garnet and hornblende and aptly defined as a fluvial Piedmont source because of the preponderance of contributions from this source relative to the Coastal Plain contributing source.

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HEAVY MINERAL PATTERNS OF DELAWARE BAY

PHYSICAL AND DYNAMIC CHARACTERISTICS OF DELAWARE BAY

Several factors which affect the heavy mineral and sediment distribution in Delaware Bay include the physical characteristics, bathymetry, tidal currents, river discharge and wave action of the bay. The present-day morphology of Delaware Bay is relatively simple and uncomplicated. The bay is funnel shaped except for the capes at the mouth; the bay has a maximum width of 26.0 miles, a length of 46.7 miles, mean width of 16.7 miles, and a total surface area of 782 square miles. The shores are bordered mainly by low lying salt marshes which are dissected by a network of tidal creeks which drain into a few small tributary rivers. The major relief along the shore of the bay occurs at the two capes forming the constriction at the mouth of the bay.

The maximum depth of Delaware Bay is 151 feet and occurs along ancestoral Pleistocene drainage lines toward the mouth of the bay. The average mean depth of the bay is 31.7 feet.

The principal features of the bathymetry at Delaware Bay include the following: (a) shoals off Cape May point, (b) series of shoals parallel to the axis of the bay and separated from each other by finger-like channels, (c) shallow mud-flats which fringe most of the bay shore, and (d) the central channel which maintains depths of approximately 40 feet or greater. The locus of the deepest points in the lower bay lie on the western (Delaware) side and does not coincide with the navigation channel.

The variation of tidal current speeds and direction, obtained from current U. S. Coast and Geodetic Survey, Tidal Current Table and Tidal Current Atlas for Delaware Bay is shown in Figure 19. In general, the currents are stronger on the New Jersey side of the lower bay area and decrease towards the shores because of increased bottom friction on the mud flats. Current speed also decreases where the bay widens, and increases where the bay converges.

According to Oostdam (1971) currents in the lower part of Delaware Bay consist almost entirely of tidal currents; this is based on average river discharge of 12,000 c.f.s. at Trenton but even record discharge conditions in Delaware River would not influence the velocity appreciably. Oostdam (1971) shows the predominant tidal current direction through the vertical for 12 station location in Delaware Bay (Figure 20), and Oostdam and Jordan (1972) show a net transport flow from the bay in a seaward direction for a station located in the central portion of the bay on a line between the capes.

A composite plot of mean currents across Delaware Bay by Oostdam (1971) shows that current velocities are greater in deeper water than in shallow water because of decreasing influence of boundary friction.

Pronounced wind waves and swells in Delaware Bay are common in the late fall, winter, and early spring associated with storms. Within the bay area, Oostdam (1971) has indicated that waves 6 to 7 feet maximum are rarely experienced but 4 feet waves may occur about once a year. Winds from the NNW, NNE, and SSE present optimum fetch conditions.
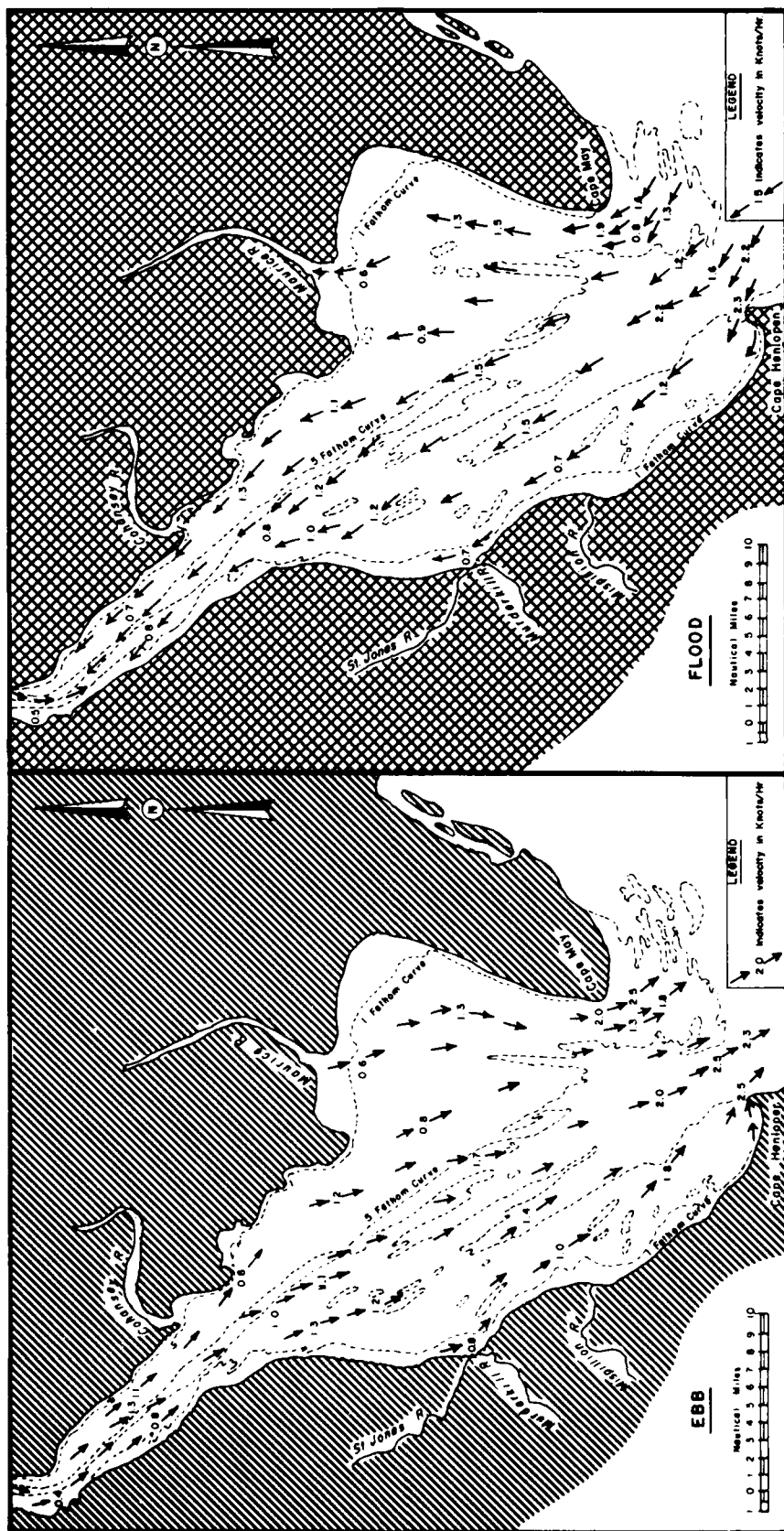
FIGURE 19 . Maximum ebb and flood tidal current velocity and direction in Delaware Bay After Coast and Geodetic Survey (1960).
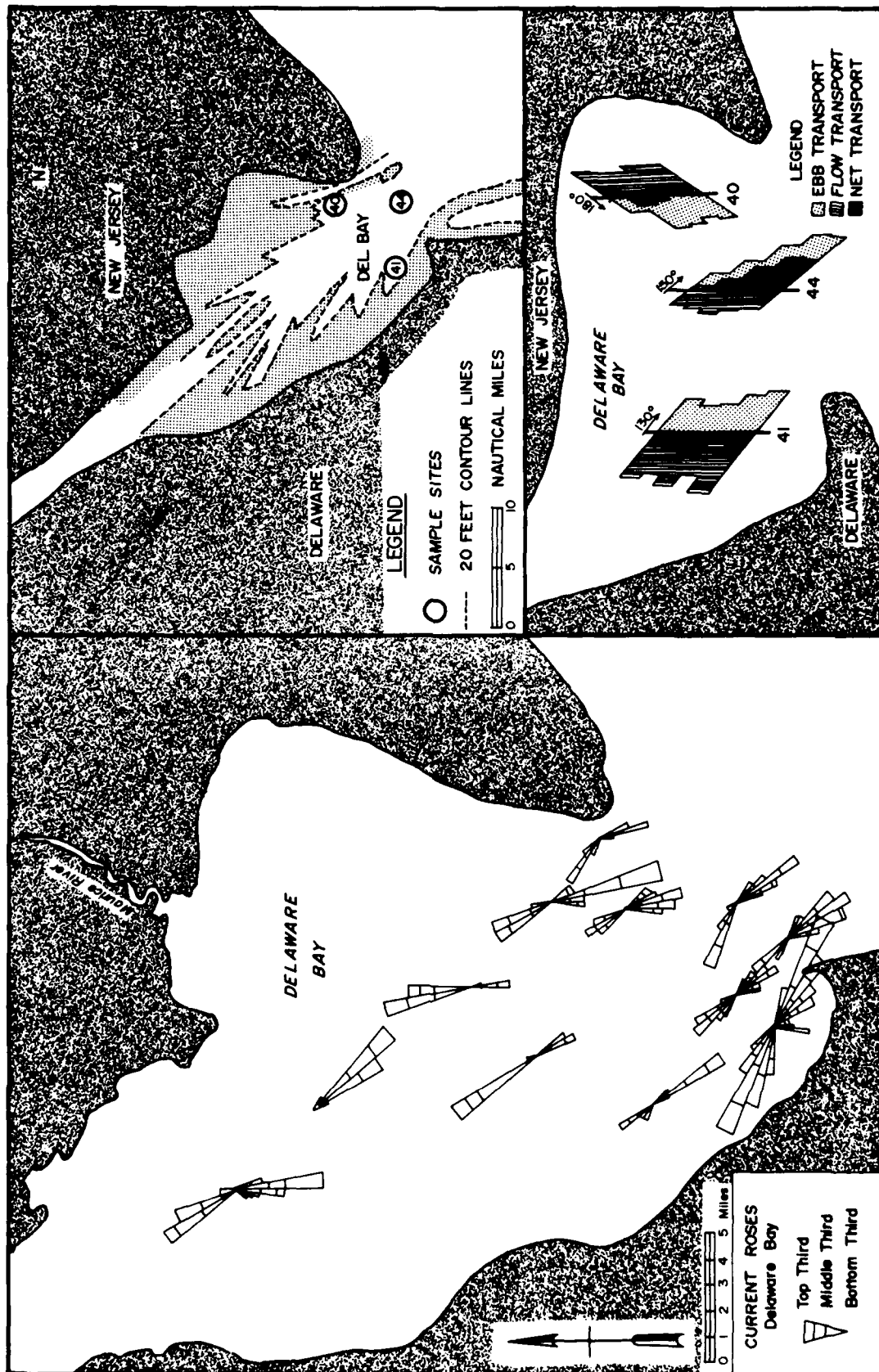
FIGURE 20. Current roses showing current directions through the vertical (after Oostdam, 1971) and net suspended transport as measured from three stations at the mouth of Delaware Bay (after Oostdam and Jordan, 1972).

NATURE OF SEDIMENT
DISTRIBUTION IN DELAWARE BAY

The composition of bay bottom sediments is largely quartz with minor feldspar, mica, organic matter, clay minerals, and heavy minerals (see Tables 1 thru 3 of Annex A). Clay minerals are comprised of illite (50-70%), chlorite (20-25%), and minor kaolinite and montmorillonite. The higher chlorite than kaolinite in the clay fraction is one of the more pronounced sediment changes in the bay areas as compared with the Delaware River north of mile 49; this is attributed to the Coastal Plain source of chlorite.

Oostdam (1971) and Strom (1972) performed grain size analysis of 300 bottom samples in Delaware Bay. Most of the sediments in the bay area are medium-grained sands coarsening toward the capes and generally decreasing in size in both upriver and shoreward directions. Off the capes, gravel patches are relatively abundant on shoals. Deposits along both shores are predominantly silts and muds.

The sedimentary parameters of the sands of Delaware Bay by Oostdam (1971) show a distinct bimodal mediam grain size distribution with prime mode in the interval 1.00 to 1.50 phi and a secondary mode between 2.75 and 3.00 phi which probably reflect the abundance of samples collected in the vicinity of the capes and the large areal extent of the fines along the shores and upriver areas. The sands of the bay area are relatively well sorted with most sorting coefficients ranging from 0.26 to 0.75 phi units which is evident of effective current action in Delaware Bay.

Oostdam (1971) interprets the textural distribution of the bottom sediments in Delaware Bay as reflecting a large scale sorting process in operation in Delaware Bay due to

wave and current action. Fines are winnowed from the sediment by these agencies and either not deposited or else deposited in the quieter water along the shore or flushed from the bay. Thus the sand in the central portion of the bay is envisioned by Oostdam (1971) as representing a "lag" deposit from which the fines have been removed by hydrodynamic agencies.

Jordan (1968) concluded from preliminary investigations of the Delaware Bay area that the upper portion of the estuary is filling with stream-derived sediment and the lower bay is filling with coarser materials derived from the continental shelf and ocean shores and both Oostdam and Jordan (1969) suspect that sediment transport into Delaware Bay from the ocean may be several times larger than from the rivers.

HEAVY MINERAL ANALYSIS
OF DELAWARE BAY SEDIMENTS

Introduction

Heavy mineral analysis of the sand fraction from 44 bottom sediment samples in Delaware Bay and 32 beach samples around the bay area reveals a pattern of mixed fluvial Piedmont and Coastal Plain heavy mineral suite which is characterized by a high sillimanite fraction. Covering approximately 85 percent of the Delaware Bay area, this heavy mineral province is in solid control of the bay from the null point near mile 49 to the lower bay area in vicinity of the capes. Marked differences exist in the lower eastern portion of the bay area in the vicinity of the capes; here sillimanite is poorly represented and pyroxene is generally more abundant in the heavy mineral suite.

The concentration of heavy minerals (in the sand fraction between 74 and 420 micron size) in the bottom sediment samples of Dela-

ware Bay ranges from trace amounts to 18 percent with an average of approximately 3 percent. The average concentration of the heavy minerals is greater on the Delaware side of the bay which averages 4 percent for bottom samples tested and include the two anomalies of 18 percent heavy minerals near Woodland Beach and 8 percent heavy minerals off Bowers Beach, Delaware (see tables of Annex B). The heavy mineral fractions range widely with a general average of 68 percent transparent, 30 percent opaques, and 2 percent mica. The predominant opaque minerals are magnetite and ilmenite with minor amounts of hematite, leucoxene, and others. The transparent heavy mineral species for the Delaware Bay bottom samples are summarized in Table 6 and listed for individual locations in Annex B. Figure 21 is a graphic plot of the heavy minerals for the bay area and tributary rivers to the bay. Some of the more diagnostic minerals will be treated in detail in the following paragraphs.

Hornblende and Garnet

Generally high values of both hornblende and garnet prevail in the heavy mineral suite of the upper bay area with increasing dilution toward the shores and in the seaward direction. Toward the bay margins and the major central portion of the bay, hornblende values range between 5 and 40 percent with no definite trend apparent. The Pleistocene sands in the formations rimming the bay area average 14.2 percent amphibole (predominantly hornblende) in the 75 Pleistocene sediment samples reported by Jordan (1964) and 8 percent for the 25 samples examined from the Pleistocene sediments by Groot (1955); older Coastal Plain formations vary from trace amounts to a few percent (see Figure 17). Erosion of the beaches around the bay and sediment discharge from tributary streams (estimated at 80 tons of heavy minerals annually) and the mixing conditions by waves

and currents as cited previously would appear responsible for the hornblende distribution in the bay area. Toward the lower eastern bay area, hornblende values locally in excess of 50 percent are attributed to the high hornblende content of the New Jersey shelf sands which are projected into the lower bay area around Cape May; McMaster (1954) reports an average of 35 percent hornblende in these sands (see Table 7).

Garnet values in the upper part of the bay area tends to parallel the trend of hornblende distribution with higher values (20 percent) in a projection of the fluvial Piedmont source heavy minerals into the bay but generally diminishing to about half this amount around the margins of the bay. Both Jordan (1964) and Groot (1955) report an average of 2 percent garnet in the Pleistocene Formations in the Delaware; unlike the hornblende, however, garnet has a fair representation in the older Cretaceous Coastal Plain Formations (see Figure 17) where averages between 10 and 20 percent of the transparent heavy mineral fraction occur in the Manasquan, Vincetown, Mount Laurel and Merchantville Formations. The generally high values of garnet, ranging between 20 and 25 percent of the heavy mineral fraction toward the central portion of the bay, may be related to the factors contributing to the "lag" deposits previously cited. Coastal sands and glacially derived sands off the New Jersey coast average 16 percent garnet (McMaster, 1954) while garnet in the eastern bay area averages 14 percent. Such similarity in garnet population would appear to support the view that shelf sediment is transported into the bay in this general area.

Zircon, Rutile, and Tourmaline

Zircon, rutile, and tourmaline constitute the most stable heavy mineral species and occur in greatest abundance in older Coastal Plain sediments. Considerable variability has been

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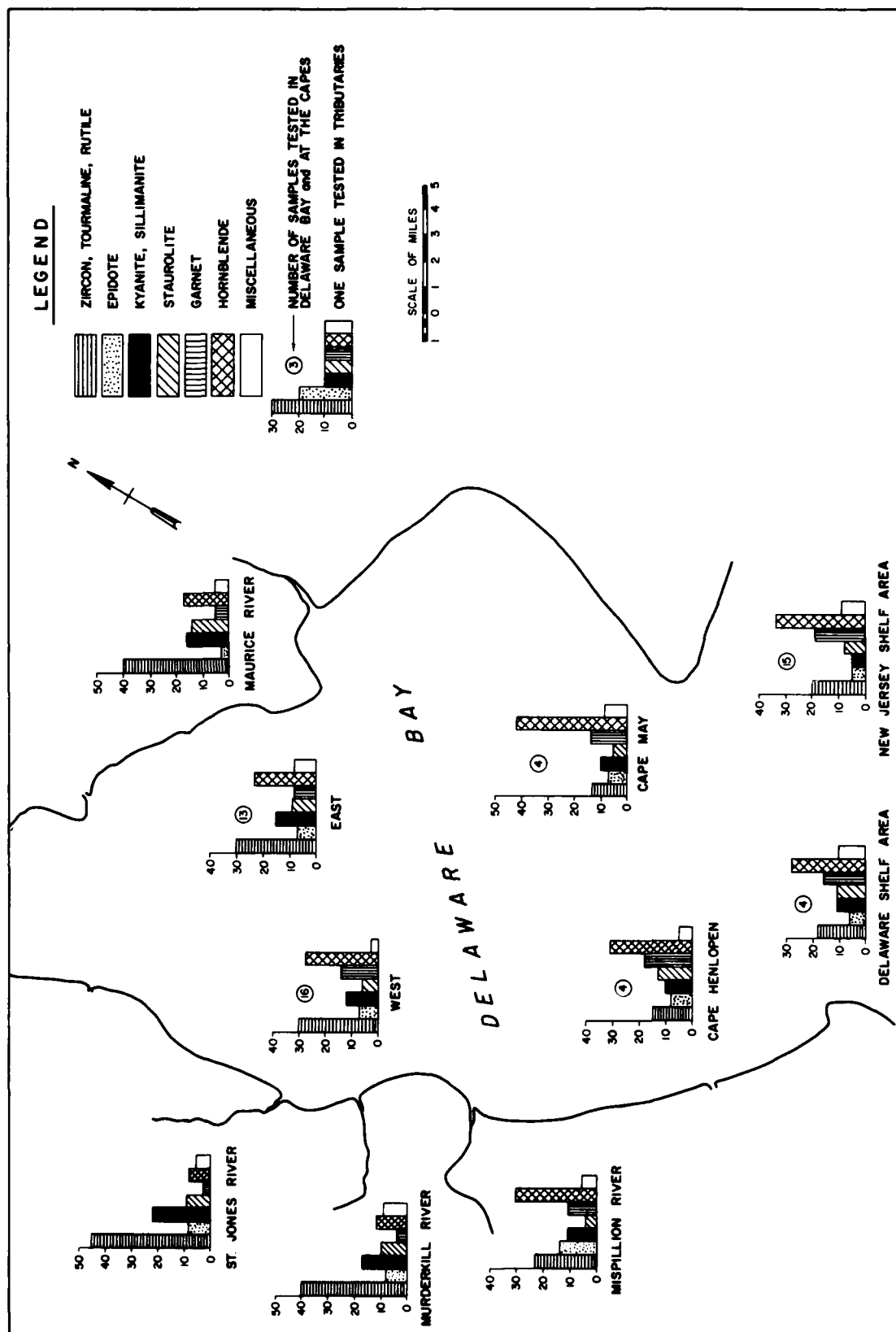
FIGURE 21. Composition of transparent heavy-mineral fraction of Delaware Bay and Vicinity

TABLE 7

HEAVY MINERAL DISTRIBUTION IN VICINITY OF THE CAPES AND CONTINENTAL SHELF OFF DELAWARE BAY

Heavy Mineral Species	UPPER BAY		VICINITY OF CAPES					CONTINENTAL SHELF		
	Delaware West Side	New Jersey East Side	Delaware Bay West Side	Delaware Bay East Side	Strom S.W. Del. Bay	New Jersey Coast	Delaware Coast	McMaster N.J. Coast	Shepard & Cohee N.J. Coast	Alexander Md. Coast
				% Heavy Minerals in Sand fraction – Range and Average						
	Tr-18.0	1-6.0	0.5-3.5	0.8-5.0	–	0.0-8.1	1.2-1.7	–	–	–
	4.0	3.0	1.3	2.0	–	2.4	1.6	–	–	–
				% Mineral Species in Transparent Heavy-Mineral Fraction—Range and Average						
Hornblende	8-46	5-59	31-53	13-55	19-49	21-55	27-30	–	–	–
	28	23	42	31	35	34	28	35	Abt.	Abt.
Staurolite	Tr-21	3-26	Tr-12	2-23	1-16	3-18	6-10			
	6	9	5	13	6	8	9	13	High	High
Garnet	3-34	2-20	6-22	6-24	2-7	12-27	16-19			
	14	8	14	18	4	19	18	16	High	Higher
Zircon	6-50	5-48	6-12	8-15	1-9	9-25	14-15			
	25	23	9	11	4	15	15	5	Low	Low
Epidote	5-14	1-20	5-7	6-9	1-10	3-7	5-6			
	7	7	7	8	6	5	5	4	Low	Low
Tourmaline	1-5	1-7	2-7	1-5	4-9	2-5	2-5			
	3	4	3	3	7	3	4	5	Abt.	Abt.
Sillimanite	3-34	5-20	5-13	6-8	6-30	2-7	2-8			
	11	13	8	7	15	3	6	3	Low	Higher
Kyanite	Tr-3	1-4	Tr-5	1-4	2-16	1-6	2-3			
	1	2	2	3	9	2	3	2	Low	Higher
Rutile	1-4	1-6	Tr-1	Tr-2	2-7	1-4	2-3			
	2	3	1	1	4	2	2	1	Low	Low
No. Samples	16	13	4	4	6	15	3	–	–	–

NOTES:
1. West side bay (vicinity of capes) includes field samples B-8, B-9, B-12, B-13 and East side of bay (vicinity of capes) includes field samples B-1, B-10, B-11, and B-14.

2. Southwest side of bay as reported by Strom (1972). The heavy minerals were recomputed to nonopaque fraction minus micaceous minerals for similar comparison.

3. New Jersey coastal sands based on averaged samples of McMaster and Light as reported by Hubert and Neal (1967).

4. Relative abundance of minerals based on Continental shelf studies as reported by Cohee and Shepard (1936) and Alexander (1934).

5. Samples from Continental shelf received from Coastal Engineering Research Center as part of offshore sand sampling program.

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reported by different investigators for zircon in the Coastal Plain formations with Pleistocene sands averages between 22 percent (Grott, 1955) and 34 percent (Jordan, 1964) and older sediment averaging even higher values. Within the bay area, zircon high values (20 percent) occur around the rim of the bay with but half this amount in the central bay area (see Figure 2 of Annex B). Zircon in the Mantua and Rancocas Creek sediment averages respectively 33 and 28 percent of the heavy mineral fraction reflecting formations older than Pleistocene in the Coastal Plain sediments drained by these streams.

Rutile, like zircon, is one of the most resistant heavy minerals, and its relative distribution pattern is similar to zircon. Highest rutile concentrations occur in Coastal Plain sediments and streams draining the Coastal Plain (see Table 6); rutile ranges up to 6 and 7 percent respectively in Mantua and Rancocas Creeks which also is the site of highest zircon concentration in the Coastal Plain sediments (see Table 1 of Annex B). Within the bay area, rutile averages 2 percent of the heavy mineral fraction with greater occurrence around the margins of the bay area. Rutile, however, is relatively impoverished in the glacially derived shelf sands off the New Jersey coast; McMaster (1954) reports less than one percent rutile in the transparent heavy mineral suite of these sands.

Tourmaline is also one of the most resistant heavy minerals, but unlike zircon and rutile, it is less abundant in Delaware Bay than in the coastal or continental shelf area. Tourmaline in the bay area averages 4 percent of the heavy mineral fraction with greatest occurrence around the margin of the bay where values of 7 and 8 percent are common as shown in Figure 2B, Annex B. Since tourmaline averages 5 percent in Pleistocene sands and nearly double this amount in older Coastal Plain sediment (see Table 5), it would appear that the higher values

could possibly reflect erosion of older Coastal Plain formation source areas while in the lower bay area this could reflect the influence of shelf derived sands.

Staurolite, Kyanite and Sillimanite

Staurolite, kyanite, and sillimanite are varieties of medium and high rank metamorphic minerals but staurolite differs considerably in its distribution pattern from sillimanite and kyanite. Staurolite has an abundant source in Cretaceous sediments whereas sillimanite has greatest populations in the Pleistocene sediments; kyanite is always subordinate to sillimanite with similar trend. Sillimanite averages 12.7 percent and staurolite averages 4.4 percent of the 75 Pleistocene samples reported by Jordan (1964) and the typical Delaware Bay heavy mineral suites are generally of this magnitude (see Table 6). Staurolite attains highest values (20 percent) in the lower eastern portion of the bay which is consistent with the general high staurolite averages (13 percent) reported by McMaster (1954) off the New Jersey coast (see Table 7). The major portion of the bay area reflects generally low staurolite values and is consistent with the concept of mixing of predominantly Pleistocene Coastal Plain sediment (4.4 percent) and fluvial Piedmont source sediment (4 percent) in the central bay area.

Sillimanite averages in the bay area range between 11 and 15 percent except for the lower east bay area where averages are about half this much (see Table 7). Lowest sillimanite occurrence found in this investigation was from the shelf area off the New Jersey Coast (three percent) which is also in excellent agreement with the more intensive study of McMaster (1954) for the New Jersey coastal area (see Table 7). Investigation of the southwest corner of Delaware Bay by Strom (1972) provides cooroborative evidence of the high sillimanite

values (15 percent) in this portion of the bay (see Table 7). Sillimanite along the Delaware coast averages 6 percent and this stands in sharp contrast to the impoverished sillimanite content of the heavy mineral suite of the New Jersey shelf area (see Table 7).

In general, high sillimanite averages and a full heavy-mineral suite characterize the Delaware Bay heavy mineral province.

Epidate and Pyroxenes

Epidote and pyroxene (augite, hypersthene, and diopside) occur in the Delaware estuary sands but are more variable in distribution than the other heavy minerals. Epidote in Pleistocene formation averages 17.2 percent (Jordan, 1964), 7 percent in the bay area (Table 6), 4 percent in the glacially derived sediment of the shelf (Table 7) and 4 percent in the Piedmont dominated upper estuary source. Thus the average bay sediment appears to reflect mixing of appreciable Coastal Plain Pleistocene sands for the 7 percent average found in Delaware Bay.

Pyroxenes, as orthopyroxene (hypersthene) and clinopyroxene (augite and diopside), comprise from 1 to 4 percent of the bay sediment with highest values in the lower eastern portion of the bay (see Table 1 of Annex B). Highest source areas of pyroxene, especially hypersthene, is from Piedmont formations at discharge points south of Philadelphia; the 9 percent total pyroxenes occurring here are more local with dispersal to a few percent within several miles in a seaward direction (see Annex B). Hubert and Neal (1967) report 8 percent pyroxene from investigations off the New Jersey coastal and shelf areas and this may account for the highest pyroxene values in the lower eastern portion of Delaware Bay. Coastal Plain formations average

up 2 percent pyroxene in younger Pleistocene sediments (Jordan, 1964) but are impoverished in older Coastal Plain formations. Thus, the low pyroxene values for the "Delaware Bay" heavy mineral province is consistent with source areas delineated by other heavy minerals.

Chloritoid ranges from trace amounts to 1 percent of the bay sands. Both tremolite and actinolite are present throughout the bay in amounts ranging from 1 to 4 percent but show no distinct pattern.

HEAVY MINERAL PROVINCES OF DELAWARE BAY

The foregoing description of the heavy mineral distribution in the bay bottom sediments clearly defines the following heavy mineral provinces:

(a) The river from head of tide at Trenton to the null point at mile 49 is characterized by a fluvial Piedmont hornblende-garnet heavy mineral suite.

(b) The upper and central bay area is characterized by a "full" heavy mineral suite, i.e., heavy-minerals of all stability ranges and abundant sillimanite. Sillimanite is in similar proportions in this heavy-mineral suite of mixed Coastal Plain and Piedmont source materials and thus maintains a similar value while less resistant Piedmont minerals (hornblende and garnet) are somewhat reduced in value. This "full" heavy mineral suite characterized by sillimanite extends the entire length of the bay on the western side and a recent investigation of 7 bottom samples in the southwest corner of Delaware

Bay for heavy minerals by Strom (1972) provides corroborative evidence for including this southwestern bay area in the "Delaware Bay" heavy mineral province (see Table 7).

(c) The lower east and central bay area contains a heavy-mineral suite of mixed Delaware Bay and glacially-derived continental shelf sands. Sillimanite in this mixed suite ranges from 4 to 8 percent and pyroxene attains highest values in the bay area. Distribution of the sediment drift, reflected by the heavy minerals, correlates with findings by Bumpus (1965) on directional flow of bottom drifters (see Figure 22).

HEAVY MINERAL DISTRIBUTION IN VICINITY OF THE CAPES

GENERAL CONSIDERATIONS

Several investigations of the hydrodynamics and sediment of the New Jersey and Delaware coastal areas in vicinity of the Delaware Bay capes have been conducted by the U. S. Army, Corps of Engineers (1972, 1968, 1963, 1959, 1946), Bumpus (1965), Meade (1959), Moody (1964), Kraft (1971), Fairchild (1966), and others. The sediments off the New Jersey coast are coarser grained than those off the Delaware coast and it is apparent that mixing of sediment does not occur between the capes; current studies and diagnostic heavy minerals will be shown to support this view. In the vicinity of the capes, strong erosion is in progress with littoral currents around the capes into the bay from the seaward direction.

Bottom sediment samples for heavy minerals in this phase of the investigation were provided by the Coastal Engineering Research Center and the University of Delaware; two samples were provided in vicinity of the capes by Philadelphia District.

New Jersey Coast in Vicinity of Cape May

U. S. Army Corps of Engineer (1972) records reveal that erosion has been prevalent from Cape May point to 7 miles north along the New Jersey coast since earliest survey records to 1842. It is also indicated in an earlier report (U. S. Army Corps of Engineers, 1961) that the New Jersey shore of Delaware Bay from the tip of Cape May Point to Maurice River had eroded an average of about 220 feet between 1842 and 1957. Waves as high as 9 feet were observed at Cape May City, during a short study from September to December 1948. Based on hindcasting methods, waves in excess of 6 feet in height occur off the Delaware Bay entrance about 18 percent of the time. The predominant littoral current produced by the refracted waves is in a southerly direction from a point about 60 miles north of Cape May toward the bay entrance. Cape May is an eroding Pleistocene ridge and the south-westerly longshore drift has been estimated by Fairchild (1966) at 200,000 cubic yards per year; some of this sediment builds up the extensive shoals and banks of coarse sediments off Cape May point.

An investigation of the net movement of bottom water on the continental shelf area south of Cape Cod by Bumpus (1965) using records of sea-bed drifters released at sea and eventually recovered by fishermen and beach-combers indicated movement of bottom currents around Cape May into the bay (see Figure 22). Sediment drift
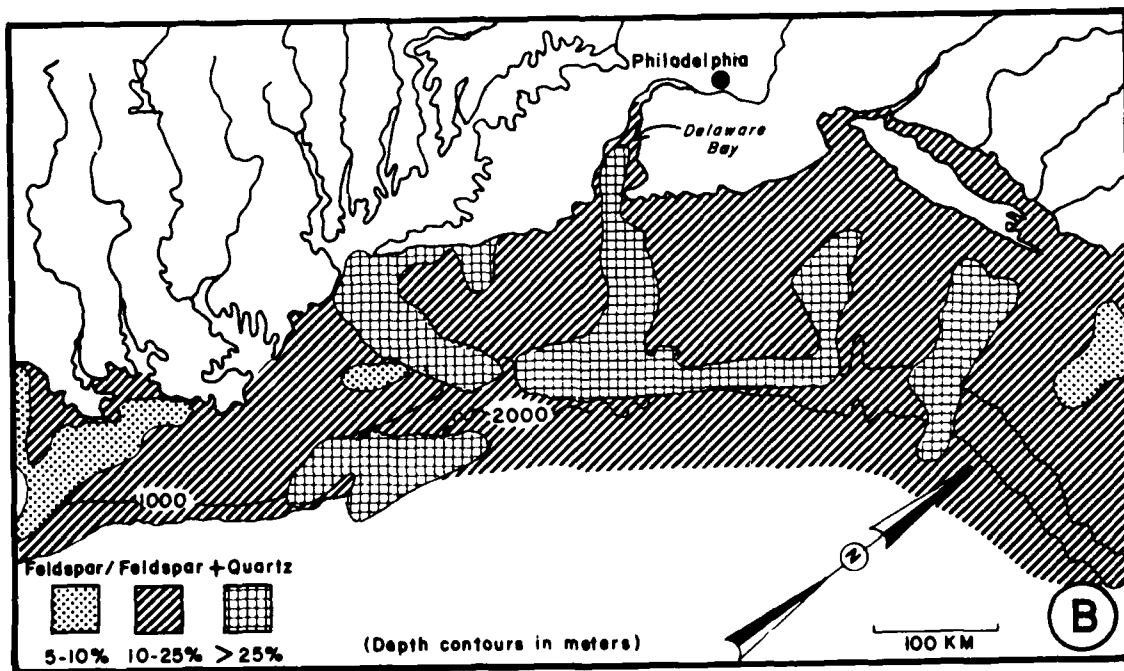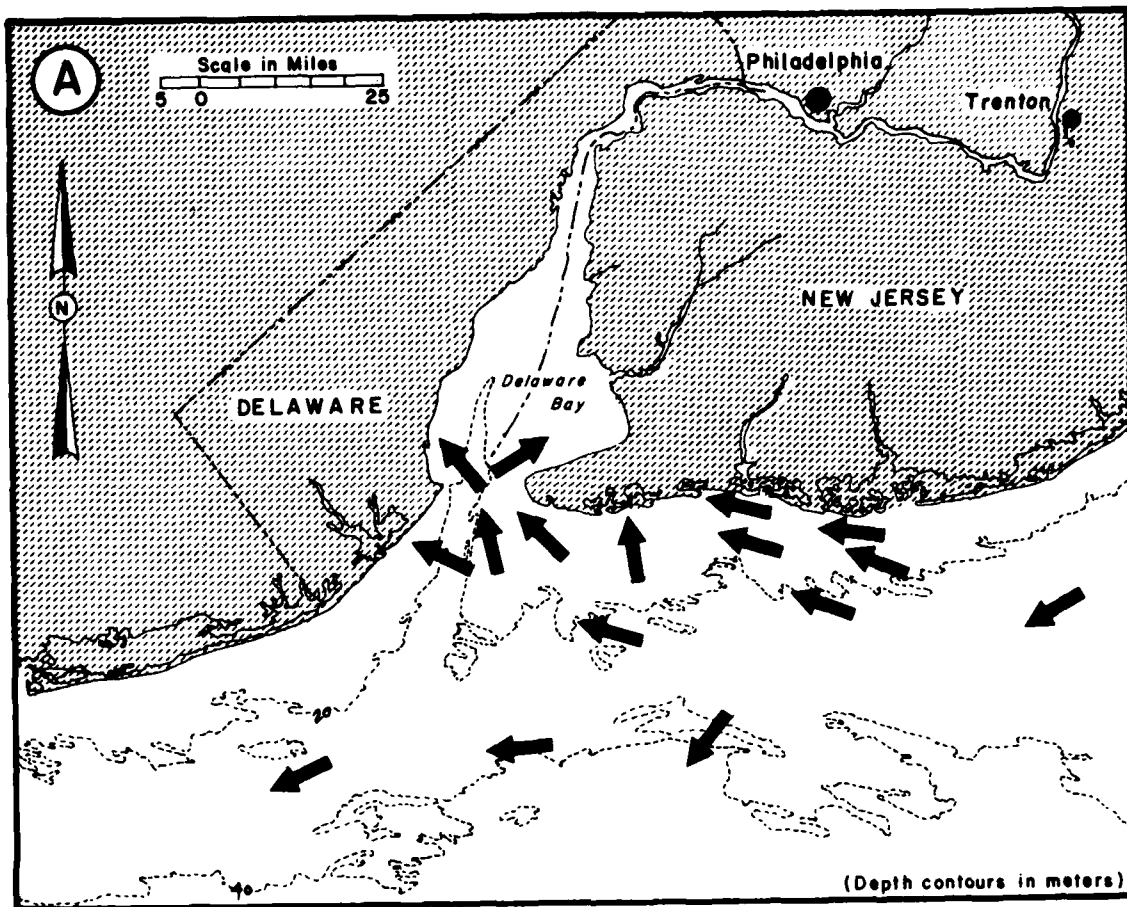
FIGURE 22. Direction of general residual current along the bottom on the continental shelf (Bumpus, 1965) and the ratio of feldspar to feldspar + quartz (f/f+q) in the 125 to 250 micron fraction of surface sediment on the continental shelf (Milliman, et al, 1972).

also follows this general directional movement as will be shown by diagnostic heavy minerals.

Delaware Coast in Vicinity of Cape Henlopen

Records of the U. S. Army, Corps of Engineers (1968) reveal that since 1843 strong erosion at a rate of 7 to 10 feet per year has occurred along the Delaware coast for the 2 miles of beach extending southward from the tip of Cape Henlopen. The shoreline from Cape Henlopen to Rehoboth Beach has experienced a continual landward recession averaging 6 feet per year while the shoreline from Rehoboth Beach to 1.8 miles above Indian River Inlet has receded 4 feet per year for most of the same period of time since 1843. The 30 miles of Delaware Bay shoreline from the tip of Cape Henlopen to Kitts Hummock has not experienced progressive erosion between 1843 to 1954 as indicated by the U. S. Army, Corps of Engineers (1956); four reaches of this shoreline, totalling about 4 miles, are the only eroding portions and these four reaches have a reported annual loss of 7,000 cubic yards annually. The eroding materials have provided sediment to the northerly directed littoral drift along this section of Delaware coast, and the northern tip of Cape Henlopen has been extended bayward approximately 3,850 feet north of its 1843 location. Turner (1968) has estimated the northward longshore transport past Cape Henlopen as 450,000 cubic yards per year.

According to Moody (1964), Cape Henlopen is probably several thousand years old having grown northward from Rehoboth Beach over gently sloping gravel deposits left by the Delaware River during the last sea level recession. Kraft (1971) predicts that Cape Henlopen is destined to become a recurved spit of the type that it was in the prehistoric past and in the process it may join with the southwest

corner of Delaware Bay mainland (see Figure 23). Because of the 55 ft. water depth in the gap between the mainland and Cape Henlopen and the strong current in this gap, it seems unlikely that any closure will be effected in the near future.

Bathymetry in Vicinity of the Capes and Adjacent Shelf

The submarine topography of the approaches to Delaware Bay is depicted in Figure 23. A ridge and trough topography with northeast or east northeast trend is characteristic. Some of the shoals near Cape May conform to the orientation of the coastline and curve into the mouth of Delaware Bay. Perhaps one of the most striking bottom features is the Delaware submarine channel approximately five miles east of Cape Henlopen; this feature has a narrow channel with depths in excess of 100 feet extending for 50 miles to the southeast across the continental shelf. Kraft (1971) has shown this submarine channel to be the site of ancestoral Delaware Bay approximately 7,000 years before present (see Figure 24). This feature probably attained its greatest depth during the lower sea level approximately 10,000 years before present. Sediment distribution also conforms to this Pleistocene feature as will be shown in a later section of this report.

Swift (1973), in a study of the transverse shelf valleys of the North Atlantic Shelf area has cited the Delaware Submarine Canyon as especially informative example of an estuary retreat path; unlike other estuary mouths of the shelf area, this canyon, which he terms shelf valley, has not been decoupled from the generative estuary mouth by the late Pleistocene reduction in the rate of sea level rise. The seaward-trending flood channel of the bay is continuous with the Delaware Submarine Canyon and is only approximately superimposed on the subsur-

Bathymetry

B Coastal Dynamics

Hen & Chickens Shoal

Fine Sand

Major Erosion

Sand & Gravel

Active Coastal Dune

Dunes

Mini Area

Ebb Tide

Fossil Dune

Advancing Beach Ridges

Great Dune

Breakwater Harbor

Pre-Holocene Pleistocene Highland

Average Wave Front Approach

Littoral Drift

Deposition Erosion

0   ½   1 Mile

A Bathymetry

Nautical Miles
0   5   10

Tidal Marsh

Transgressive Barriers

0 - 10' Water

10 - 60' Water

>60' Water

FIGURE 23   Bathymetry of Delaware estuary and Atlantic coast (A) and coastal dynamics in vicinity of Cape
Henlopen (B), after Kraft (1971).
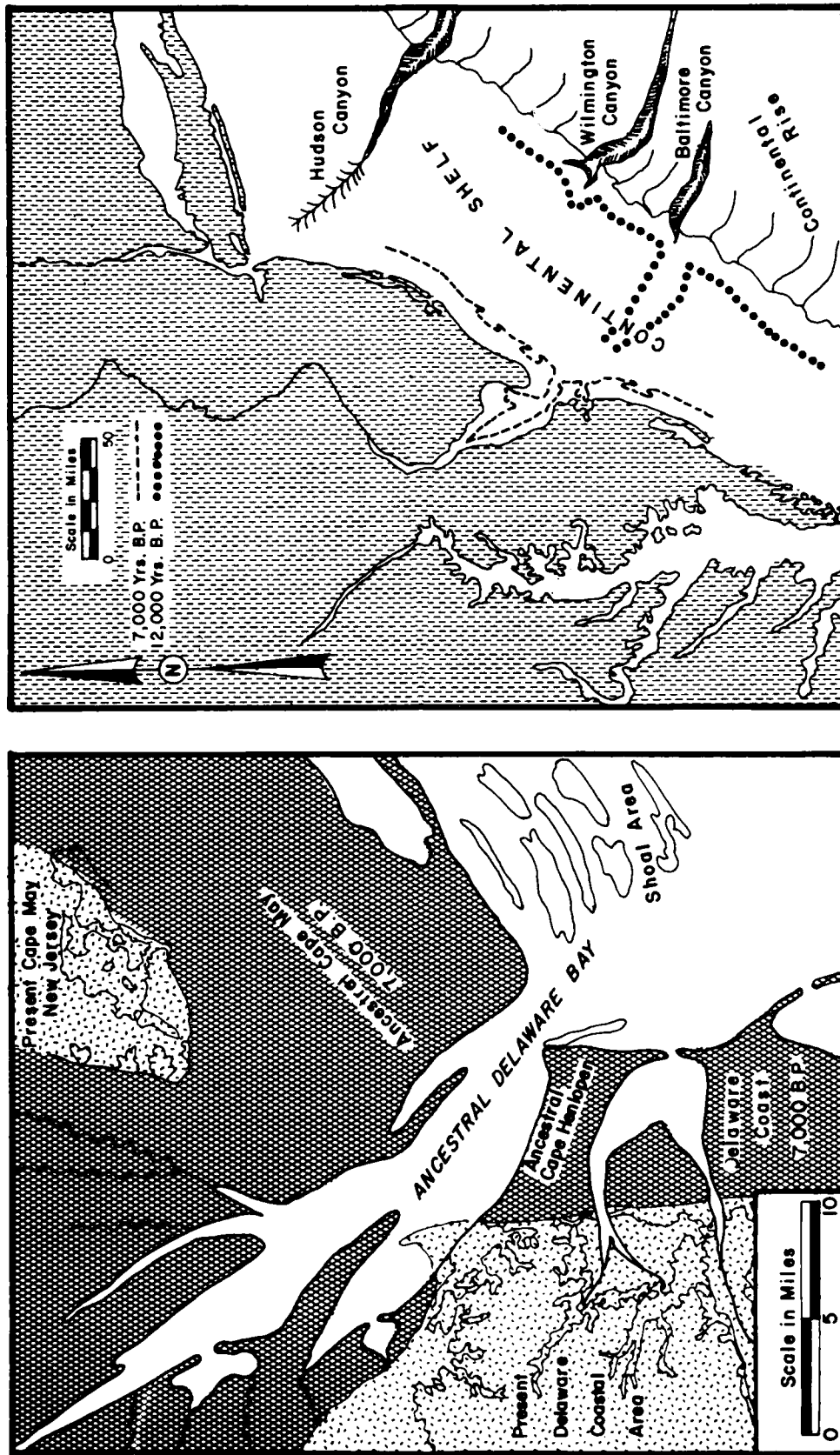
FIGURE 24. Paleogeography of the continental shelf and coastal area off Delaware and New Jersey 7,000 and 12,000 years before present. After Kraft (1971).

face fluvial channel. The curved shoal areas off Cape May receive the predominant sediment as littoral drift from the New Jersey coast and these may be traced seaward into a shelf-transverse high which Swift (1973) terms an estuary shoal-retreat massif. The massif reflects an equilibrium system in the rotation of ridge and swale orientations from nearly right angles at the capes to essentially parallel to shore on the shelf. Along the Delaware coast, an important shoal area, Hen and Chicken Shoal, occurs between the submarine channel and Delaware shoreline (see Figure 23). This shoal extends 12 miles south of Cape Henlopen and terminates 6 miles offshore. The shoal is 2.5 miles wide at the southern end and tapers to less than 0.2 miles at Cape Henlopen where it has a maximum relief of about 36 feet on its northeast side. This shoal is an important source of sediment which is transported by littoral currents into the bay.

Sediment in Vicinity of the Capes

The sediments in vicinity of the capes have been described by Moody (1964) and general types are depicted in Figure 25. The terraces east and west of the submarine channel are covered with sand, gravelly sand, and scattered patches of sandy gravel in depressions. Sand and gravelly sand occur in the submarine channel; local sandy gravels are probably fluvial deposits from the Delaware River when sea level was lower. Sandy silt and gravelly sand cover seaward parts of Hen and Chicken Shoal and the bottom sediments between the shoreline and shoal. Texture examination of Cape Henlopen beach materials by U. S. Army, Corps of Engineers (1968) supports the view that little if any material from the New Jersey beaches crosses the Delaware Bay to feed the Delaware beaches. Heavy mineral provinces delineated in this investigation supports this view as will be demonstrated later.

As described in previous sections, glacially derived heavy minerals of the New Jersey coast are transported by hydrodynamic agencies into the eastern portion of Delaware Bay and onto the shoals off Cape May but do not mix across the capes. This, then, would explain the impoverishment of pyroxene in the sediment south of Delaware Bay. It has also been shown that littoral currents carry sediment into the bay from the south and that mixing does not occur across the capes from Delaware Bay. Oostdam and Jordan (1972) also concluded from suspended sediment studies along 3 stations across the mouth of Delaware Bay that net sediment transport is into the bay near both shore stations whereas a station near the center of the bay mouth displays net seaward transport at all levels. Thus, the Delaware Submarine Channel appears to be a controlling feature governing *sediment transport.* It will be shown that sillimanite distribution patterns reflect the long term transport of sediment as reflected by the hydrodynamic picture developed to this date in vicinity of the capes.

HEAVY MINERAL DISTRIBUTION IN CONTINENTAL SHELF SEDIMENTS

Investigations of the heavy minerals of the continental shelf sediments between Nova Scotia and Delaware Bay have been reported by Alexander (1934), Shepard and Cohee (1936), McMaster (1954), Ross (1970), Milliman (1972), Stanley et al. (1972), Hubert and Neal (1967), and others. A comparison of some of the more extensive heavy mineral investigations of the Atlantic Continental Shelf or nearshore area to that of the average heavy-mineral suite of Delaware Bay is depicted in Figure 26. Investigations from north to south include those of Ross (1970) from Nova Scotia to New Jersey, McMaster(1954) for the New Jersey coast, Swift et al. (1971) for the Virginia-North Carolina
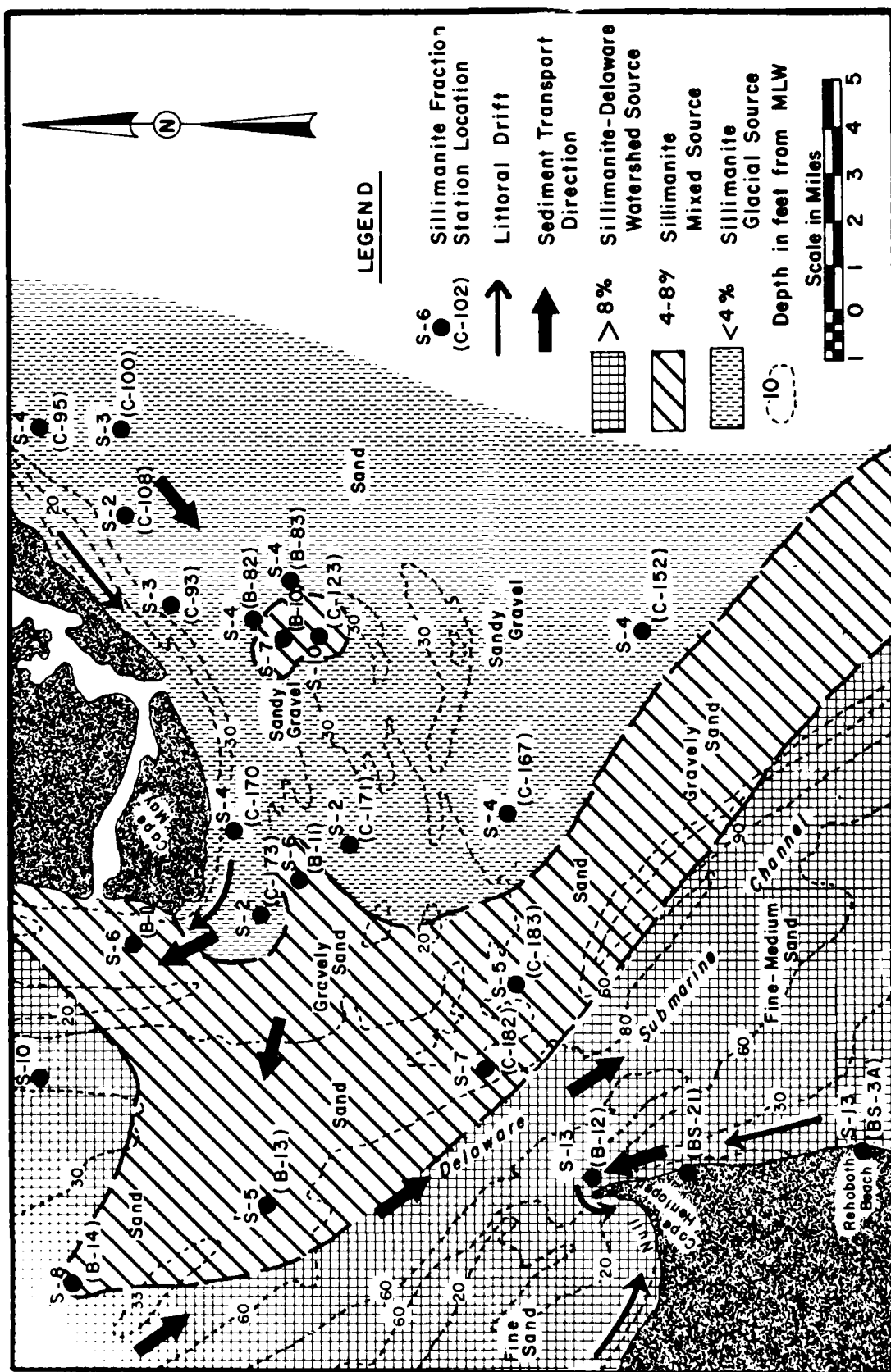
FIGURE 25. Sediment drift in vicinity of the Delaware Bay capes based on sillimanite dispersal patterns. Generalized sediment occurance after Moody (1964); littoral currents after Kraft (1971) and Corps of Engineers (1972); bottom currents after C&G chart 1219.
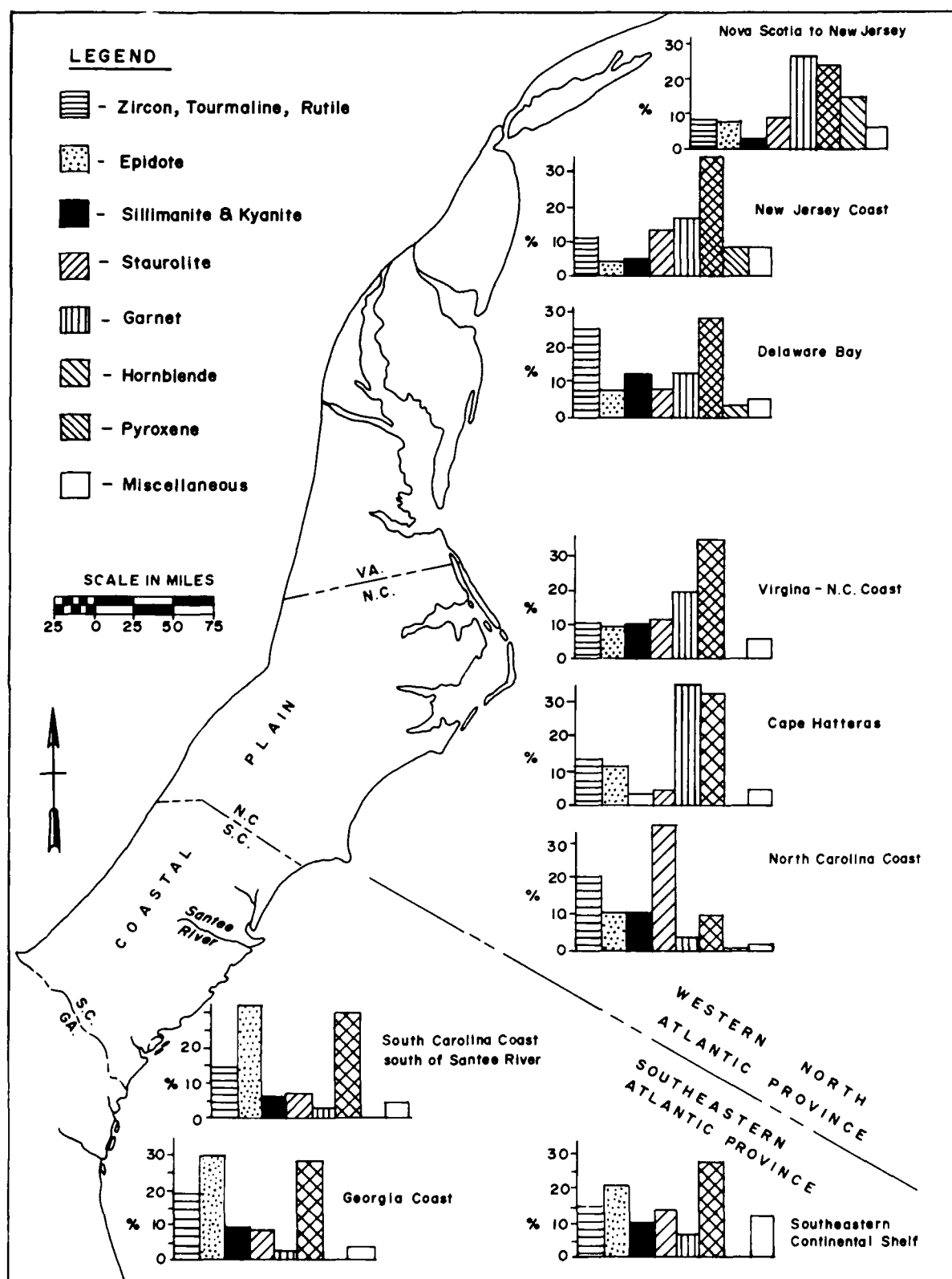
FIGURE 26. Heavy mineral assembages of the Atlantic Continental Shelf Area. (Investigators from north to south: Ross (1970), Mc Master (1954), Swift, etal.(1971), Stone and Siegel (1969), Tyler (1969), Neiheisel and Weaver (1967) and Pilkey (1962)

coast, Stone and Siegel (1969) for Cape Hatteras and Tyler (1934) for the North Carolina coast. Sediment from the continental shelf area to the north of Delaware Bay are largely glacially derived. Ross (1970) has characterized the heavy minerals of the glacial assemblages on the basis of 25 transparent species; hornblende and garnet are relatively abundant but moderate quantities of pyroxene and apatite distinguish it from the provinces south of the Hudson Bay (see Figure 26. As shown in Figure 26 McMaster (1954) also reflects a glacial source along the New Jersey coast characterized by three percent sillimanite, two percent kyanite, and eight percent pyroxene. Frank and Friedman (1972) in a more recent investigation of a study area 20 miles wide across the New Jersey continental shelf north of Atlantic City corroborate the findings of McMaster's earlier investigation and suggest that some of the sediment may have in part been derived from an ancestoral Hudson River.

A comparison of the pyroxene and sillimanite in the continental shelf area north and south of Delaware Bay is depicted graphically in Figure 26; from the figure, it is apparent that pyroxene is virtually absent while sillimanite increases in substantial amounts in the heavy-mineral suite south of Delaware Bay. The marked increase of sillimanite in the continental shelf sands south of Delaware toward the Maryland coast was noted by Alexander (1934) in one of the earlier investigations of transects along the continental shelf and he suggested from his study that the Delaware River might be the contributing source.

SEDIMENT DRIFT
REFLECTED BY SILLIMANITE

The sillimanite distribution pattern reflects sediment drift in compliance with measured hydrodynamic parameter and relict Pleistocene surfaces as follows:

(a) Sediment transport along the New Jersey coast and shelf area from at least 60 miles north of Cape May is in a southerly direction with some of the sand transported into the lower eastern and central portion of the bay and another component projected to the shoals off Cape May.

(b) Gravelly sands in some of the bathymetry locations off Cape May may reflect relic sediment from fluvial Pleistocene surfaces.

(c) Delaware Bay sediments appear to move onto the continental shelf along the western side of the bay via Delaware submarine channel, the site of ancestoral Delaware Bay.

(d) Littoral currents along the northern Delaware coast are moving sediment into the southwestern corner of Delaware Bay from eroding Delaware shoals and beaches.

(e) Sediment differences, including texture and heavy minerals, suggest that there is no direct mixing between the capes.

The net sediment drift from Delaware River to Delaware Bay is summarized in Figure 27 for evidence existing in heavy mineral assemblages and hydrodynamic factors. The strong fluvial Piedmont dominated source emanating from the river estuary gives way to the sillimanite-rich mixed Coastal Plain and fluvial Piedmont source sediment constituting the major portion of the bay bottom sediments. The bay sediment is projected seaward along Pleistocene carved surfaces to the Continental Shelf. Continental Shelf sand impoverished in sillimanite is projected into the lower eastern and lower central bay area by littoral currents from

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PIEDMONT

5x Heavy Mineral Concentration
"Full" Heavy Mineral Suite
Rich in Garnet and Hornblende
Rich in Sillimanite

COASTAL PLAIN

1x Heavy Mineral Concentration
Pre - Pleistocene Formations
"Stable" Heavy Mineral Suite
Rich in Zircon, Tourmaline and Rutile

Pleistocene Formations
"Full" Heavy Mineral Suite
Rich in Sillimanite

TRENTON

PHILADELPHIA

Fall Line

WILMINGTON

Delaware River

Mile 49

Null Pt.
(Approx.)

DELAWARE
BAY

Glacial Continental Shelf Source
Impoverished in Sillimanite

DELAWARE BAY ENTRANCE

HEAVY MINERAL PROVINCES

Fluvial Piedmont Source

Mixed Fluvial Piedmont and
Coastal Plain Source

Mixed "Delaware Bay" and Glacial
Derived-Continental Shelf Source

Glacial Derived - Continental Shelf
Source

LEGEND

Sediment Drift

60' Depth Contour

Scale in Miles
0   5   10

FIGURE 27. Sediment source and dispersal direction of sand size sediment of Delaware River estuary and bay - based on heavy-mineral assemblages.

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the New Jersey coast. Cape Henlopen on the northern Delaware coast is being projected into the bay by sediment drift in a northerly direction along the Delaware coast from a sillimanite-rich heavy mineral source.

FELDSPAR AS CORROBORATIVE EVIDENCE OF SEDIMENT DRIFT

Milliman et al (1972) shows tongues of arkosic sediment stretching across the continental shelf area from eastern Long Island, the Bight of New York, Delaware Bay, and Chesapeake Bay (see Figure 22); these are thought to be from rivers draining glacier-covered terrain during the last glaciation. The feldspar is expressed as a ratio of feldspar to feldspar plus quartz for sediment in the 125 to 250 micron size. The examination of the feldspar fraction of Delaware Bay and coastal sediments in vicinity of the capes for the 125 to 177 micron size shows comparable highs and lows (see Figure 16). As shown in Figure 16, the feldspar from the eastern side of Delaware Bay ranges from 4 to 10 percent (this would be slightly higher using the ratio method expressed by Milliman et al, 1972) and 8 to 28 percent for

the western side of Delaware Bay. The coastal sands near the Delaware coast reflect the higher ratios up to 33 percent and the coastal sands toward the New Jersey coast the lower values, thus presenting corroborative evidence that the feldspar is from Pleistocene terrain. Feldspar values of contemporary fluvial Piedmont source sand-size sediment of the river estuary range between 2 and 19 percent with a general average of 6 percent (see Table 2 of Annex A). Similar low values exist in tributary streams draining areas virtually free of Pleistocene deposits. Jordan (1964) reports a range of 4 to 37 percent feldspar and 18.4 percent average in 75 samples of Pleistocene sands of Delaware; this value would also be somewhat higher if expressed in similar size fractions as Milliman et al (1972). Thus, within the Delaware Bay area, the higher feldspar content on the west side of the bay correlates with the Delaware Bay heavy mineral province while the eastern portion of the bay reflects (a) older Coastal Plain source formation impoverished in feldspar and (b) influence of sediment transported around Cape May from the New Jersey coastal sands generally low in feldspar.

TOXIC AND POLLUTION MATERIALS IN BOTTOM SEDIMENTS

INTRODUCTION

Maintenance dredging of shoaling materials in estuaries has been recognized in recent years as an environmental problem since estuaries are known traps for toxic heavy metals and other polluted materials. Windom (1972) and other investigators have shown that wherever industrial wastes such as heavy metals or toxic pollutants are discharged into an estuary, their concentration in sediment is several times higher

than that found seaward. While the mechanism of concentration of heavy metals and other toxic materials is as yet poorly known, it is certain that when these materials are released as industrial effluents, they are deposited within a few miles of their input. The precipitation of iron from industrial effluents has been previously cited in this investigation and many of the heavy metals follow similar lines. Arsenic and phosphorus appear in part related to sewage discharge and to industrial waste distributions as well as

watershed runoff while DDT is mainly related to insecticide use in the watershed. The following sections will deal with the concentration of the toxic and pollution materials that exist in the bottom sediments while later sections will treat the mechanism of concentration from the water medium.

HEAVY METAL DISTRIBUTION

Heavy metals, including mercury, lead, zinc, copper, nickel, and cadmium from bottom sediments of more than 80 locations in the river estuary, tributary streams, and bay are reported for individual locations in Table 8 and depicted graphically in Figures 28 through 30. Heavy metals in suspended samples will be treated later in trace evaluations; however, it is significant to know that heavy metals in the bottom sediment represent an increase by a factor of 10^3 to 10^6 over those in the water column. A general comparison of the suspended heavy metals (EPA Storet information 1972) and bottom locations of this investigation are summarized below.

Water Medium mg/1 (suspended & dissolved)	Bottom Sediment mg/1000 grams of dry solids
Cu^{++} 0.003 – 0.10	1.9 – 411
Zn^{++} 0.005 – 2.7	1.0 – 2500
Ni^{++} 0.001 – 0.01	0.3 – 110
Hg^{++} 0.005 – 0.0001	0.5 – 5.3
Pb^{++} –	0.5 – 360
Cd^{++} –	0.1 – 10
Mn^{++} 0.001 – 0.017	27.5 – 670

Inspection of Figure 28 reveals a maximum of mercury (5.3 ppm) in Delaware River about 11 miles south of Wilmington and general highs between 2 and 4 ppm in the Marcus Hook shoal and Fort Mifflin areas. Between 1 and 2 ppm mercury is apparent in the Schuylkill and Christina Rivers and in the Delaware River near their discharges. Most other locations contain less than 1 ppm mercury (see Table 8). Mercury concentrations in dredge spoil areas which contain sediment dredged between 1911 and 1966 (see Table 3) range from 0.6 to 1.7 ppm which is on the average less than contemporary samples. According to Windom (1972), mercury from dredge spoil areas could in time be subjected to processes which lead to release of mercury from the sediments due to volatization by bacteria, uptake by plants or other phenomena; the data from this investigation supports this view.

Highest lead concentrations in the sediments occur in Schuylkill River (381 ppm) and values in excess of 100 ppm occur between mile 60 and mile 92 (see Figure 28). Lead in old dredge spoil samples from Schuylkill River and Chester Range (between 1955 and 1966) also show higher values, (240-330 ppm) when compared to old dredge spoil from Marcus Hook and Wilmington Harbor which ranges between 80 and 260 ppm (see Table 3). Lead in the bay area and north of Philadelphia does not generally exceed 50 ppm.

Zinc has the highest concentration in the Christina and Schuylkill Rivers where values range between 400 and 1000 ppm (see Figure 29). Dredge spoil in the Pigeon Point Disposal Area dredged from Wilmington Harbor between 1958 and 1966 shows a maximum value of 2500 ppm. Other areas in the estuary
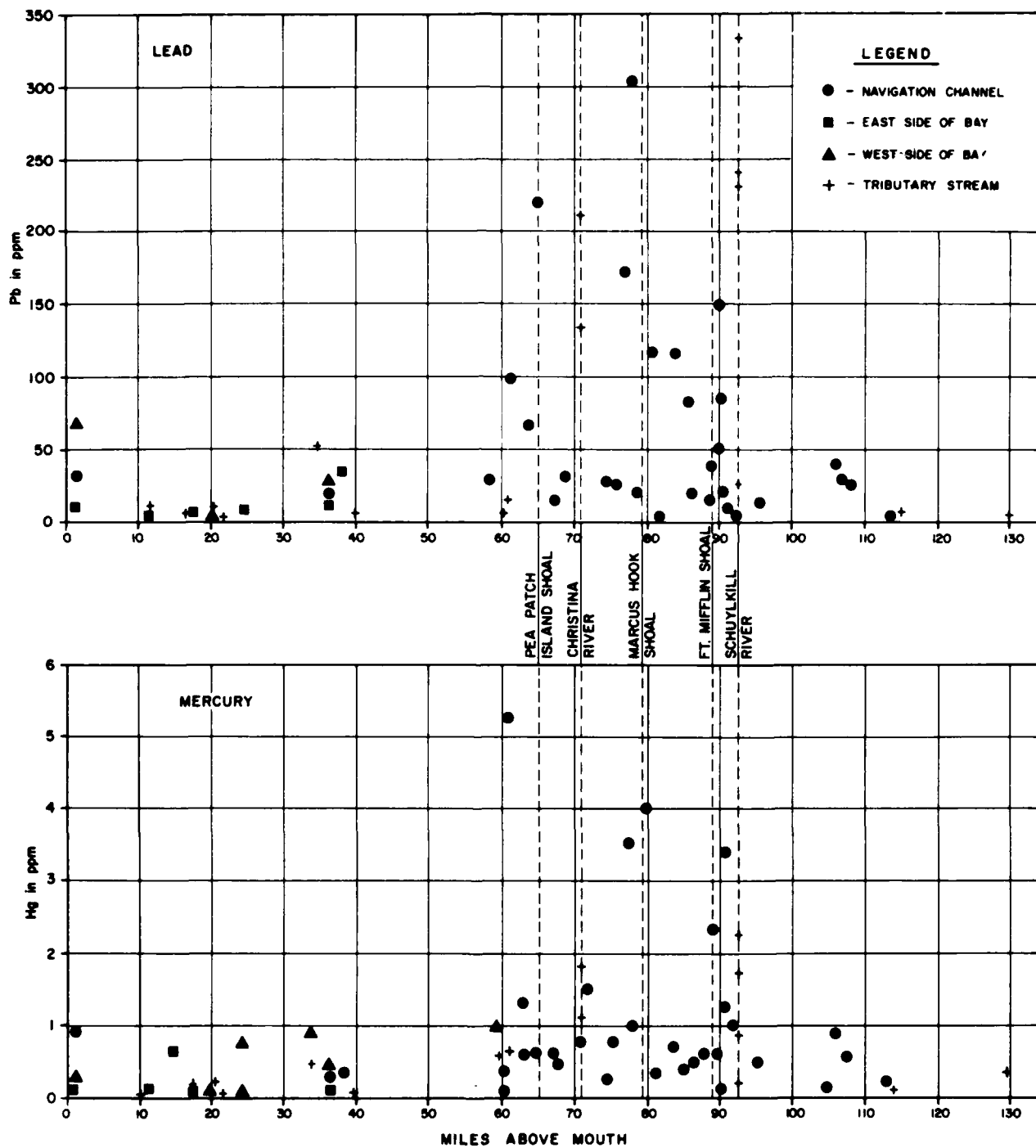
FIGURE 28. Concentration of mercury and lead in mg/1000 grams of dry bottom sediment, (ppm), from Delaware estuary.
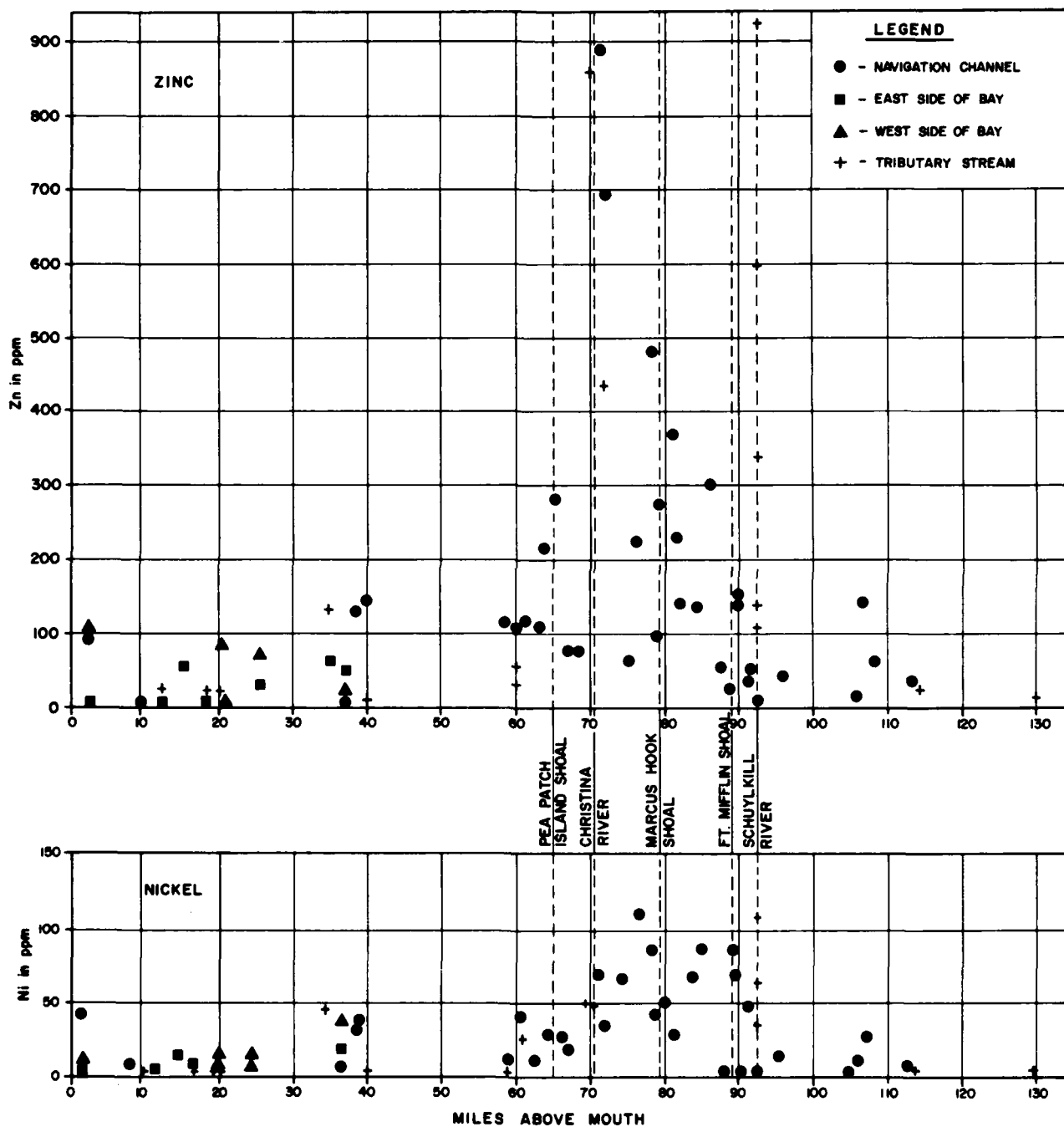
FIGURE 29. Concentration of zinc and nickel in mg/1000 grams of dry bottom sediment, (ppm), from Delaware estuary.
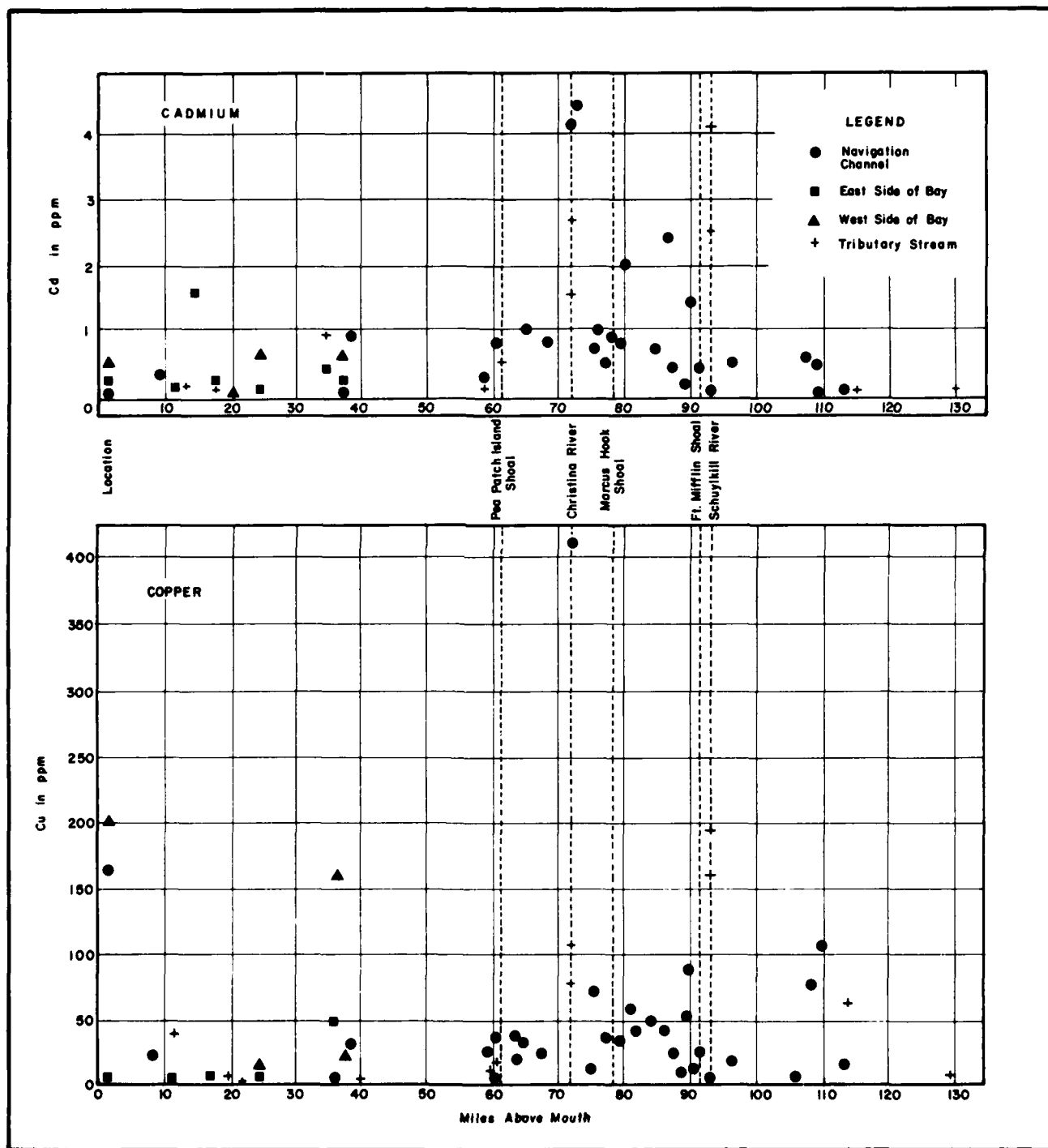
FIGURE 30. Concentration of copper and cadmium in mg/1000 grams of dry bottom sediment, (ppm), from Delaware estuary.

TABLE 8
HEAVY METALS AND IRON CONCENTRATIONS IN BOTTOM SEDIMENTS
OF DELAWARE ESTUARY AND VICINITY EXPRESSED AS MILLIGRAMS PER
1000 GRAMS OF DRY SOLIDS

Sample Control Number	Sample No.	Ferric Oxide (Dithonite Method)	Mercury (Hg)	Lead (Pb)	Nickel (Ni)	Copper (Cu)	Zinc (Zn)	Cadmium (Cd)
		Milligrams/1000 grams of dry solids						
BB36	B-1	100	0.12	11.0	0.7	4.4	6.4	0.2
BB37	B-2	700	0.15	1.4	0.7	2.3	4.9	0.1
BB38	B-3	400	0.04	7.1	8.9	9.0	7.5	0.2
BB39	B-4	300	0.04	7.3	18.8	13.1	30.4	0.1
BB40	B-5	400	0.06	11.6	29.0	53.8	49.9	0.2
BB41	B-6	2300	0.51	23.0	44.0	161.3	17.2	0.6
BB42	B-7	100	0.01	1.4	0.9	1.1	6.1	0.0
BB44	B-9	2800	0.28	72.4	18.0	218.5	110.0	0.5
BB45	B-10	200	0.23	7.8	76.0	93.4	48.4	0.1
BB46	B-11	300	0.05	5.2	73.0	68.0	40.0	0.2
BB47	B-12	100	0.15	11.1	44.3	72.0	42.5	0.0
BB48	B-13	100	0.96	33.5	46.0	165.4	94.6	0.0
BB52	B-17	900	0.13	13.5	6.0	4.9	46.8	0.0
BB53	B-18	2100	0.35	37.0	34.0	30.0	131.1	0.9
RB75	R-1	700	1.05	7.8	2.8	4.8	12.9	0.1
RB88	R-14	3600	1.35	12.6	50.0	8.6	42.0	0.5
RB89	R-15	2700	3.40	23.5	6.0	22.4	49.3	0.5
RB96	R-22	1300	0.09	89.1	5.0	10.1	42.2	0.4
RB109	R-35	5700	2.37	50.7	71.0	52.0	141.1	1.4
RB110	R-36	11500	0.68	161.1	89.0	91.1	142.8	2.7
RB122	R-48	600	0.61	17.1	2.9	8.9	26.3	0.2
RB126	R-52	2300	0.59	22.2	18.0	23.5	49.6	0.4
RB139	R-65	12100	0.43	79.7	89.0	39.8	312.0	2.4
RB154	R-80	7100	0.74	120.9	70.0	48.4	137.6	0.7
RB198	R-124	8700	1.00	24.1	89.0	37.4	99.6	0.8
RB306	R-139	14900	0.83	184.6	110.0	36.4	227.8	0.5
RB227	R-153	6000	0.28	30.2	60.9	13.3	63.7	0.7
RB241	R-167	9700	0.81	200.0	72.0	95.6	900.7	4.2
RB255	R-181	6900	0.54	30.7	29.4	21.6	77.0	0.8
RB304	R-188	14400	0.69	224.0	39.0	42.1	294.0	1.0
RB268	R-200	13200	0.67	71.1	12.9	17.9	106.4	0.6
RB294	R-222	6200	0.46	100.0	42.0	43.1	146.3	0.8
RB299	R-231	9000	0.23	27.8	16.0	16.0	49.5	0.8
RB306	R-232	6300	0.57	30.2	30.0	75.0	61.7	0.6
RB307	R-233	300	0.14	4.5	1.5	4.0	12.8	0.0

TABLE 8 (Continued)
HEAVY METALS AND IRON CONCENTRATIONS IN BOTTOM SEDIMENTS
OF DELAWARE ESTUARY AND VICINITY EXPRESSED AS MILLIGRAMS PER
1000 GRAMS OF DRY SOLIDS

Sample Control Number	Sample No.	Ferric Oxide (Dithonite Method)	Mercury (Hg)	Lead (Pb)	Nickel (Ni)	Copper (Cu)	Zinc (Zn)	Cadmium (Cd)
TB5	S-5	800	0.11	30.4	3.7	11.9	134.4	0.0
TB6	S-6	23000	1.76	381.0	98.4	352.0	1687.0	7.9
TB8	S-8	1100	0.04	5.6	1.5	60.6	23.0	0.0
TB9	S-9	2000	0.34	1.6	1.3	3.0	9.4	0.0
TB11	S-11	11400	1.97	136.4	51.0	107.5	869.4	2.7
TB12	S-12	23000	0.98	214.5	50.0	87.8	444.0	1.5
RB14	S-14	400	0.02	0.1	0.7	0.1	0.3	0.0
RB15	S-15	2300	0.17	10.7	3.7	6.2	24.3	0.1
RB16	S-16	2100	5.31	15.3	12.0	18.2	79.8	0.0
TB17	S-17	12000	0.06	1.5	3.3	10.2	31.5	0.1
TB18	S-18	800	0.16	6.0	2.2	6.8	14.7	0.1
TB19	S-19	500	0.05	1.3	0.9	3.6	5.7	0.1
TB20	S-20	8800	0.53	53.2	45.2	193.6	139.0	0.9
TB21	S-21	1300	0.12	8.2	4.2	36.6	25.9	0.1
RB22	S-22	13000	7.84	30.1	38.1	71.5	135.8	1.0
RB23	S-23	11400	1.62	213.8	41.2	411.8	792.0	4.4
RB24	S-24	900	0.67	16.8	28.3	23.5	79.2	0.5
RB25	S-25	13200	1.35	180.0	33.0	45.0	219.7	0.8
RB26	S-26	3000	1.00	30.5	30.5	21.3	108.9	0.3
TB27	S-27	10000	0.65	22.4	28.3	11.5	57.2	0.5
TB28	S-28	1400	0.11	5.0	2.8	3.1	18.5	0.1
TB29	S-29	300	0.02	1.0	0.5	1.2	5.0	0.0
RB30	S-30	12600	0.36	39.0	33.2	40.5	141.0	0.8
RB32	S-32	500	0.05	4.5	8.0	11.7	23.0	0.1
RB33	S-33	27000	0.50	11.9	16.9	29.0	41.5	0.4
RB34	S-34	7200	1.10	32.6	18.1	109.5	146.9	0.6
RB35	S-35	1200	0.20	3.9	5.0	13.4	34.2	0.1
—	P-5	—	1.82	26.0	8.3	11.4	72.8	0.5
—	P-8	—	0.84	29.3	9.2	21.4	78.1	0.6
—	W-5	—	0.80	48.0	29.6	27.2	128.0	0.8
—	T-5	—	0.77	20.1	15.5	17.4	53.8	1.6
—	BW-4	—	0.25	38.8	15.2	14.0	93.9	0.3
—	SB-8	—	0.96	21.6	11.2	15.2	67.2	0.4
—	SR3-2	12500	2.38	246.4	109.2	196.0	108.5	4.2
—	SR6-6	10800	0.96	185.4	66.5	161.7	610.0	2.4
—	MH6-1	—	4.05	294.4	47.1	44.2	495.0	0.9

TABLE 8 (Concluded)
HEAVY METALS AND IRON CONCENTRATIONS IN BOTTOM SEDIMENTS
OF DELAWARE ESTUARY AND VICINITY EXPRESSED AS MILLIGRAMS PER
1000 GRAMS OF DRY SOLIDS

Sample Control Number	Sample No.	Ferric Oxide (Dithonite Method)	Mercury (Hg)	Lead (Pb)	Nickel (Ni)	Copper (Cu)	Zinc (Zn)	Cadmium (Cd)
—	MH11-1	—	3.52	122.5	51.9	56.8	380.2	2.0
—	MH72	6100	0.4	174.0	42.0	81.0	501.0	3.0
—	M72	2800	0.2	76.0	43.0	68.0	353.0	2.0
—	NC72	3600	0.3	80.0	43.0	44.0	266.0	1.0
—	C-93	—	0.10	5.4	5.4	21.0	16.3	0.2
—	C-100	—	0.06	5.1	5.1	12.4	9.4	0.1
—	C-173	—	0.02	0.6	0.6	1.0	0.2	0.1
—	C-182	—	0.11	2.0	2.0	38.7	12.1	0.0
—	C-183	—	0.12	0.3	0.3	1.4	2.4	0.0

NOTE: 1: Sample locations are shown in Figure 3; sample control numbers TB = tributary stream, RB = Delaware River, B = bay area and those without sample control numbers are profile bay samples (P, W, T, and BW), major composite shoal samples (MH, M, and NC) and shelf sample received from CERC (C numbers).

and bay seldom exceed 250 ppm. Suspended samples also contain highest concentration of zinc from the Christina River area and dispersal patterns will be shown in a later section to point out the general point of origin of the effluent.

Nickel concentrations appear highest in the Marcus Hook shoal with highs of 90-120 ppm extending from Schuylkill River to Marcus Hook (see Figure 29). Maximum nickel in old dredge spoil was found in Darby Creek spoil for material dredged between 1955 and 1959 from Chester range and Schuylkill River; the 85 ppm maximum dredge spoil correlates well with contemporary samples (see Table 3). Most bay and estuary locations, other than the region cited, seldom exceed 50 ppm of nickel.

Copper concentration has an anomalous high of 411 ppm in the Delaware in vicinity of the confluence of the Delaware and Christina River (see Figure 30). Both the Schuylkill River and Christina River sediments contain between 100 and 200 ppm of copper and dredge spoil samples contain similar concentrations at Darby Creek disposal area (90-140 ppm) and Edgemoor Disposal Area (60-110 ppm). Local bay areas near the capes and on the west side of the bay appear to contain anomalies in concentrations between 100-200 ppm (see Figure 30). Copper in most locations does not exceed 50 ppm in the bottom sediment.

Cadmium compounds are very toxic and this metal is now receiving proper attention. This heavy metal has general highs in the Christina River and Schuylkill River with maximum (4.5 ppm) in the Delaware River where the copper maximum occurs (see Figure 30). Cadmium occurrence in old dredge spoil samples corresponds

to contemporary samples with maximum occur-
rences of 6-10 ppm from Darby Creek spoil area
(see Table 3). Cadmium in most other locations
seldom exceeds 1 ppm.

In general, the heavy metals of contempo-
rary and old dredge spoil areas are in good
agreement except that mercury values are
generally less since this metal apparently has
avenues of return to the environment by organic
processes after deposition in disposal areas.

ARSENIC DISTRIBUTION

Arsenic concentrations in the Delaware
River appear to parallel the organic matter as
depicted in Figure 31; arsenic highs of between
10 and 40 ppm occur between Pea Patch Island
and Schuylkill River. Ruch, et al (1970), in a
study of the distribution of arsenic in unconsoli-
dated sediments from southern Lake Michigan
concluded that arsenic observed in the upper-
most portions of bottom sediments generally
varies directly with the organic carbon content
and is probably a result of man's activities.
Arsenic in old dredge spoil samples (see Table 3)
ranges between 20 and 29 ppm which is
generally similar to that of contemporary bottom
sediment sam

DDT DISTRIBUTION

Analysis of DDT in several bottom sam-
ples by the State of Delaware Water and Air
Resources Commission (Oral Communication,
1972) reveals a range between 0.02-0.11 ppm
in the river estuary but generally less than 0.02
ppm (dry weight basis) in the bay sediments

PHOSPHATE DISTRIBUTION

Phosphate is an index to the amount of
pollution in sediment and has a source mainly

associated with municipal wastes and to a lesser
degree from fertilizers and vegetation in the
watershed. Phosphate in bottom sediment of the
estaury has a maximum of 0.89 percent in
Marcus Hook shoal and ranges between 0.25
and 0.60 percent from Pea Patch Island shoal to
vicinity of Schuylkill River. As shown in Figure
14, the diatom concentration tend to parallel the
phosphate distribution. Phosphate in historic
dredge spoil areas contain up to 0.7 percent
phosphate from Marcus Hook and Chester
Range, (see Table 3) while other locations range
up to 0.5 percent phosphate. Because of the
parallel of siliceous diatom frusticules and high
phosphate in sediments, it is possible that phos-
phate may be concentrated after decay of the or-
ganic matter in the large diatom accumulations.
That phosphate is trapped in the sediment or
again made available as a nutrient for phytop-
lankton growth is poorly known. Analysis of sus-
pended sediment nutrients will be considered in
a later section as regards this limiting element in
eutrophication of the estuary waters.

SEWAGE INDICATION IN
BOTTOM SEDIMENT

The solvent extractable organic matter in
19 bottom sediment samples between the
Schuylkill River and Pea Patch Island analyzed
by Reuter (1970) contained 90 percent
proteinaceous matter; remaining organic matter
consisted of "fatty acids" and hydrocarbons.
Analysis of the amino acids in the proteinaceous
matter reveals that both the ratio of acidic amino
acids (aspartic to glutamic acid) and the sum of
the basic amino acids (lysine + histidine +
arginine) compare well with each other. Reuter
attributes the origin of such an amino acid pat-
tern to a great mass of dead organic matter
which can not be converted into plant and
animal food as rapidly as it accumulates. Or-
ganic matter thus accumulates in abnormal
amounts and probably reflects eutrophication
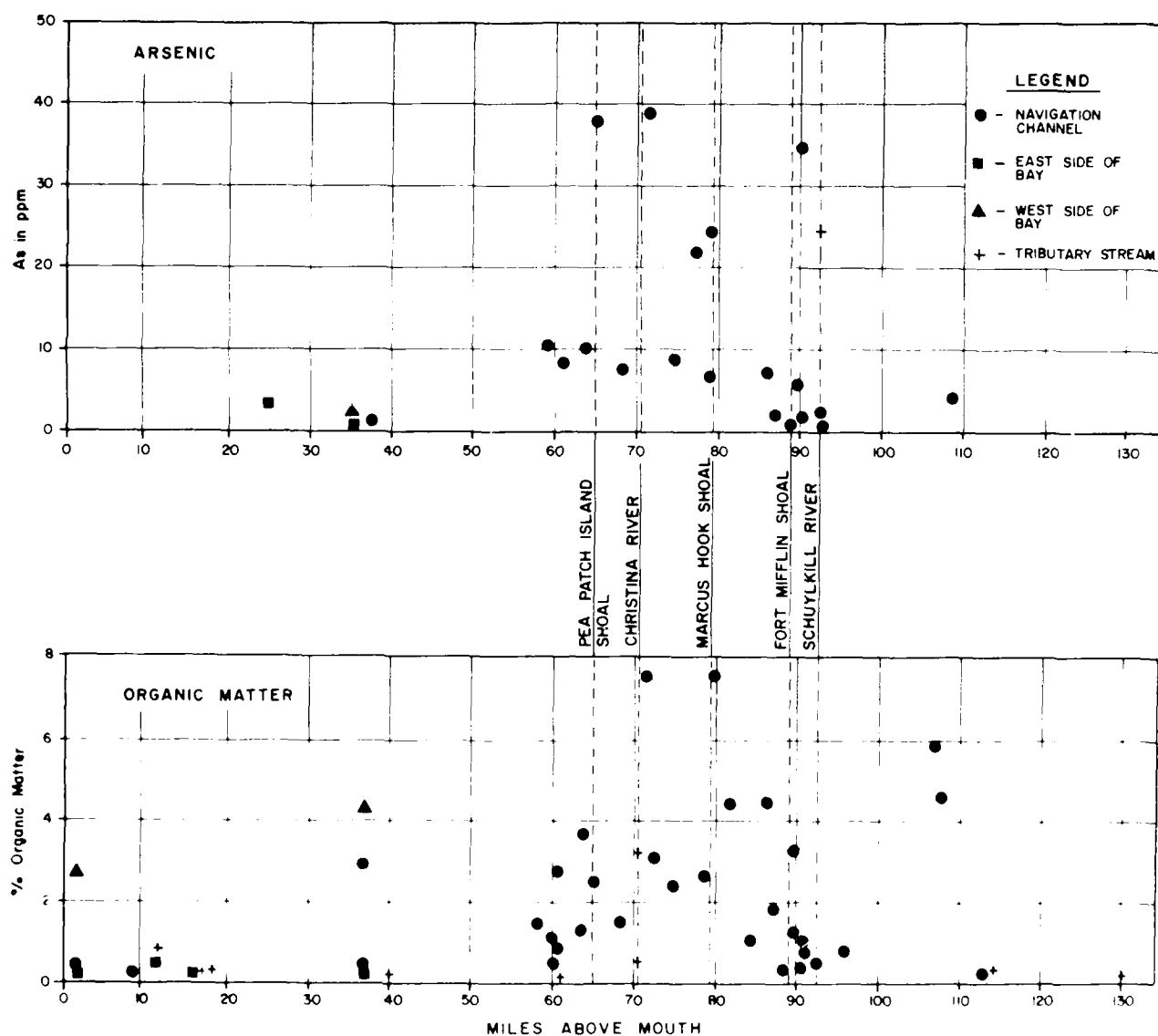
FIGURE 31. Concentration of arsenic and organic matter in bottom sediment of Delaware estuary
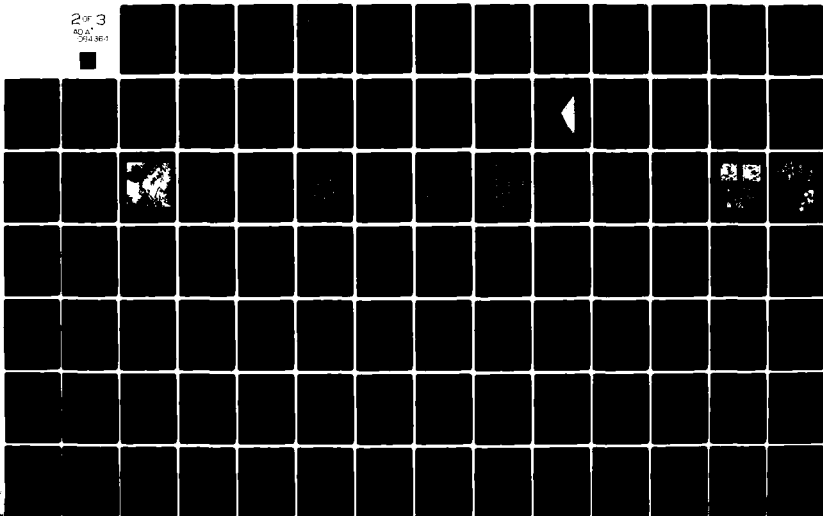
conditions in the estuary. The origin of this accumulating proteinaceous matter is believed to be the municipal sewage wastes which occur in the estaury. The "fatty acid" content is most abundant nearest sewage outfalls and this material has a most offensive odor; the occurrence of this material could possibly serve as an index to sewage waste in future studies. Less fatty acid and proteinaceous materials occur south of Marcus Hook shoal which will be shown to correlate with decrease in pollution of the surface waters of the estuary.

The organic carbon to organic nitrogen ratios of the bottom sediment is useful in drawing some general conclusions about the organic fraction of the sediment. The C:N ratios of vegetable matter and fresh domestic wastewater has a C:N ratio between 6-12 while plants have higher values generally averaging 15. Limited

studies by the City of Philadelphia on samples collected in 1972 for several bottom locations in Delaware River reveals a C:N ratio ranging between 2 and 7. Thus sewage appears evident in some of the bottom sediment locations.

The pH and Eh (redox potential) of sediments have been used by many investigators to describe changes in chemical reactivity of materials, diagenetic changes, biological change, and other variations in recent sediments. Measurements of pH and Eh were made on the 3 shoal samples on 2 March 1972 by means of a shipboard portable meter within minutes after retrieval of the harpoon sample. Temperatures of the bottom mud during the operation ranged from 10 to 14 degrees centigrade. Field samples were frozen in dry ice and composite shoal samples measured in the laboratory for pH and Eh. The results are summarized below:

	Fort Mifflin Shoal	Marcus Hook Shoal	Pea Patch Island Shoal
	Field Measurements — Surface		
pH	6.43 - 6.55	6.60 - 6.62	—
Eh	(+)55 - (+)75	(+)25 - (+)50	—
	Field Measurements — 3 ft. depth		
pH	6.35 - 6.50	6.55 - 6.60	—
Eh	(+)55 - (+)80	(+)15 - (+)25	—
	Laboratory Measurement (Composite Sample)		
pH	6.60	6.75	7.00
Eh	(+)71	(+)74	(+)107

The pH of the surface sediments ranges from 6.35 to 7.00 with lowest value at Marcus Hook and increasing alkalinity in the most seaward location at Pea Patch Island shoal. The pH reflects similarities that will be shown to exist in surface waters in a later section; the distinctly acid condition of Marcus Hook is strongly influenced by sewage discharge from

Philadelphia while Pea Patch Island reflects the salinity intrusion from seaward.

The oxidation-reduction potentials in the surface sediments to 3 foot depth are positive. Values range from +25 to +107 millivolts and fall within the range of Eh values typical of surface sediments in estuaries as reported by Biggs

(1967) and others. The Eh tends to decrease below the surface to lowest values (+15 millivolts) as a result of bacterial decay of organic matter and depletion of oxygen. The fact that negative values were not reached at 3 foot depth is attributed in part to the relatively rapid deposition in these shoaling areas.

ANALYSIS OF SUSPENDED SEDIMENTS IN DELAWARE ESTUARY

INTRODUCTION

The composition of the shoal sediments in the Delaware River are largely organic clayey silts derived from suspended sediment transported from the watershed and from organic processes and chemically precipitated materials from industrial and municipal effluents along the estuary. Analysis of the composition and quantity of the suspended sediment can be useful in evaluating the source of the suspended sediments which are eventually trapped in the shoaling areas of the river estuary. In this investigation, the composition of suspended sediment from tributary streams is analyzed from samples collected during greater than average discharge from the watershed and also at 9 points in the river estuary in the region of major shoaling for a complete tidal cycle. The station locations for the samples collected during the complete tidal cycle of 23 July 1969 is shown in Figure 32. Analysis of individual samples is contained in the tables of Annex C.

CLAY MINERALOGY OF GEOLOGIC FORMATIONS

Detailed knowledge of the mineralogy of the sediment from the source areas is limited to the investigation of Owens and Sohl (1969), Groot and Glass (1960) and others. Since the suspended load is comprised largely of silt and clay, the search for diagnostic minerals is more limited than would be available in sand-size sediment containing heavy minerals. Perhaps the most diagnostic materials in the suspended sediment is the clay-mineral suite. The clay-mineral suite from limited investigation of several geologic formations in the Delaware watershed is listed below:

FORMATIONS	% CLAY MINERALS			
Cretaceous Formations	Illite	Chlorite	Kaolinite	Montmorillonite
Raritan, Patapco, and Patuxent	15	—	85	Tr
Magothy	39	—	61	—
Merchantville	21	—	55	24
Woodbury	29	—	41	30
Englishtown	38	—	35	27
Marshalltown	28	42	12	18
Wenonah	40	—	28	32

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FORMATIONS	% CLAY MINERALS			
Cretaceous Formations	Illite	Chlorite	Kaolinite	Montmorillonite
Mount Laurel	23	27	28	22
Navesink	23	38	16	23
Red Bank	39	9	37	15
Tertiary Formations				
Hornerstown	1	98	–	1
Vincentown	–	70	15	15
Manasquan	5	45	15	35
Kirkwood	26	–	68	6
Cohansey	40	–	60	–

Extensive examination of shoal sediments previously reported revealed illite, kaolinite, chlorite and minor montmorillonite in the clay-mineral suite. Hathaway (1972), and Oostdam (1971), indicate that chlorite exceeds kaolinite in the bay area and correlates with samples reported for the bay in this investigation. The wide variation in the Cretaceous and Tertiary Coastal Plain Formations are listed above, however, suggest the strong influence of Pleistocene "blanket" deposits. However, since detailed knowledge of clay minerals is poorly known, suspended samples from tributary streams draining source areas to the estuary were examined for evaluation purposes.

SUSPENDED SEDIMENTS OF TRIBUTARY STREAMS

Tributary streams of the Delaware estuary were sampled during the spring and summer of 1969 during greater than average runoff conditions in the respective watersheds in order to get as representative a sample as possible for analysis. Samples at the river station location were taken at 20 minute intervals for 1 hour from 1 foot above bottom and 0.2 and 0.8 ft. depth of the water column. The samples were analyzed for sediment load, organic matter and mineral composition and the results are listed in Table 1 of Annex C for individual stations and a summary is presented in Table 9.

Sediment from Piedmont streams contained between 17-209 ppm sediment load averaging 7 percent organics, 41-71 percent silt and 26-46 percent clay as compared to 13-149 ppm sediment load, 10 percent organics, 31-75 percent silt and 19-46 percent clays in Coastal Plain streams (see Table 9). Clay minerals from both source areas contain illite as the most abundant species and both areas contain appreciable kaolinite and chlorite, however, kaolinite is far more abundant in Piedmont source sediments than the chlorite-rich Coastal Plain streams. Silt consists in the main of quartz and feldspar with the former more abundant in all samples. Feldspar content, in streams tributary to the river estuary, seldom exceeds 20 percent while feldspar in Delaware Coastal Plain streams sometimes exceeds 40 percent of the silt fraction (see Table 1 of Annex C).

This increase in feldspar in the lower Coastal Plain streams of Delaware is attributed to Pleistocene "blanket" deposits which are increasingly abundant in this area.

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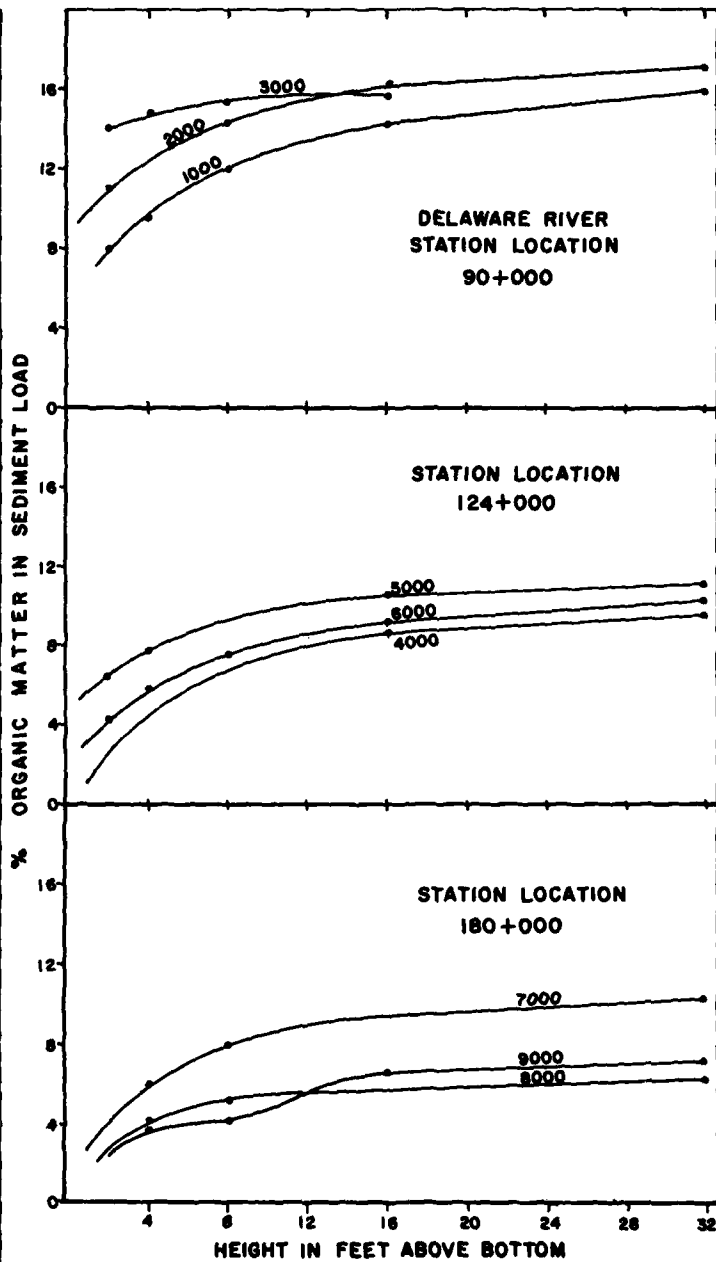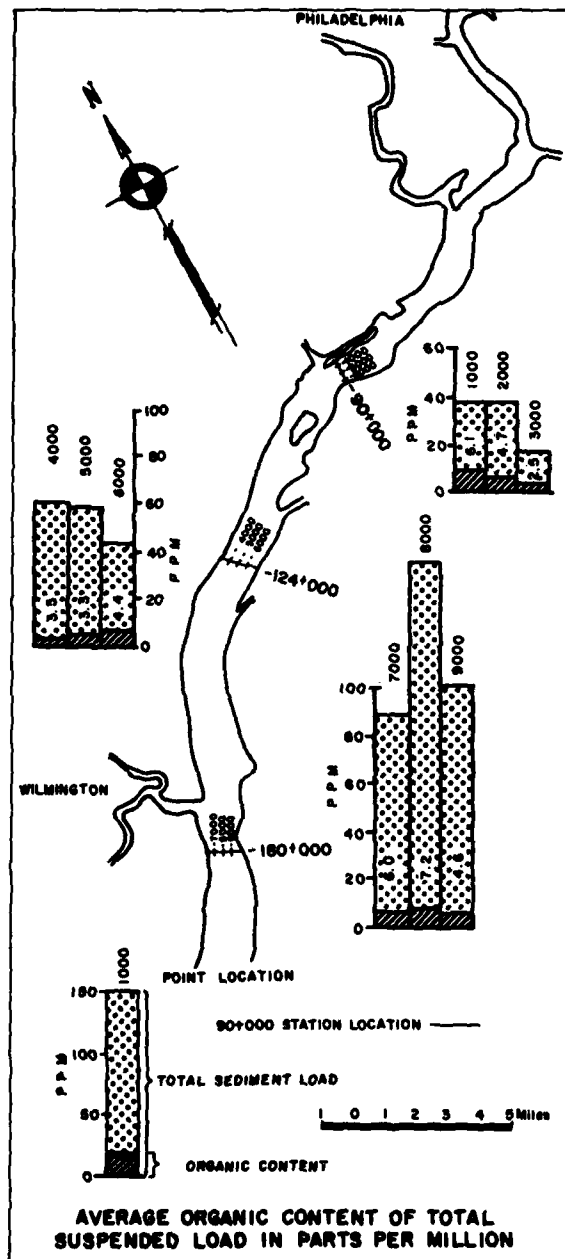
FIGURE 32. Organic matter in total sediment load and as per cent of sediment load from suspended sample locations in Delaware River on 23 July 1969.

TABLE 9
SUMMARY OF SUSPENDED LOAD AND COMPOSITION OF TRIBUTARY STREAMS TO DELAWARE ESTUARY

	SUSPENDED LOAD NON FILTRABLE SOLIDS (PPM)		ORGANIC MATTER	SILT FRACTION	CLAY FRACTION	% CLAY MINERAL FRACTION			
	Range	Average	Average Percent	Average Percent	Average Percent	Illite	Kaolinite	Chlorite	Montmorillonite
Delaware R. (N. of Trenton)	62-67	64.7	12	60	28	50	19	26	5
Piedmont Streams									
Neshaminy Creek	14-34	25.7	5	65	30	48	29	17	6
Pennypack Creek	18-33	20.9	3	71	26	62	19	15	4
Schuylkill River	8-27	17.0	13	41	46	55	20	20	5
Chester Creek	60-88	71.8	11	47	42	30	35	25	10
Brandywine Creek	10-79	49.2	5	62	33	45	33	17	5
New Jersey Coastal Plain Streams									
Crosswick Creek	63-73	67.5	12	55	33	51	19	24	6
Rancocas Creek	31-59	44.7	6	74	20	66	12	18	4
Big Timber Creek	22-31	27.3	9	69	22	48	15	29	8
Woodbury Creek	16-40	32.0	9	60	31	72	10	14	4
Mantua Creek	22-44	35.0	10	53	37	60	10	22	8
Cooper River	26-47	19.0	10	53	37	74	9	11	5
Raccoon Creek	66-74	69.9	8	72	20	43	22	28	7
Oldmans Creek	40-66	54.8	13	58	29	45	18	27	10
Salem River	85-98	81.4	10	58	32	44	25	24	7
Alloway Creek	88-145	104.8	6	72	22	70	13	15	3
Cohansey River	54	54.0	–	68	32	43	21	28	8
Maurice River	63-79	70.9	10	57	33	63	8	24	5
Delaware Coastal Plain Streams									
Christina River	33-47	42.2	16	54	30	45	17	27	11
Appoquinimink River	19-29	24.0	6	70	24	74	10	12	3
Smyrna River	25.8	25.8	6	75	19	48	21	21	10
Leipsic River	97-170	148.9	–	71	29	59	13	21	7
St. Jones River	33-48	36.6	5	62	33	48	22	24	6
Murderkill River	11-40	17.9	11	56	33	63	13	17	7
Mispillion River	33-41	35.1	8	57	35	39	24	28	9
Broadkill River	10-15	13.0	23	31	46	57	15	21	7

NOTES: 1. Suspended samples were obtained from 1 foot above bottom and 0.2 and 0.8 feet depth at 20 minute intervals for a period of 1 hour at peak discharge of the stream after greater than average runoff from the watershed during 1969.

2. Organic matter includes fiberous plant material, colloidal size organics, and fine grained coal.

3. Silt fraction consists of quartz, feldspar, mica, and minor detrital heavy minerals.

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Organic matter averages from tributary streams ranges from 3 to 23 percent of the sediment with highest percentages common to Coastal Plain streams. Microscopic examination of organic matter from suspended samples of the Smyrna and Cohansey Rivers draining the Coastal Plain sediments reveals predominantly plant and vegetable matter of relatively large size in contrast to the inorganic sediment. Organic matter due to sewage stands in sharp contrast in being predominantly of colloidal size as previously shown by differential thermal analysis of shoal sediment in earlier phases of this investigation.

SUSPENDED SEDIMENTS OF DELAWARE RIVER

General

The suspended load for the estuary between Trenton and Reedy Island (mile 55), expressed as total non-filtrable solids and volatile non-filtrable solids is listed in Table 10 and depicted graphically in Figure 23 for monthly mean values between 1967-1973 and for months of higher variability in March and June 1969. From Figure 33, it is apparent that sediment load for both the non-filtrable and volatile non-filtrable suspended solids increases steadily from mile 128 to mile 55 in the seaward direction with a local anomaly at mile 107. The significance of this distribution for the entire estuary will be treated in a later section.

In order to evaluate the characteristics and behavior of suspended sediments in the major shoaling reaches of the river, sampling was effected simultaneously at different depths during a complete tidal cycle on 15 May 1969 and 23 July 1969 at 3 river cross sections containing 3 point locations in each of the sections. The cross-sections selected were at Chan-

nel Station 90 + 000 (mile 86), Channel Station 124 + 000 (mile 79), and Channel Station 180 + 000 (mile 68); the station locations are shown in Figure 32 and in Figure 1-C of Annex C. The rate of shoaling at Station 90 + 000 is relatively light, that at Station 124 + 000 extremely heavy, and that at Station 180 + 000 is zero. The samples taken during the tidal cycle were at distances of 1, 2, 4, 8, 16, and 32 feet above the bottom of the estuary and tested in the laboratory of the South Atlantic Division for salinity, total suspended solids, and mineral composition. Individual sample values are listed in Table 2 of Annex C for the 23 July 1969 sampling period.

Sediment Load

A summary of the sediment load during the tidal cycle for near bottom and near surface locations is presented in Table 11 for the 15 May 1969 and 23 July 1969 period. River discharge during 15 May 1969 at Station 180 + 000, 124 + 000 and 90 + 000 in Delaware River was respectively 12,850 cfs, 12,270 cfs and 12,050 cfs while discharge during 23 July 1969 was respectively 10,530 cfs, 9,780 cfs, and 9,610 cfs. In almost all cases, the suspended sediment load in the samples taken near the river bottom was more than double the sediment load of the near surface samples and the sediment load in the samples at Station 180 + 000 was considerably larger than that at the upstream stations (see Table 11). At Marcus Hook, the site of maximum shoaling, the 23 July 1969 surface sediment averages 30 ppm and near bottom sediment 93 ppm.

Sediment Composition

The composition of the suspended sediment varies considerably in relation to the dynamics of the water column at various stages of the reversing tidal cycle; over the distance of

TABLE 10

MEAN, SUSPENDED, NON-FILTRABLE SOLIDS FOR PERIOD OF RECORD (1967-1973) AND FOR MARCH AND JUNE 1969 AT STATION LOCATIONS IN DELAWARE RIVER

Station Location	Miles above Capes	RESIDUE (Non-Filtrable)		RESIDUE (Non-Filtrable)				RESIDUE			
		TOTAL(mg/1)	VOL(mg/1)	TOTAL (mg/1)		VOL (mg/1)		TOTAL (mg/1)		VOL (mg/1)	
		Period Jul 1967 to Jan 1973	Period Jul 1967 to Jan 1973	Mar 69	Jun 69	Mar 69	Jun 69	Mar 69	Jun 69	Mar 69	Jun 69
Reedy Is., Del.	54.9	51.31	20.71	21	83	19	32	7581	2102	1103	406
Pea Patch Is., Del.	60.6	52.47	20.39	21	102	19	26	5651	1355	942	286
New Castle, Del.	66.0	40.30	16.74	14	42	13	29	2540	565	487	150
Cherry Is., Del.	71.0	38.21	16.96	23	32	17	20	1577	360	274	101
Oldmans, N.J.	74.9	33.85	15.17	38	33	21	23	584	222	144	71
Marcus Hook, Pa.	78.1	26.71	14.48	47	30	24	12	351	207	91	66
Eddystone, Pa.	84.0	27.17	13.56	33	29	22	20	258	205	77	63
Paulsboro, N.J.	87.9	26.81	13.52	46	18	24	18	237	193	64	64
Navy Yard, Phil.	93.2	23.53	13.08	33	30	23	27	204	175	68	57
Wharton St. Br., Phil.	98.5	22.20	12.24	17	22	17	22	184	158	61	58
Ben Franklin Br., Phil.	100.2	26.35	12.69	46	29	28	19	153	139	58	14
N.E. Sewage Plant, Phil.	104.0	22.24	11.96	14	24	10	22	110	137	47	57
Palmyra, N.J.	107.1	26.83	14.46	33	86	26	66	161	149	58	50
Torresdale, Phil.	110.7	19.16	11.20	34	16	14	8	148	129	46	51
Burlington, Pa.	117.8	22.57	11.45	38	30	24	13	157	156	24	54
Florence, N.J.	122.5	21.36	11.74	31	28	11	12	151	157	52	55
Fieldsboro, N.J.	127.5	23.59	11.31	42	30	18	18	146	149	53	55

NOTE: Values from Storet Data of the Environmental Protection Agency.

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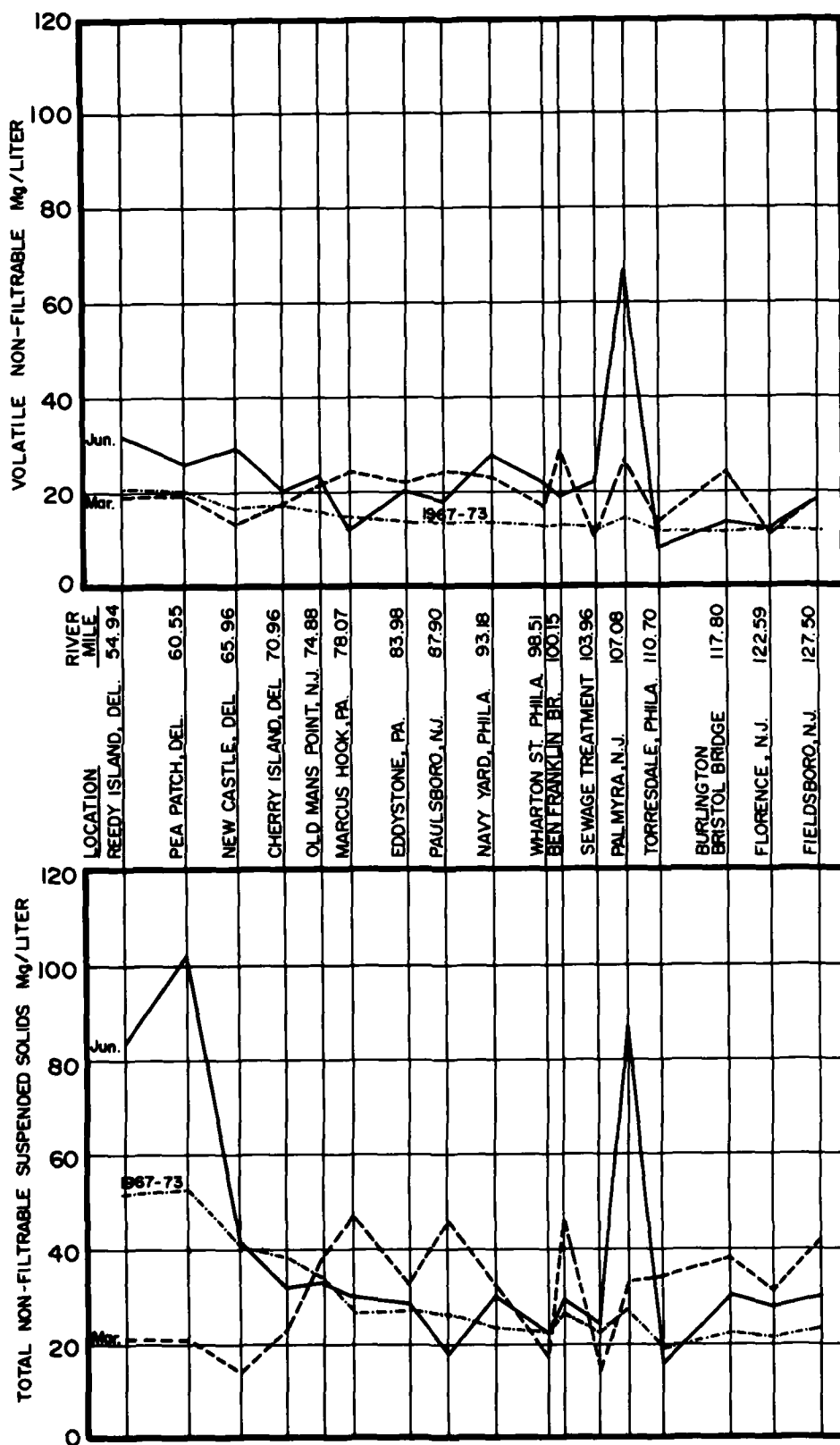
FIGURE 33. Total non-filtrable and volatile suspended sediment from Delaware Estuary during March and June 1969, and average value for period 1967-1973.

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TABLE 11

SUMMARY OF SUSPENDED LOAD (NON-FILTRABLE) IN SUSPENDED WATER SAMPLES FROM DELAWARE RIVER DURING TIDAL CYCLE OF 15 MAY 1969 AND 23 JULY 1969

Height of Sample Above River Bottom	Station 90 + 000						Station 124 + 000						Station 180 + 000					
	Point 1000		Point 2000		Point 3000		Point 4000		Point 5000		Point 6000		Point 7000		Point 8000		Point 9000	
	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
Total Suspended Load in p.p.m.																		
15 May 1969																		
Near Bottom																		
Range	30-150	31-75	45-161	45-104	22-75	30-44	36-377	42-255	41-574	30-668	35-294	25-572	71-471	89-443	64-752	72-1258	48-480	70-366
Average	65	60	76	69	42	32	145	90	285	305	63	130	265	215	325	405	240	145
Near Surface																		
Range	16-35	25-48	22-63	15-43	11-38	11-26	12-82	28-73	24-150	16-106	20-76	21-67	40-102	42-250	38-140	40-222	41-121	48-190
Average	27	42	42	31	25	22	45	50	70	54	38	40	62	153	65	90	60	102
23 July 1969																		
Near Bottom																		
Range	18-136	19-186	35-79	27-89	15-19	15-22	26-383	27-105	19-442	21-197	18-146	20-1168	29-196	30-216	76-849	31-344	57-401	57-908
Average	38	63	50	60	18	16	116	65	95	86	52	145	102	115	285	200	190	190
Near Surface																		
Range	9-35	18-35	20-105	18-35	12-20	13-18	14-58	15-50	18-70	12-71	10-50	13-38	13-121	23-123	24-119	23-163	32-205	22-67
Average	20	25	30	20	18	16	35	30	38	38	38	22	71	82	65	62	62	55

NOTE: Near bottom samples at 1 foot above river bed and near surface samples 16 to 32 feet above bottom depending on height of water column.

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the estuary, source areas are reflected by differences in clay minerals and feldspar. Composition analysis for the 23 July 1969 suspended samples are listed individually in Table 2 of Annex C.

Silt-size minerals generally occur in greatest proportion in suspended samples when tidal velocities increase. Clay minerals are generally less abundant except locally on slack tide conditions. The inorganic silt size fraction consists of quartz and feldspar with minor, more highly variable biogenous materials. Depending on current velocities, the range of inorganic silt, clay, and organic matter is respectively 50-70 percent, 10-40 percent, and 5-25 percent of the sediment load.

The clay minerals carried in suspension in general order of abundance include illite, kaolinite, chlorite, and montmorillonite. The most variable clay mineral in the estuary is kaolinite which appears more abundantly in the suspended sediments on the side of the estuary near the Piedmont crystalline rocks. Schubel (1968) reports similar clay mineral distribution in the suspended sediments of upper Chesapeake Bay.

The organic matter is highly variable in the estuary depending on proximity to sewage outfalls, watershed discharge, and other factors. A relative index of volatile non-filterable suspended matter versus total non-filterable suspended matter is gained from inspection of Figure 33; from this figure it is apparent that volatile, non-filtrable matter averages about 10 ppm while total non-filtrable matter (including the volatiles) averages about 25 ppm. Analysis of the organic matter versus sediment load is shown

for the river stations sampled 23 July 1969 in Figure 32. The organic matter is shown to increase from the bottom to the surface at all locations except station 90 + 000 (mile 86). This rather uniform distribution and generally higher concentration of organics occurs in the region showing marked sewage in the bottom samples cited previously. The uniformity of organic matter will be shown in a later section to relate to lack of sufficient oxygen to support life activities of microorganisms which convert organic matter into plant and animal food. Thus, this is a graphic display of organic detritus to the estuary south of Marcus Hook where normal activities of microorganisms again influence the biogenous materials of the water column. Reuter (1970) in analysis of the organic matter by chromatograph techniques found that the proteinaceous matter and free amino acid content at station 90 + 000 (mile 86) is in pollution proportions due to undigested sewage wastes from Philadelphia.

Sediment Source

Analysis of the clay-mineral suites from suspended samples of tributary streams has established that kaolinite exceeds chlorite in the Piedmont streams and chlorite exceeds kaolinite in Coastal Plain streams discharging to the Delaware estuary. The annual tons of kaolinite discharged from the headland waters, and Coastal Plain and Piedmont streams to Marcus Hook shoal is estimated at 34,500 tons annually while chlorite is calculated as 47,700 tons annually. Tonnages of kaolinite and chlorite from each source area are listed below with values based on known sediment discharge and composition analysis of tributary streams as reported in tables of Annex C:

	Suspended Chlorite Tons/yr	Suspended Kaolinite Tons/yr
Delaware River North of Trenton	31,700	19,600
Coastal Plain Streams	1,600	900
Piedmont Streams	4,800	5,900
Schuylkill River	9,600	8,100
	47,700	34,500

Since much of the sediment found in suspension in the estuary at any time is derived from resuspension or cannibalization of bottom sediments, a comparison of chlorite to kaolinite ratio at the stations occupied during the tidal cycle of 23 July 1969 reflect upon source area evaluations. The chlorite/kaolinite ratio for 257 suspended samples taken during the tidal cycle of 23 July 1969 at Marcus Hook averages 1.38 which is in fair agreement with the 1.25 ratio from the watershed discharge. Chlorite increases steadily toward the bay and tributary streams discharging into the bay contain nearly twice as much chlorite as kaolinite in all tributary streams tested (see Table 1 of Annex C). Oostdam (1971) also reports chlorite as more abundant than kaolinite in the suspended samples of the entire bay area.

It is apparent from the foregoing that the clay minerals transported to Marcus Hook are from the upland discharge source areas. This material tends to flocculate and become trapped in the shoal. The physiochemical aspects of this massive flocculation at this shoal site will be considered in a later section.

SUSPENDED SEDIMENTS OF DELAWARE BAY

Oostdam (1971) in an exhaustive study of suspended sediment concentrations of Delaware

Bay found a log-normal distribution through the water column with concentrations increasing with depth and greater in shallow than deep water; average concentration was found to be 30 parts per million (ppm). The suspended sediments were found by Oostdam (1971) to consist mainly of silt and clay-sized particles with mean diameters of approximately 1.5 microns. Predominant clay minerals were found to be chlorite, illite, and kaolinite. Organic matter averages 4 ppm in the bay sediments which was estimated at 15 percent of the average suspended load.

Oostdam (1971) concluded from his analysis of suspended samples in Delaware Bay that fine sediments, in contrast to the marine sands in the bay, are predominantly eroded rather than deposited, so that the bay floor and marshes rimming the bay, constitute a source of the suspended sediments. Other sources are from river discharge, bank erosion, industrial effluents, sewage and organic productivity.

Since landward movement of sand into the bay has been demonstrated in a previous section, it is highly probable that considerable suspended material may move in similar directions and in substantial quantity in the relatively unexplored 2 feet of water column above the bay floor.

SUSPENDED SEDIMENT OF CHESAPEAKE BAY

Chesapeake Bay is similar to Delaware Bay in that each drain similar source areas and both are similar in major hydrodynamic aspects. Schubel (1968) made an intensive study of the suspended sediment of the northern Chesapeake Bay in 1966 and 1967 and reported that the minerals of the suspended sediments consisted of clay minerals, mainly illite, but also chlorite and kaolinite, and of quartz and feldspar. The mean diameter ranged from 2.3 to 12.2 microns, and in nearly 75 percent of samples, the diameter ranged between 3 and 6 microns. The average percentage of combustible organic matter ranged from 10 percent in the bottom waters during winter to over 50 percent near the surface in summer.

Biggs (1970) found that the Susquehanna River discharged 0.084×10^6 cubic meters of sediment into the upper Chesapeake Bay during the period 1 February 1966 through 31 January 1967; 13 percent of this was organic carbon. Only 41 percent of the total suspended sediment escaped seaward from the upper bay. Shore erosion contributed 13 percent of the mass of suspended material in the upper bay, and 52 percent in the middle bay, while primary production and production of skeleton material contributed 4 percent to the upper bay and 40 percent to the middle bay. Of the total input of suspended material in both upper and middle Chesapeake Bay, only 9 percent (0.11×10^6 tons/year) escaped seaward. The calculated nominal rate of sedimentation for these parts of Chesapeake Bay amounted to 3.7 mm/year.

ENVIRONMENTAL ASPECTS OF DELAWARE ESTUARY

INTRODUCTION

Analysis of bottom sediments in the Delaware River has disclosed abnormal amounts of organic matter and unusually high concentration of heavy metals and other toxic materials with peak occurrences between Schuylkill and Christina Rivers along the estuary. Suspended sample analyses of chemical and biological parameters have been taken since July 1967 by the Delaware River Basin Commission and tables for the 1967 calendar year have been published by the U. S. Department of Interior (1970); more recent listings are maintained in the Storet System of the Environmental Protection Agency and some of this data is presented in the following paragraphs. Dispersal patterns of zinc actually disclose knowledge of the point

of discharge of this toxic heavy metal and analysis of phosphorus and nitrogen values will be shown to correlate with sewage discharge and eutrophication conditions in the estuary. The polluted nature of the estuary controls the amount of organic detritus found in the sediment.

Investigation of the spread of pollution by Prichard (1954) in the Delaware River model at the Waterways Experiment Station of the Corps of Engineers at Vicksburg, Mississippi shows that pollution appears to move downstream more slowly than the net downstream movement of water. The pollutants spread longitudinally along the channel axis as a result of tidal action and isolated pollution materials become trapped in shore indentures. The temporary entrapment

of the pollution materials which feed out into the main channel contribute to the longitudinal spreading of pollution in the estuary.

DISSOLVED OXYGEN AND FECAL COLIFORMS

Of the several parameters used to describe water quality, the dissolved oxygen and quantity of pathogens expressed as fecal coliforms per 100 ml are most frequently employed. The dissolved oxygen is a measure of the oxygen available for destroying organic pollutants and fecal coliforms contain the disease causing bacteria. The monthly mean value of dissolved oxygen and fecal coliform count is listed in Table 12 and depicted graphically in Figure 34 for the Delaware estuary during March and July 1969; mean values for the period 1967-73 and for June 1969 are also included in Figure 34. The mean value curve for the 1967-73 period lies between both the dissolved oxygen and fecal coliform values shown for March and July 1969; these months were chosen because they represent respectively high discharge and low discharge periods. From inspection of Figure 34, it is apparent that the waters entering the estuary at Trenton are of good quality with oxygen values near saturation and fecal coliform in negligible quantities. However, as one proceeds down the estuary, water quality conditions become progressively poorer as observed in the dip of the dissolved oxygen curve and the increase of fecal coliforms; low dissolved oxygen and peak mean fecal coliform occur in the vicinity of Wharton St. in South Philadelphia at Mile 98.5 where summer values (July 1969) attain an astronomical fecal coliform count of 22,000 per 100 ml and dissolved oxygen drops to 2 ppm (Figure 34). This sharp drop in water quality is in close proximity to the City of Philadelphia and Camden County sewage treatment plants.

The lowest dissolved oxygen of 1 mg/1 occurs in June 1969 in vicinity of the confluence of the Schuylkill and Delaware Rivers; this point is in close proximity to the Southeast and Southwest sewage treatment plants of Philadelphia. In addition, the month of June 1969 contains less than average discharge for that section of the river. During the month of March 1969, the discharge in the river reaches maximum proportions and dilutes the sewage to values between 4000 and 6000 fecal coliform per 100 ml and increases dissolved oxygen to a respectable 5 to 10 mg/1. During less than average discharge, however, the Delaware River between Philadelphia and Marcus Hook is polluted to the extent that it can support only very limited forms of life and is indeed a "dead sea" unable to support even bacteria. During these periods of low discharge, relatively large amounts of organic materials accumulate in the Fort Mifflin and Marcus Hook shoals. In Pea Patch Island shoal area, the river is not as seriously polluted with fecal coliforms, and the dissolved oxygen content, which ranges between 4 and 8 mg/1, is considered barely adequate for fish populations (see Figure 34). At the entrance to Delaware Bay, the dissolved oxygen values have recovered to about the saturation level.

pH AND Eh OF SUSPENDED WATER SAMPLES

The pH and Eh mean values of suspended samples for the period of record (1967-1973) as well as monthly mean values for March and June 1969 for station locations in Delaware estuary are listed in Table 13 and depicted graphically in Figure 36. A plot of monthly pH values for a point location (see Figure 35) reveals little seasonal change; however, as shown in Figure 36, the values vary with location in the estuary. The pH from head of tide at Trenton, decreases steadily from 7.4 to neutral (7.0) at Philadelphia. Downstream of Philadelphia, the water becomes more acid with lowest point of

TABLE 12

MEAN DISSOLVED OXYGEN AND FECAL COLIFORM VALUES IN SUSPENDED SAMPLES FOR PERIOD OF RECORD (1967-1973) AND FOR SELECTED MONTHS AT STATION LOCATIONS IN DELAWARE RIVER

Station Location	Miles above Capes	Dissolved Oxygen in ppm (mg/1)				Fecal Coliforms (1000's/100 ml)		
		Mar 69	Jun 69	Jul 69	Jul 67–Jan 73	Mar 69	Jul 69	Jul 67–Jan 7?
Reedy Is., Del.	54.9	9.1	5.2	4.8	6.9	42	552	742.?
Pea Patch Is., Del.	60.6	8.4	3.3	3.7	5.9	12	1168	907.?
New Castle, Del.	66.0	8.2	1.9	2.5	4.8	275	2350	1085.?
Cherry Is., Del.	71.0	6.5	1.5	1.7	3.9	117	5180	1961.?
Oldmans, N.J.	74.9	5.2	1.9	1.5	3.7	272	1772	108?
Marcus Hook, Pa.	78.1	4.6	1.8	2.0	3.6	352	12408	16??
Eddystone, Pa.	84.0	5.0	1.8	1.6	3.6	970	4420	38?
Paulsboro, N.J.	87.9	4.9	1.1	1.7	3.6	1825	5400	7?
Navy Yard, Phil.	93.2	6.1	0.7	2.1	4.0	1775	7660	80
Wharton St. Br., Phil.	98.5	8.2	1.4	2.0	4.1	3475	22820	18?
Ben Franklin Br., Phil.	100.2	8.7	2.0	2.4	5.0	4900	15820	?
N.E. Sewage Plant, Phil.	104.0	10.2	3.9	3.3	5.8	2650	4480	?
Palmyra, N.J.	107.1	9.9	4.1	2.8	6.6	2590	4470	
Torresdale, Phil.	110.7	10.8	3.5	4.4	7.4	742	2180	?
Burlington, Pa.	117.8	9.9	3.5	4.6	7.8	635	694	?
Florence, N.J.	122.5	11.3	4.0	5.5	8.4	920	840	??
Fieldsboro, N.J.	127.5	10.0	4.8	6.0	8.9	180	480	?

NOTE: Values from Storet Data of the Environmental Protection Agency.
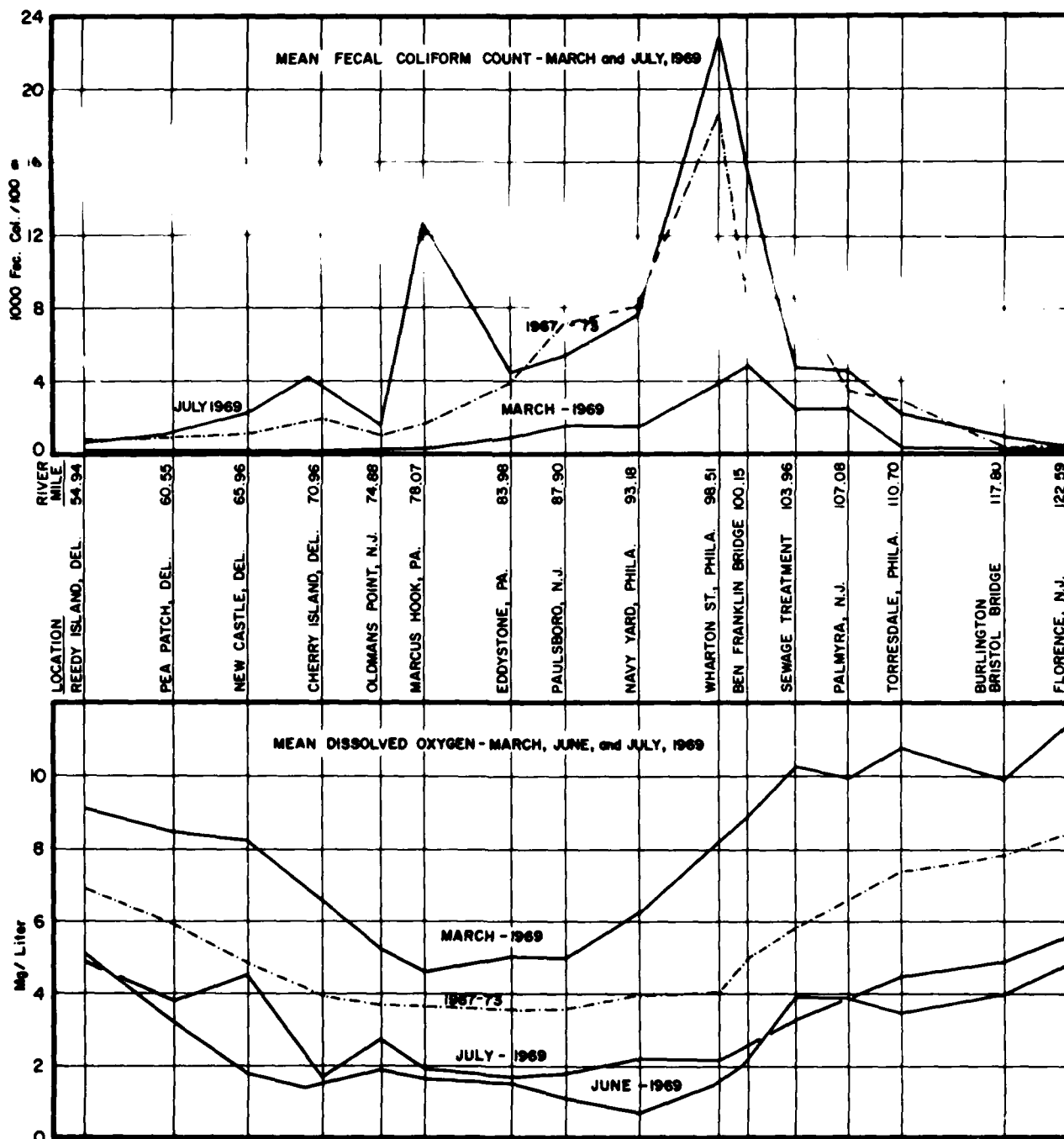
FIGURE 34. Mean average dissolved oxygen and fecal coliforms in Delaware River during March and July, 1969, and average values for period 1967 thru 1973.

TABLE 13

MEAN pH AND Eh IN SUSPENDED SAMPLES FOR ... OD OF RECORD (1967-1973) AND MARCH AND JUNE 1969 AT STATION LO... ONS IN DELAWARE RIVER

Station Location	Miles above Capes	pH			Eh (mv)		
		Mar 69	Jun 69	–Jan 73	Mar 69	Jun 69	Jul 67–Jan 73
Reedy Is., Del.	54.9	7.2	6.9	7.08	182.5	143.3	169.9
Pea Patch Is., Del.	60.6	6.8	6.6	6.99	167.5	143.3	160.9
New Castle, Del.	66.0	6.6	6.5	6.83	122.5	130.0	154.6
Cherry Is., Del.	71.0	6.3	6.6	6.76	83.8	116.7	150.3
Oldmans, N.J.	74.9	6.6	6.8	6.82	65.0	110.0	146.3
Marcus Hook, Pa.	78.1	6.8	6.8	6.85	68.8	105.0	145.8
Eddystone, Pa.	84.0	6.9	7.3	6.95	72.5	106.7	140.6
Paulsboro, N.J.	87.9	6.9	6.9	6.93	77.5	103.3	141.3
Navy Yard, Phil.	93.2	7.0	7.2	6.90	82.5	90.0	142.0
Wharton St. Br., Phil.	98.5	7.1	–	6.99	85.0	98.0	140.2
Ben Franklin Br., Phil.	100.2	7.4	–	7.07	85.5	94.6	140.3
N.E. Sewage Plant, Phil.	104.0	7.4		7.16	87.5	89.3	137.8
Palmyra, N.J.	107.1	7.3		7.23	86.3	95.0	136.8
Torresdale, Phil.	110.7	7.3		7.28	84.8	95.0	136.0
Burlington, Pa.	117.8	7.4		7.32	85.6	95.0	134.3
Florence, N.J.	122.5	7.4		7.40	86.8	79.3	134.5
Fieldsboro, N.J.	127.5	7.5		7.58	87.3	78.3	132.3

NOTE: Values from Storet Data of the Environment... ...ection Agency.
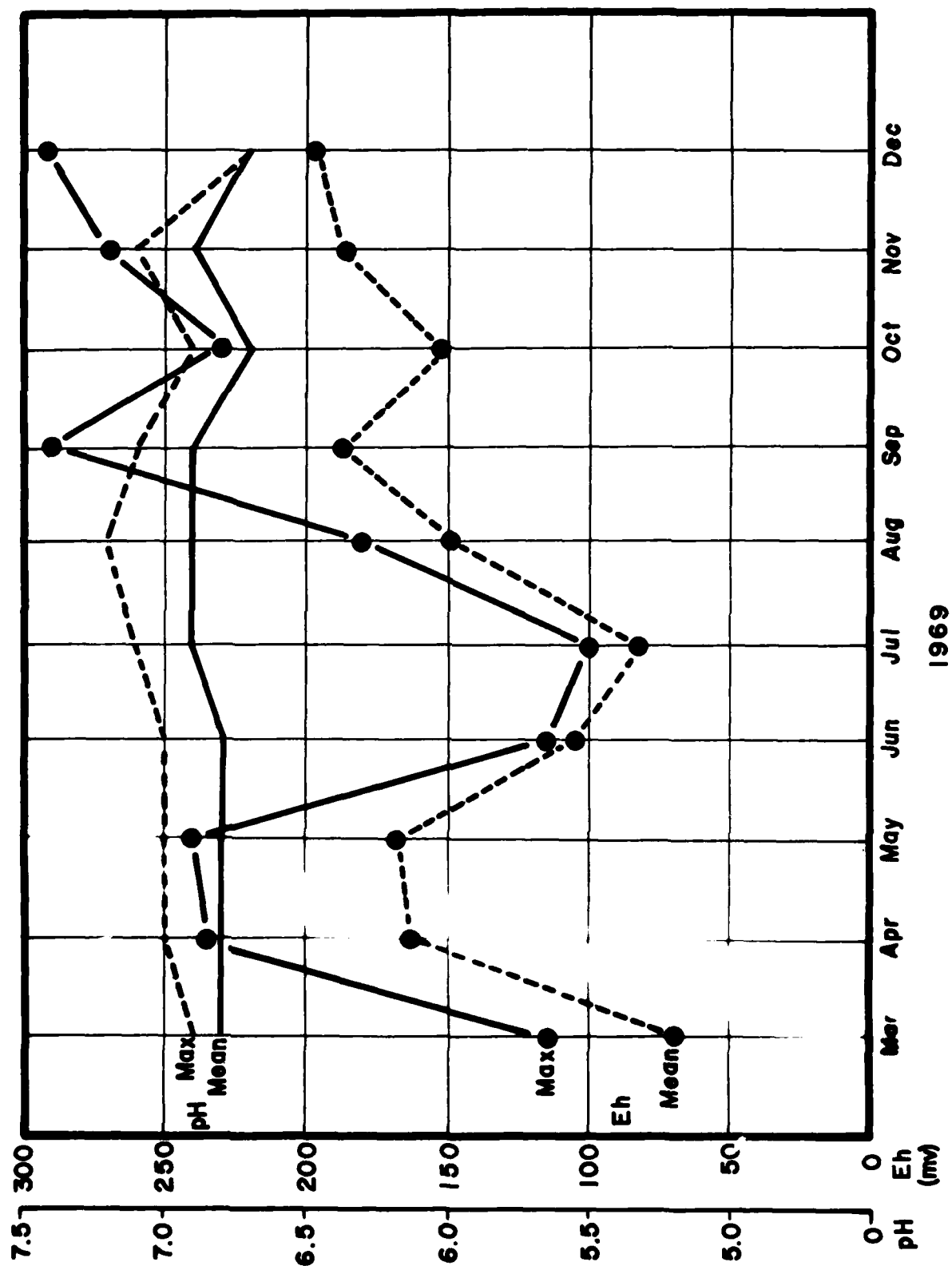
FIGURE 35. Plot of pH and Eh monthly mean and maximum at Marcus Hook-1969
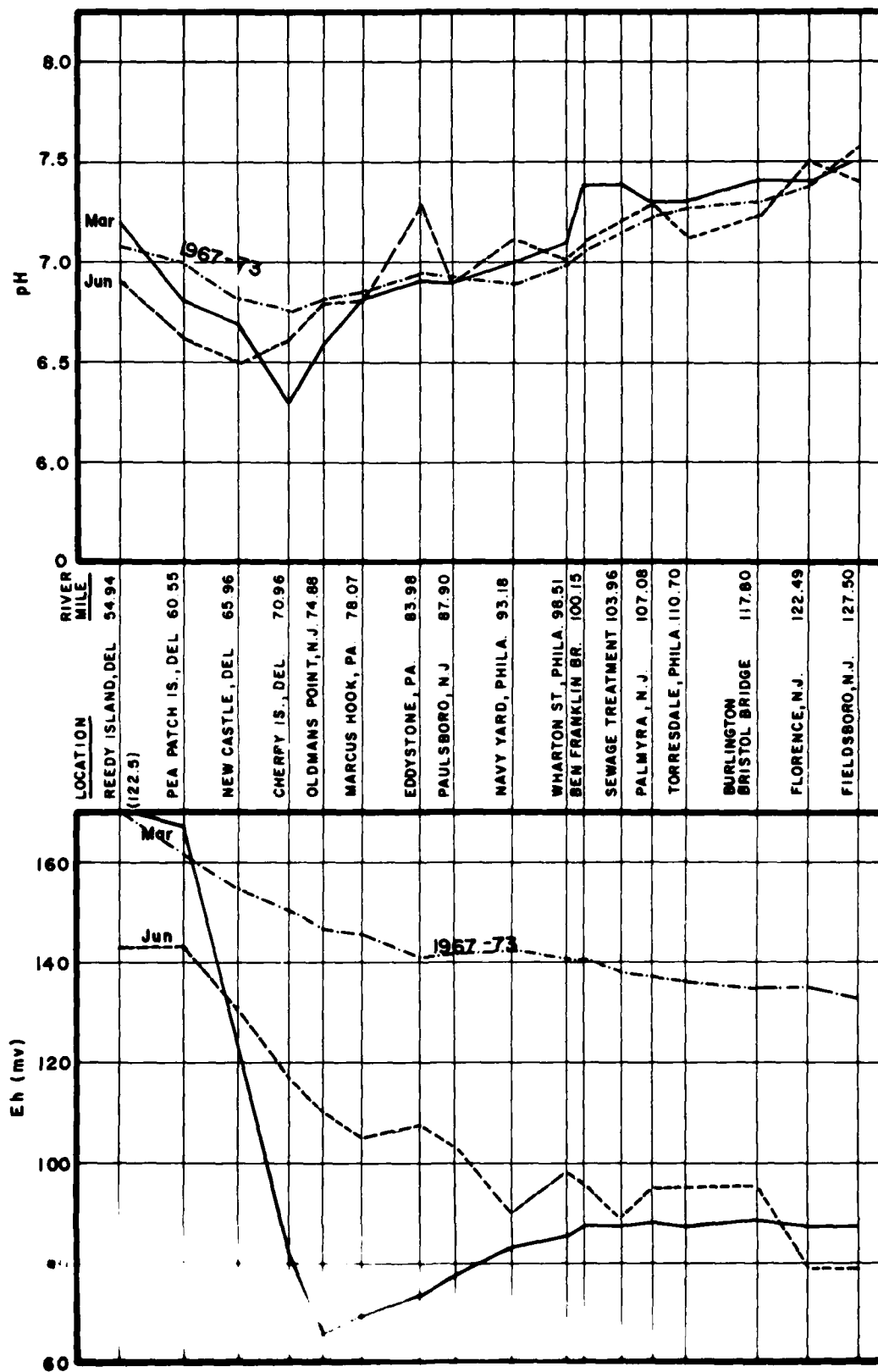
FIGURE 36. Plot of mean pH and Eh in the Delaware estuary during March and June 1969, and average value for period 1967 thru 1973

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6.3 at mile 71.0; here the trend reverses and the water becomes less acid and about 45 miles below Philadelphia becomes neutral. The increasing acidity is probably due to the acid industrial wastes and sewage in the upper and middle point of the estuary, and the gradual recovery downstream is due to increasing dilution by seawater. The Eh (measure of oxidation or reduction of a water system) follows a similar trend as pH for Delaware estuary with lowest value (66 mv) at mile 74.9.

The Eh steadily increases in the estuary from head of tide to the bay but has no real correlation to location in the estuary. At point locations, such as Marcus Hook, a noticeable decrease in Eh exists when discharge from the watershed is less during the summer with more polluted conditions in the river.

The pH and Eh measured in the bottom sediment during 2 March 1972, as discussed in an earlier section, generally correlates with the measured values of the water column. The pH values are especially similar for the reaches of estuary considered with more acidic conditions at Marcus Hook shoal and more alkaline conditions in the more seaward shoaling areas.

HEAVY METALS IN SUSPENDED SAMPLES

The concentrations of suspended total iron generally exceed the other heavy metals in the estuary (see Table 14). Normally, the concentrations of total iron ranged from 0.6 mg/liter at mile 122.5 to 1.0 mg/1 at mile 84 (see Figure 37). The concentration of total iron increases to 1.2 mg/1 at Marcus Hook (mile 78), then increases erratically to a maximum of 1.8 mg/1 at mile 61. Highest concentration of iron occurs in the bottom muds of Marcus Hook shoal; from studies of thin films on particle sur-

face it will be shown in a later section that the suspended iron coats surfaces and enhances flocculation. All other metals normally occur in amounts less than 0.1 mg/1 although all metals occasionally showed higher values (up to 1.0 mg/1) at various times for points in the estuary.

A plot of mean and maximum zinc concentration available for suspended samples in the Christina River during 1969 is shown in Figure 38. Analysis of this data reveals a maximum zinc concentration of 2.7 mg/1 and a mean value of 1.3 mg/1 during 1969 at the Newport Bridge sampling station in the Christina River. Suspended zinc concentrations 6 miles upstream at Smally Dam is in more normal concentrations, and zinc concentration at all stations downstream of Newport Bridge is markedly less with a dispersal pattern evident in the progressive decrease to the confluence of the Christina and Delaware Rivers (see Figure 38). Bottom sediment in the Christina River and probably Delaware River sediment containing higher than average zinc concentrations represent sediment receiving the incorporation of the dissolved zinc by whatever process effects concentration. That dissolved zinc is incorporated in the sediment within a few miles of the injection point seems to be the popular view by most investigators. Sediment transport of this material by hydrodynamic water agencies, effects a dispersal pattern from the main point of incorporation of the zinc in the source area. Inspection of Figures 29 and 38 leaves little doubt that the point of injection of the zinc is somewhere within a few miles upstream of Newport Bridge. More study points using this method could easily "pin point" the contributing source of zinc. If suspended samples were obtained in the Schuylkill River a dispersal pattern of zinc would undoubtedly be delineated since the bottom sediment reveals abnormal highs (see Figure 29). The maximum concentration of zinc found in the estuary bottom sediment in this

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TABLE 14
MEAN TOTAL IRON AND HEAVY METALS IN SUSPENDED SAMPLES FOR PERIOD OF RECORD AND SELECTED MONTHS AT STATION LOCATIONS IN DELAWARE RIVER

Station Location	Miles above Capes	Iron (µg/l) Mar 69		Iron (µg/l) Jul 67–Jul 73	Zinc (µg/l) Mar 69		Zinc (µg/l) Jun 69	Nickel (µg/l) 1969	Copper (µg/l) 1969	Chromium (µg/l) 1969
		Max.	Mean	Mean	Max.	Mean	Max.	Max.	Max.	Max.
Reedy Is., Del.	54.9	1100	817	1586	160	147	100K	100K	100K	100K
Pea Patch Is., Del.	60.6	2200	1400	1777	180	160	100K	100K	100K	100K
New Castle, Del.	66.0	1800	1500	1545	180	157	100K	100K	100K	100K
Cherry Is., Del.	71.0	3300	2450	1643	180	157	100K	100K	100K	100K
Oldmans, N.J.	74.9	3200	2275	1335	160	145	100K	100K	100K	100K
Marcus Hook, Pa.	78.1	2400	1850	1197	136	120	100K	100K	100K	100K
Eddystone, Pa.	84.0	1600	1350	976	100	100	100K	100K	100K	100K
Paulsboro, N.J.	87.9	1800	1283	925	100	127	100K	100K	100K	100K
Navy Yard, Phil.	93.2	1300	1175	871	140	120	100K	100K	100K	100K
Wharton St. Br., Phil.	98.5	1100	925	817	130	112	100K	100K	100K	100K
Ben Franklin Br., Phil.	100.2	1000	790	749	110	102	100K	100K	100K	100K
N.E. Sewage Plant, Phil.	104.2	1000	778	718	110	105	100K	100K	100K	100K
Palmyra, N.J.	107.1	1100	885	705	150	130	100K	100K	100K	100K
Torresdale, Phil.	110.7	1100	923	680	140	125	100K	100K	100K	100K
Burlington, Pa.	117.8	1100	910	682	140	120	100K	100K	100K	100K
Florence, N.J.	122.5	920	740	688	100	100	100K	100K	100K	100K
Fieldsboro, N.J.	127.5	1100	788	623	180	120	100K	100K	100K	100K

NOTE: 1. Data from Storet System of the Environmental Protection Agency.
2. Micrograms per liter (µg/l) equivalent to 1 part per billion.
3. K indicates actual value is less than value given.

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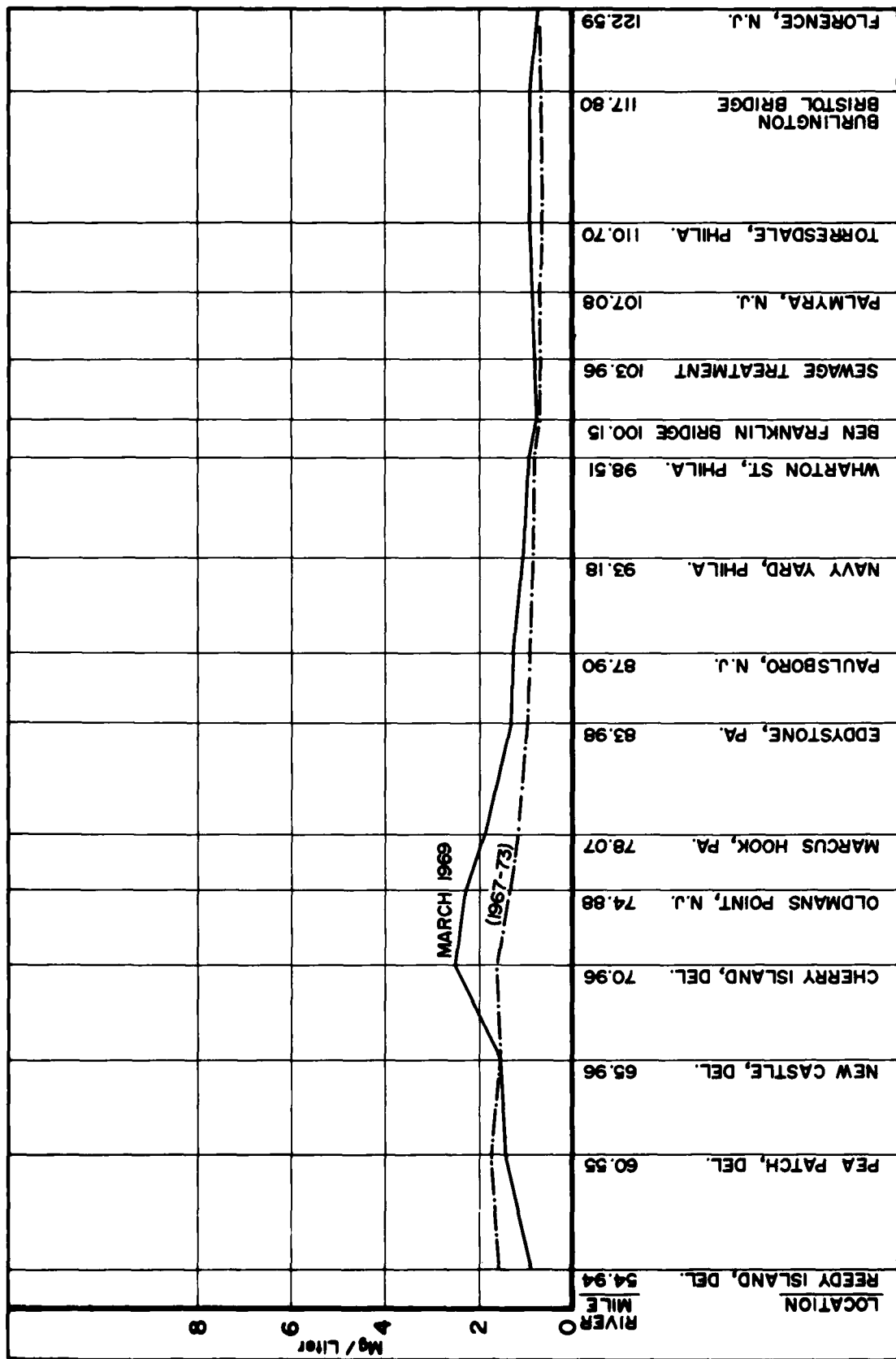
FIGURE 37. Mean suspended total iron values in Delaware estuary during period 1967-73 and for March 1969
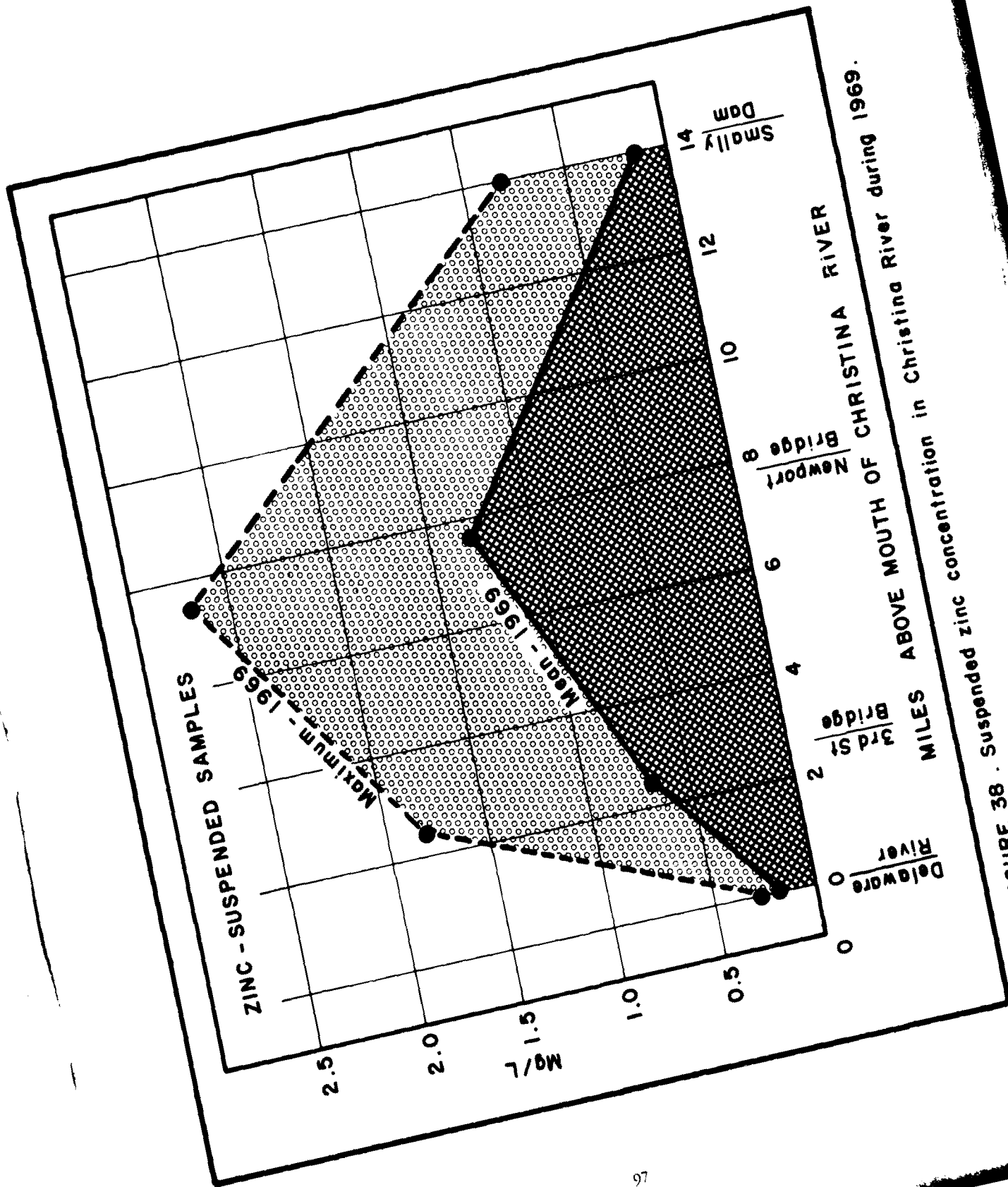
FIGURE 38. Suspended zinc concentration in Christina River during 1969.

investigation occured approximately 3.7 miles above the mouth of the Schuylkill River.

In a limited investigation of the mechanism causing flocculation and incorporation of the heavy metals in bottom sediment it will be shown that ferric hydroxide precipitation tends to scavenger a considerable portion of the heavy metals. Other investigators cite organic matter and clay minerals in addition to ferric hydroxide as being important in fixing heavy metals in bottom sediments.

EUTROPHICATION EVIDENCE IN DELAWARE ESTUARY

INTRODUCTION

Eutrophication of bodies of water is the advanced biological aging due to increased amounts of nutrients entering the water and which in practically all cases is associated with excessive phytoplankton and algal growth. The excess organic matter in effect causes oxygen depletion and further pollutes the estuary. In the last few years, a scientific controversy has been ranging over the identification of the critical nutrient supporting eutrophication. Kerr et al (1971) and others have concluded that not phosphorus but rather carbon (in the form of carbon dioxide) is the limiting nutrient in many waters and thus claim carbon as the key to control of eutrophication. Other authorities including Ryther and Dunstan (1971), have recently concluded that in marine coastal waters, nitrogen is the critical nutrient limiting algal growth. Bowen (1970) has summarized the key issues of the carbon and phosphorus schools of thought as regards limiting nutrients in the eutrophication process.

In evaluating criteria to establish the existence of eutrophication conditions, in surface waters, the latest criteria by Ryther and Dunstan (1971) will be utilized. The evidence found in the bottom sediment will also be reviewed as supporting evidence of eutrophication in the Delaware estuary.

EVIDENCE IN THE ESTUARY
BOTTOM SEDIMENTS

The distribution of amorphous siliceous diatom tests in Delaware estuary sediment in amounts ranging from trace to 20 percent by weight with a general average on the order of a few percent has been cited in an earlier section. Largest accumulation of diatom frusticles occur in Marcus Hook shoal which also contains higher concentration of phosphate (0.7 percent) than other river locations (see Fig. 14). Identification of diatom species by optical and electron microscope techniques disclosed the source of these diatoms as from the brackish water of the river estuary. Thus, the source area for diatom growth lies within the part of the estuary receiving strongest sewage inputs as well as abundant effluents from the industries which occur along this part of the estuary. Diatom "blooms" in the estuary are an expression of the eutrophication condition. Sediments stirred up by shipping in the navigation channels as well as sediment from run-off in the watershed effect diatom kills with resulting deposition of the diatoms in shoaling areas. Soft parts of the diatom decay leaving behind the siliceous diatom test and nutrients such as phosphate used in the life process. Elemental phosphorus in the Marcus Hook shoal is higher (0.3 percent) than other bottom sediment samples. Total nitrogen averages 0.35 percent giving a ratio of nitrogen

to phosphorus of approximately 1 to 1. In this case it would appear that nitrogen is the limiting nutrient, however, the actual case is best described in suspended water samples.

Proteinaceous matter found in the March 1972 Marcus Hook shoal samples averages 2600 ppm with 1900 ppm in the plus 2 micron size and 5600 ppm in the minus 2 micron size fraction. Such values tend to reflect the polluted condition of the overlying water column. The relatively high amorphous hydrous iron oxide up to 3.0 percent is also instrumental in removing oxygen from the water. Any oxidizable iron stirred up by shipping or dredging in the channel causes some depletion of dissolved oxygen in the change from the ferrous to the ferric oxide.

NITROGEN—PHOSPHORUS RATIO IN SURFACE WATERS

Mean monthly values of phosphorus and inorganic nitrogen (NH_3-N, and NO_2-N) in suspended samples from EPA Storet System are listed in Table 15 and depicted in Figure 39 for Marcus Hook during 1969 and in Figure 40 for the Delaware River during March and July 1969. Analysis of these figures for Marcus Hook reveals a rather uniform phosphorus distribution between 0.2 and 0.8 mg/1 with higher values in the spring and lowest values in early summer. Nitrogen is more variable in distribution in ranging between 2 and 6 mg/1 with highs in the spring and fall (see Figure 39). Assuming an average use rate of N to P at 10 to 1 by diatoms and other phytoplankton as used by Ryther and Dunstan (1971) in a study of marine waters, the ratio obtained by dividing atoms of phosphorus

into nitrogen at Marcus Hook indicate that nitrogen is the limiting nutrient during March, April, May, August, and December when river discharge is high whereas phosphorus is the limiting nutrient during the months of low water in the estuary.

Inspection of nitrogen and phosphorus distribution in the estuary during March 1969 shows marked divergence of the phosphorus and nitrogen in the lower part of the estuary and the separation at mile 74 for nitrogen limiting and phosphorus limiting condition of nutrients available for phytoplankton production (see Figure 40). In July, during low flow in the estuary, the nitrogen is the limiting nutrient from mile 91, just north of the Schuylkill River, to Trenton while phosphorus is the limiting nutrient south of mile 91. Marcus Hook, situated between mile post 74 and 91, reflects both nitrogen and phosphorus limiting depending on the discharge from the watershed.

Since phosphorus appears to be the limiting nutrient over much of the estuary during the warmer months and during low river flow conditions, it would appear that elimination of phosphate at sewage outfalls could limit the diatom production and other eutrophication in the estuary to a marked degree. A recent 10 week pilot sudy completed in Michigan City, Indiana showed that phosphorus removal at 80 percent efficiency could be effected in sedondary treatment plants at a cost of about $1.25 per resident per year (Chem. and Eng. News, 1972). Such methods could be effective in limiting eutrophication in Delwawre estuary.

TABLE 15
MEAN VALUES OF PHOSPHORUS AND INORGANIC NITROGEN IN
SUSPENDED SAMPLES FROM DELAWARE RIVER

Station Location	Miles above Capes	Percent Mean Phosphorus		Percent Mean Nitrogen	
		Mar 69	Jul 69	Mar 69	Jul 69
Reedy Is., Del.	54.9	0.15	0.20	4.66	2.29
Pea Patch Is., Del.	60.6	0.23	0.21	4.93	3.06
New Castle, Del.	66.0	0.27	0.22	5.23	3.03
Cherry Is., Del.	71.0	0.39	0.18	5.26	2.90
Oldmans, N.J.	74.9	0.59	0.17	4.88	2.94
Marcus Hook, Pa.	78.1	0.79	0.15	4.83	2.73
Eddystone, Pa.	84.0	0.90	0.18	4.09	2.48
Paulsboro, N.J.	87.9	0.91	0.18	3.46	3.12
Navy Yard, Phil.	93.2	0.88	0.22	2.97	1.86
Wharton St. Br., Phil.	98.5	0.84	0.27	2.64	1.64
Ben Franklin Br., Phil.	100.2	0.80	0.31	2.37	1.88
N.E. Sewage Plant, Phil.	104.0	0.74	0.37	2.15	1.62
Palmyra, N.J.	107.1	0.75	0.38	2.04	0.40
Torresdale, Phil.	110.7	0.75	0.44	1.97	0.31
Burlington, Pa.	117.8	0.76	0.34	1.88	1.45
Florence, N.J.	122.5	0.67	0.29	1.70	1.74
Fieldsboro, N.J.	127.5	0.67	0.32	1.51	1.13

NOTE: Values from Storet Data of the Environmental Protection Agency.

PHYSIOCHEMICAL ASPECTS OF
SHOALING PROCESS

INTRODUCTION

The sediment characteristics governing the behavior of fine sediments in estuarine waters are very complex with surface forces rather than gravity forces dominant in the dispersed state and gravity forces effective after flocculation. Surface forces are of an electrochemical nature and depend not only on the sediment composition but also upon environ-
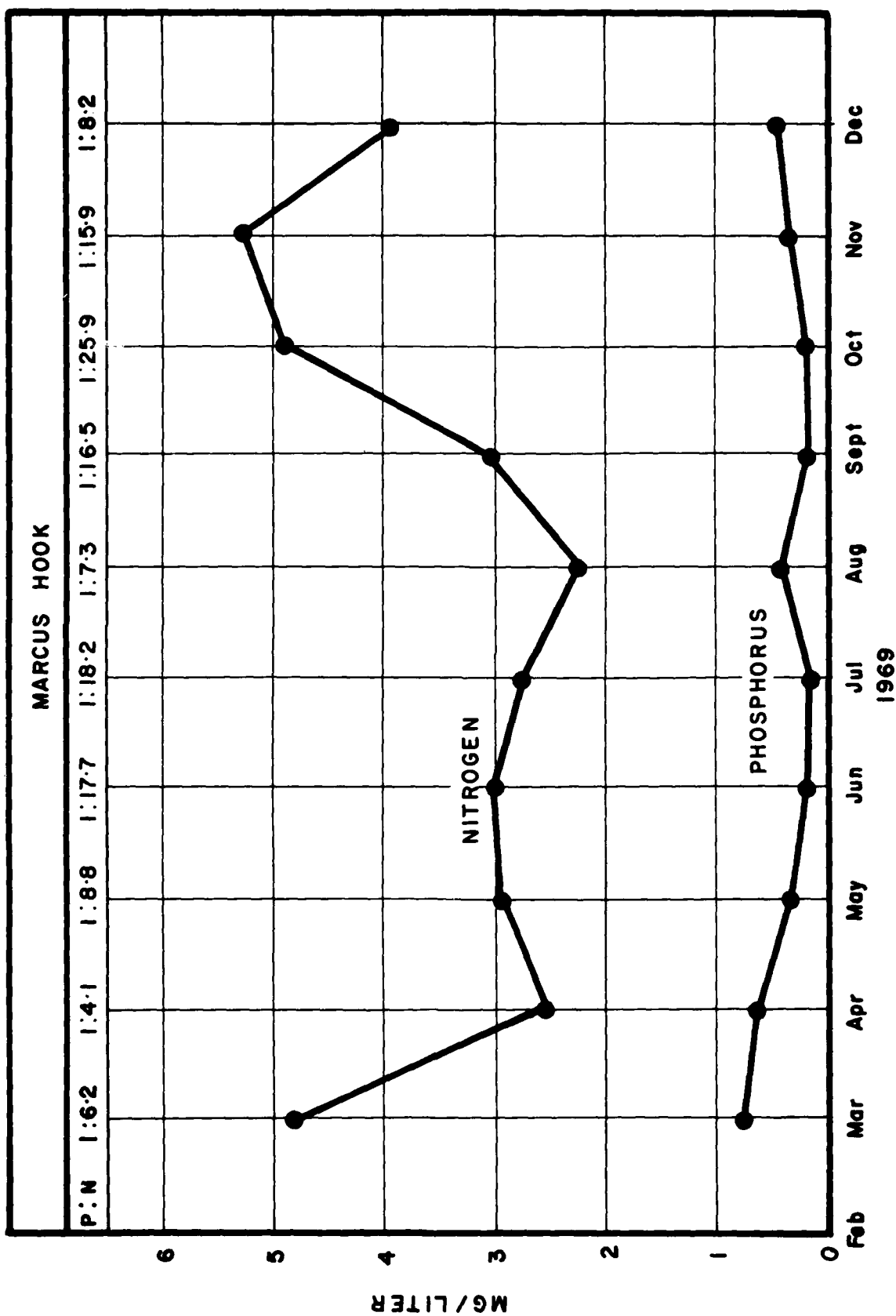
FIGURE 39. Phosphorus and nitrogen in suspended samples from Marcus Hook during 1969. Nitrogen is inorganic elemental nitrogen (NH_3-N, NO_2-N, and NO_3-N). Data from EPA Storet System.

MARCH, 1969

P – Limiting ──────────────── N – Limiting

| 31·8 | 21·3 | 19·6 | 13·3 | 8·3 | 6·2 | 4·5 | 3·8 | 3·4 | 3·1 | 3·0 | 2·9 | 2·7 | 2·6 | 2·5 | 2·5 |

Mg / Liter

5
4
3
2
1
0

NITROGEN

PHOSPHORUS

| RIVER MILE | 54.94 | 60.55 | 65.96 | 70.96 | 74.88 | 78.07 | 83.98 | 87.90 | 93.18 | 98.51 | 100.15 | 103.96 | 107.08 | 110.70 | 117.80 | 122.59 |

LOCATION

REEDY ISLAND, DEL.
PEA PATCH, DEL.
NEW CASTLE, DEL.
CHERRY ISLAND, DEL.
OLDMANS POINT, N.J.
MARCUS HOOK, PA.
EDDYSTONE, PA
PAULSBORO, N.J.
NAVY YARD, PHILA.
WHARTON ST., PHILA
BEN FRANKLIN BRIDGE
SEWAGE TREATMENT
PALMYRA, N J
TORRESDALE, PHILA
BURLINGTON BRISTOL BRIDGE
FLORENCE, N J

JULY, 1969

P – Limiting ──────────────── N – Limiting

| 11·7 | 14·9 | 13·5 | 16·2 | 17·0 | 18·2 | 13·8 | 11·8 | 8·5 | 6·0 | 6·4 | 4·4 | 1·0 | 0·7 | 4·2 | 6·0 |

Mg / Liter

5
4
3
2
1
0

NITROGEN

PHOSPHORUS

FIGURE 40 Nitrogen and phosphorus in suspended samples of Delaware River during March and July, 1969.
Nitrogen is inorganic elemental nitrogen (NH_3-N, NO_2-N, and NO_3-N). Data from EPA Storet System.

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mental conditions. Consideration will therefore be given as regards the physiochemical factor effecting flocculation in this section. A scanning electron micrograph of a "floc", shown in Figure 41, depicts the aggregate nature of this material.

The procedures employed in this investigation include conventional cation exchange capacity tests of selected bottom sediment and a combined technique employing electrophoretic mobility, electron probe and electron diffraction analysis. The latter approach will be shown to be feasible for future investigations.

CATION EXCHANGE CAPACITY

A limited number of cation exchange capacity tests and analysis of exchanged cations was performed on bottom sediment samples from Delaware and Schuylkill Rivers (see Table 16). In addition, selected samples were treated with hydrogen peroxide and similar parameters measured to note differences related to removal of organics. From this data the following is apparent:

(a) Highest total cation exchange capacity (44 Me/100 g) occurs in bottom sediment from the fresh water location in Schuylkill River with calcium ion constituting the highest partial cation exchange values (see Table 16).

(b) Bottom sediment from Delaware River have a total cation exchange capacity ranging between 7 and 30 Me/100 g. A proportional increase in sodium, potassium, and magnesium ions partial exchange capacity occurs in a seaward direction (see Table 16) which is related to increased salinity of the water column.

(c) The relatively large difference observed in the total cation exchange capacity and the sum of individual cations (sodium, potassium, magnesium, iron, calcium, and magnesium) is attributed to the influence of other specific ions which were determined; these probably include H^+, NH_4^+, and organic matter.

(d) A comparison of 10 bottom sediment samples treated with hydrogen peroxide to remove organic matter revealed that the organic matter is a major factor in determining the differences in total cation exchange capacity values (see Table 16). The total cation exchange capacity of the treated sample, except for 2 locations, was considerably lower than the untreated samples even though the slightly acidic nature of hydrogen peroxide tends to make oxides or hydroxides available for exchange. Iron discoloration in the treated sample also suggests that iron is complexed by organic matter. In general, it is concluded from this data that the oxidizable organic matter plays an important role in the cation exchange taking place in the fine grained sediments of the estuary.

More detailed investigations involving cation exchange needs to be conducted on samples from the water column as well as the bottom sediments. Recent investigations by Carter and Wilde (1972) on the cation exchange capacity of suspended material from coastal sea water off central California employing a methylene blue method shows promises of application in evaluating effects of sewage and industrial effluents on cation exchange capacity of suspended

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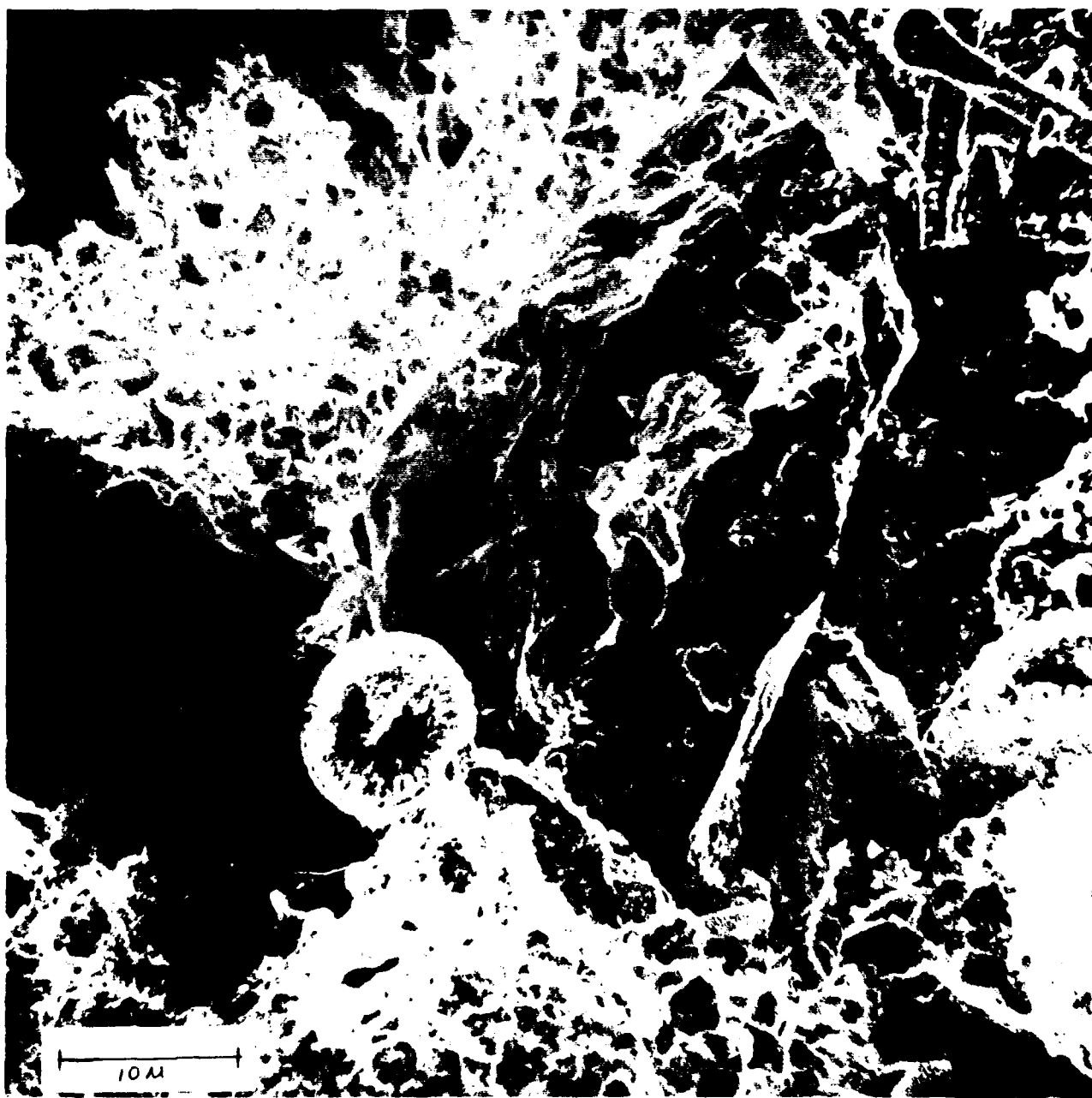
Figure 41. Scanning electron micrograph (1800X) of "floc" from Marcus Hook shoal sediment.

Sample No.	C.E.C. Me...	Na+	K+	Mg++	Ca++			Σ
					Delaware Estuary			
R-232	29.80	0.30	0.31	3.83	11.05	—	—	18.x
R-232*	15.30	1.01	0.47	4.01	4.74	0.60	0.90	10.23
R-1	7.67	0.12	0.12	0.64	1.93	—	—	2.81
R-1*	5.60	0.38	0.22	1.41	2.05	0.23	0.02	4.06
		0.35	0.40	1.58	5.12	—	—	7.45
R-								
R-								
R-								
R-181								
R-188								
R-200								
R-200*	17.80							
R-222	26.45							
R-222*	16.35		1.14		4.20	4.90	1.83	
R-231	26.08		1.16	5.08			—	17.40
				Fairmount Dam – Schuylkill River				
1-0	40.97	0.27	0.53	6.07	17.76	—	—	24.63
2-0	39.30	0.24	0.40	4.60	15.97	—	—	21.21
3-0	43.22	0.29	0.51	4.75	17.16	—	—	22.71
3-1	34.61	0.24	0.47	3.52	20.96	—	—	25.19
3-2	31.04	0.25	0.44	4.00	18.16	—	—	22.85
3-3	41.48	0.19	0.51	3.26	15.47	—	—	19.43
4-0	39.04	0.27	0.40	3.65	16.67	—	—	20.99
5-0	37.57	0.48	0.60	4.26	18.56	—	—	23.90
5-1	41.04	0.28	0.48	3.60	17.76	—	—	22.12
5-2	37.13	0.38	0.53	4.15	17.56	—	—	22.62
5-3	43.65	0.21	0.60	3.04	17.76	—	—	21.61
5-4	42.00	0.21	0.49	3.88	17.36	—	—	21.94
6-0	33.74	0.24	0.57	3.10	16.17	—	—	20.08

*Samples were treated with H_2O_2 and a partial exchange capacity determined with the organics removed. In all cases, except two, the total exchange capacity exceeds the partial exchange capacity with the exceptions due to the slightly acid H_2O_2 making oxides or hydroxides available for exchange.

NOTES: 1. The difference between the sum of individual cations specifically tested for and the total C.E.C. is probably due largely to H^+ and minor NH_4^+ or other cations.
2. All samples were washed 3 times with proponol alcohol followed by 4 washes with (1 N) NH_4OAc. The collected cations were determined by Atomic Absorption Analysis.

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ELECTROPHORETIC MOBILITY VERSUS pH MEASUREMENT

Electrophoretic mobility versus pH measurement was conducted on the shoal sediment samples collected in 1969 as a feasibility evaluation of this technique. Further investigations conducted on the shoal samples collected in March 1972 as well as for artificially prepared samples using beneficiated pro duce minerals Munoz 1972 In these investigations it was that features consistent at Marcus Hook favor electrophoretic values that favor flocculation at pH range 6-8 see Figure

Comparison of electrophoretic mobility measurements in various pH ranges for the three major shoal areas of Delaware River is listed in Table 17 and shown graphically in Figure 43 As shown in Figure 43 the Marcus Hook sediment compares favorably with the sediment in the earlier investigation (Figure 42) in the pH range of 6.5 where particle surfaces have least potential and favor flocculation conditions.

The three curves depicted in Figure 43, according to Munoz (1972), displays the following:

(a) Mifflin shoal sediment shows a dispersed system from pH 4.0 to approximately pH 5.9 where the mobility is zero and the system is flocculated. The charge is reversed and at pH 6.15 a slight degree of dispersion is apparent. An increase in pH brings about flocculation again, at approximately pH 6.4. Dispersion of the system develops rapidly, with a local maximum at pH 6.8. The system shows a decreasing value as the pH increases past 6.8 see Figure 43

b. Study of Marcus Hook mobility curve points to dispersion at pH 4, decreasing rapidly to a zero point of charge at pH 4.4. The system appears dispersed at pH 5.0 and flocculated at pH 5.5 where a zero point of charge is apparent. After showing dispersion with an opposite sign at pH 6.0, the system is flocculated again at pH 6.5 and shows a more dispersed system at pH 6.7 and finally, the mobility decreases to a zero point of charge and at pH 7.7 shows dispersion at negative values see Figure 43

c. Pea Patch Island bottom sediment shows a less complicated curve The system appears dispersed at low pH, with a zero point of charge at pH 5.7, dispersal again occurs at pH 7.0 After a zero point of charge at pH 8.0, indication of dispersal again appears at higher pH values (see Figure 43)

A comparison of these curves shows that the highest degree of dispersion (at pH 5.11) occurs in the Mifflin sediment. Marcus Hook shoal sediment shows the least degree of dispersion over the interval of approximately pH 4.3 to 8.3 as compared with the other shoals sediments. Pea Patch Island shoal sediments show least evidence of dispersion in the 3 samples for their natural pH. Thus, the curves depicted in Figure 43 reflect a more dispersed state for the settled solids in the generally fresh water portion of the estuary (Mifflin) and considerable flocculation at the point of salinity intrusion (Marcus Hook) and a completely flocculated condition at Pea Patch Island shoal.
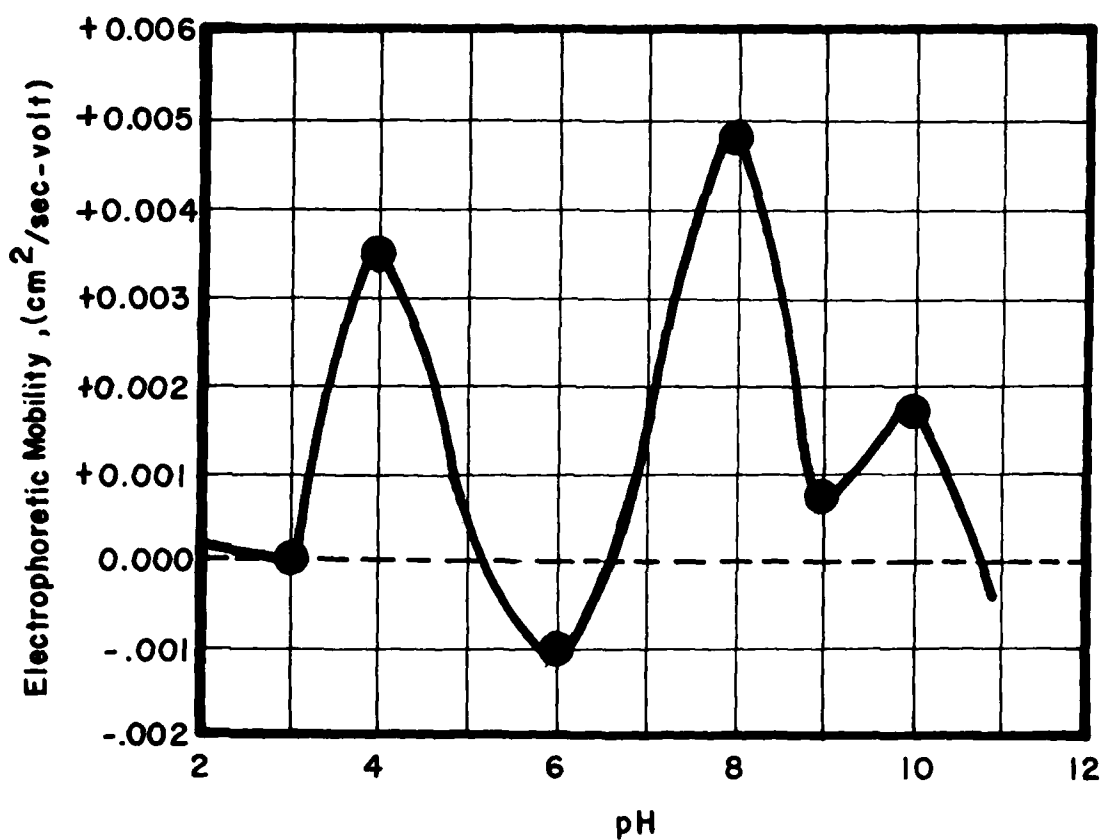
FIGURE: 42   Electrophoretic Mobility versus pH
for Marcus Hook shoal sediment.
Sampled March 1969.

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TABLE 17
ELECTROPHORETIC SEPARATION DATA FOR MINUS 74 MICRON SIZE SHOAL SEDIMENTS SAMPLED IN MARCH 1972

pH	R (Ohms)	i (Amps)	T (Sec)	Polarity	ΔW (Gms)	$\dfrac{Cm^2}{Sec\ Volt}$
MIFFLIN SHOAL SEDIMENT						
4.18	23.8	0.002	300	−	·0.1479	·0.0133
5.11	37.8	0.002	300	·	−0.7786	·0.0440
6.15	48.6	0.002	300	−	−0.1131	−0.0050
6.77	87.2	0.002	300	−	·0.1801	·0.0228
8.01	52.6	0.002	300	·	−0.2587	·0.0105
MARCUS HOOK SHOAL SEDIMENT						
4.09	32.3	0.002	300	·	·0.1440	−0.0110
5.10	61.8	0.002	300	·	+ 0.1037	+ 0.0014
6.02	106.9	0.002	300	+	+0.0802	−0.0019
6.74	178.9	0.002	300	−	+0.0668	+ 0.0009
8.32	189.6	0.002	300	+	+ 0.0396	−0.0005
PEA PATCH ISLAND SHOAL SEDIMENT						
4.10	83.6	0.002	300	−	+0.1047	+ 0.0027
4.91	48.3	0.002	300	−	+0.0709	+0.0031
5.90	98.1	0.002	300	+	+0.0258	−0.0006
7.00	100.3	0.002	300	+	+0.0939	−0.0020
8.50	90.0	0.002	300	−	+0.0342	+0.0003

Further consideration of the Marcus Hook shoal sediment involved electrophoretic mobility measurements of beneficiated prototype Marcus Hook sediment in concentrations similar to the shoal sediment. The resulting curves for the feldspar, quartz, and clay minerals are shown in Figure 44 and the measured values listed in Table 18. While no simple explanation can be given for these data, it is apparent that the contribution of these major constituents has been suspended by other factors, possibly thin films on particle surfaces. Whereas a typical quartz curve has a maximum negative electrophoretic value at pH 8, the quartz curve in Figure 44 shows a maximum negative electrophoretic value shifted toward the acid pH values. This displacement of quartz may be attributed to the previous history of the quartz including its origin, transport, and encounter with cohesive materials; surface coating could consist of organic surface active
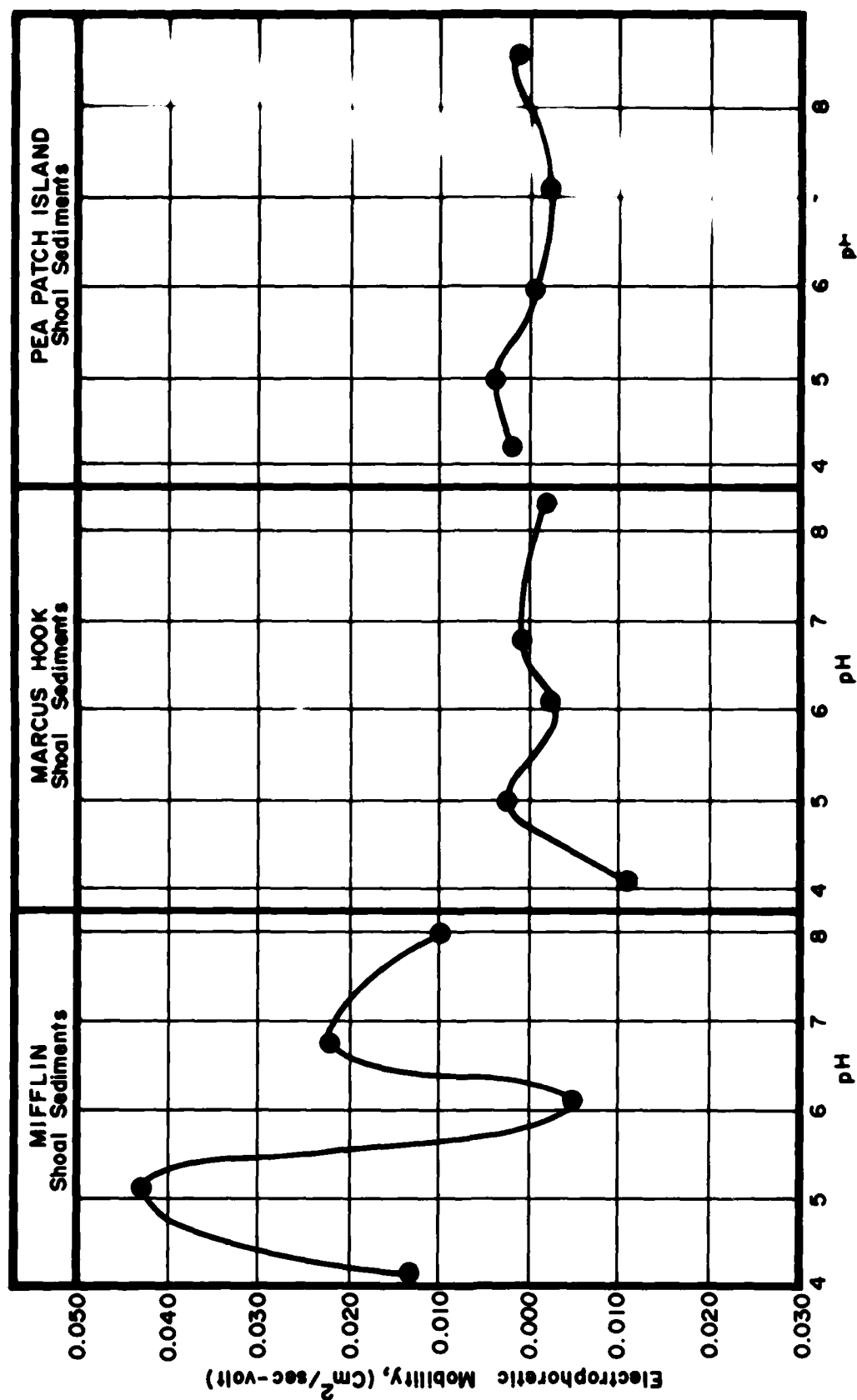
FIGURE 43. Electrophoretic mobility versus pH of silt and clay size materials (-74 microns) in major shoal areas of Delaware River. Samples obtained in March 1972
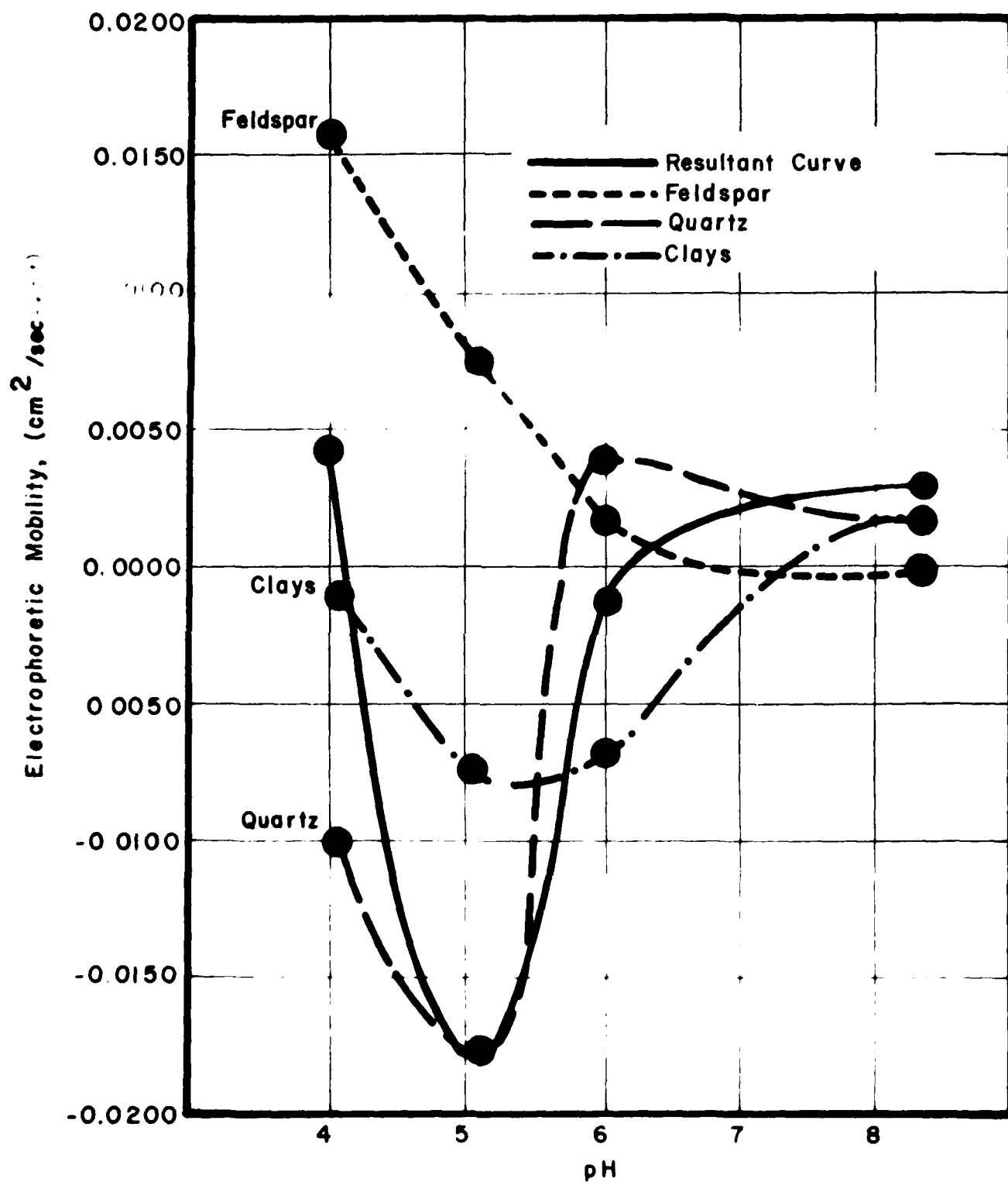
FIGURE 44 Electrophoretic mobility versus pH for minus 74 micron size materials from Marcus Hook shoal Obtained 2 March 1972

TABLE 18
ELECTROPHORETIC MOBILITY MEASUREMENTS AT VARIOUS pH VALUES FOR PROTOTYPE MARCUS HOOK SHOAL SEDIMENT (MINUS 74 MICRON SIZE) AND ARTIFICAL SAMPLES OF DIATOMS, CHLORITE, AND ILLITE

CALCULATED ELECTROPHORETIC MOBILITY VALUES OF PROTOTYPE QUARTZ, FELDSPAR, AND CLAYS IN MARCUS HOOK SHOAL SEDIMENT

Sample	pH	V_E (cm². sec. volt)		
		Quartz	Feldspar	Clays
MH 4	4.09	−0.0102	+0.0155	−0.0011
MH 5	5.10	−0.0180	+0.0075	−0.0075
MH 6	6.02	+0.0038	+0.0017	−0.0065
MH 7	6.74	+0.0046	−0.0007	−0.0020
MH 8	8.32	+0.0017	−0.0002	+0.0015

DATA FOR CHLORITE, ILLITE AND DIATOMS SAMPLES

Sample	pH	Ohms				λ	CM/V.sec
Chlorite	4.16	139.6	.002				
	4.98	416.7	.002	300			
	5.75	530.1	.002	300	·		
	6.85	321.8	.002	300	−	−0.2961	−0.0013
Illite	3.85	645.0	.002	300	+	+0.0983	−0.0003
	4.92	683.5	.002	300	+	+0.1783	−0.0006
	5.81	937.3	.002	300	+	+0.1570	−0.0004
	7.11	175.8	.002	300	+	+0.2921	−0.0004
	8.02	282.2	.002	300	+	+0.6406	−0.0005
Diatoms	4.00	559.5	.002	300	·	+0.3034	−0.0014
	5.25	529.9	.002	300	·	+0.3107	−0.0015
	6.18	455.5	.002	300	−	+0.1745	+0.0013
	7.48	471.0	.002	300	·	+0.2880	−0.0015
	8.28	571.8	.002	300	·	+0.2182	−0.0012

materials such as soaps, fatty acids, and hydrocarbons and/or inorganic salts such as ferric iron.

Electrophoretic mobility measurements of artificially prepared diatoms, illite, and chlorite at various pH values is depicted in Figure 45. From these curves the role of chlorite appears to be identified as a substantial contribution to the clay curve shown in Figure 44. Illite is relatively unresponsive to changes in pH for the range considered. It is difficult to assess the contribution of diatoms to the quartz curve, although some correspondence may be found at pH values of 4 to 6.

According to Munoz (1972), the characteristics of the electrophoretic curve for the Marcus Hook sediments seems to be due to surface films on mineral surfaces. Gaudin (1957) has demonstrated that iron, copper, lead, and calcium ions absorb on quartz surfaces and other materials making these surfaces responsive to flotation by soaps and fatty acids. Aplan and Fuerstenau (1962) have studied the surface properties of goethite and found zero point of ···· at pH 6.7. At lower pH values the elect- ··· ··········· are positive and at ···· ··· are negative. ·········· ··· ···· stated that proteins ··· charged sols, sensitize and even floc····· ··· oppositely charged sols at pHs different from their isoelectric points. Linderstrom and Nielson (1959) have also demonstrated by electrophoretic mobility data that most proteins are positively charged at acid pHs and negatively charged at basic pHs. It is, therefore, conceivable that a negative particle (such as quartz at pH 4 to 6) which is not coated with positive ions, will absorb positive proteinaceous material. Other organic substances, such as fatty acids, sulphonates and other polar compounds are surface active and will help flocculate particles which are

coated with positive ions, such iron oxide, if the charge of the organic material is negative at that pH. Gaudin (1962) has demonstrated that even bacteria and spores have definite charge in aqueous solutions; a negative charge occurs on spores of *Bacillus subtilis* at pH 5.0. The above information suggests that the combined action of proteinaceous materials, on negative surfaces such as quartz at a pH range of 4 to 6, and iron hydroxide or quartz and other silicates at the same range which are acted upon by fatty acids, sulfonates, and other negatively charged organics are the contributors to the flocculation state of the sediment.

ELECTRON MICROPROBE AND ELECTRON DIFFRACTION ANALYSIS

X-ray fluorescence of Marcus Hook shoal sediment by the microprobe reveals that while silicon is predominant in all areas, there is also appreciable iron (see Figure 46). Since iron is but a fraction of the volume, it is apparent that the iron occurs as thin films on the quartz particles. Electron diffraction analysis of these thin films reveal a composition of ferric oxide which occurs predominantly as gamma Fe_2O_3 (lepidocrocite) and some alpha Fe_2O_3, $3H_2O$ (goethite). Such hydrous iron oxides have a zero point of charge at pH 6.7 which is very near that shown in 1··· ·· ·· for Marcus Hook sediment.

IRON ···· · ON DIATOMS

The occurence of hydrous iron oxide occurs as coatings on the surfaces of some of the diatoms between 20 and 44 micron size from Marcus Hook shoal. As shown in Figure 47, the hydrous iron oxide coating on the diatoms is thick enough to cause these particles to occur in the heavy mineral fraction. Treatment of the heavily coated, opaque, disc-shaped particles with strong HCl dissolves the iron oxide and

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LEGEND
——— DIATOMS
—·—·— ILLITE
------- CHLORITE
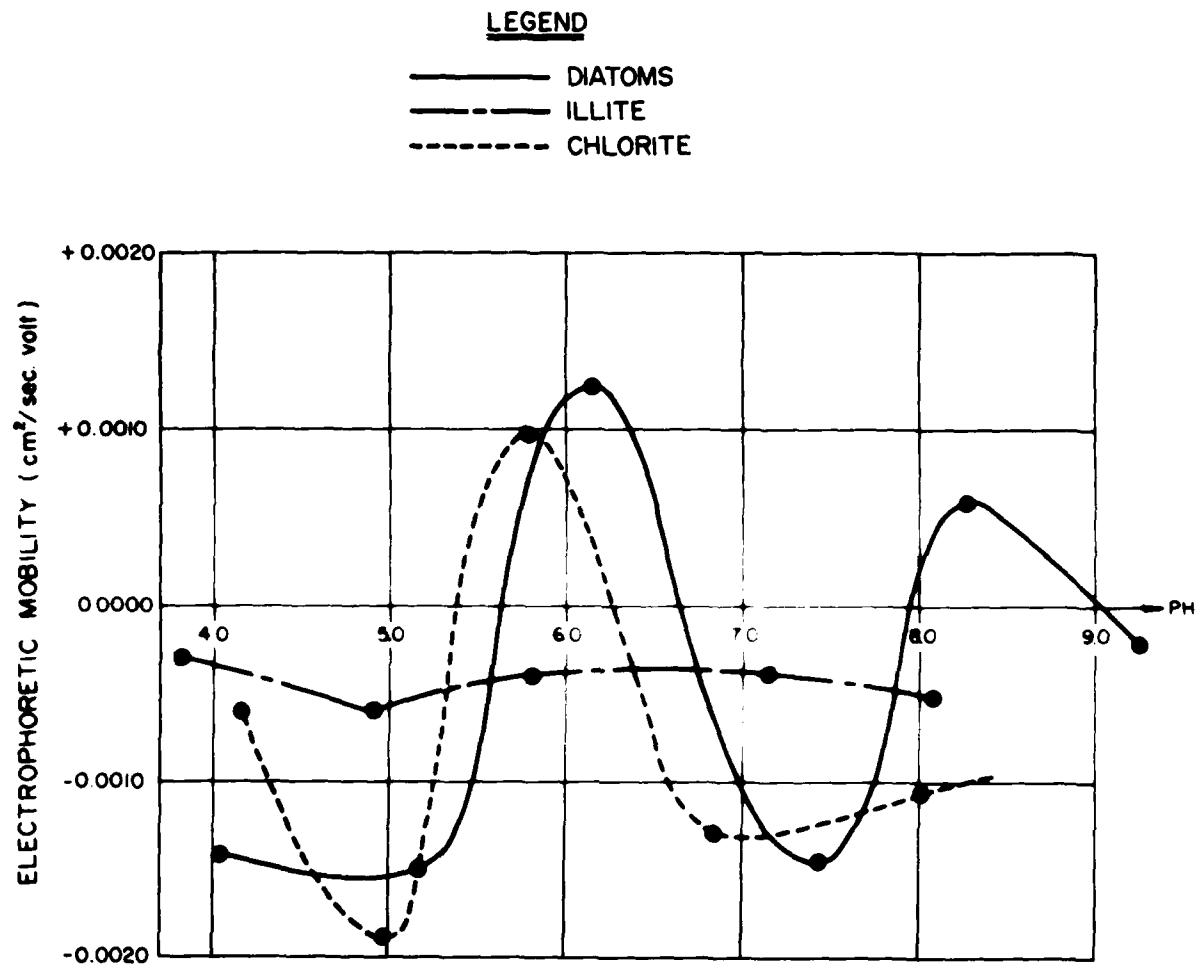
FIGURE 45 ELECTROPHORETIC MOBILITY VERSU... ...PLES
     SAMPLES
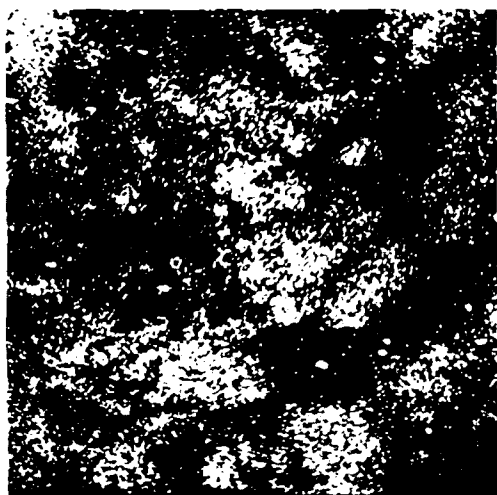
Electron Microprobe (280 x)
silicon
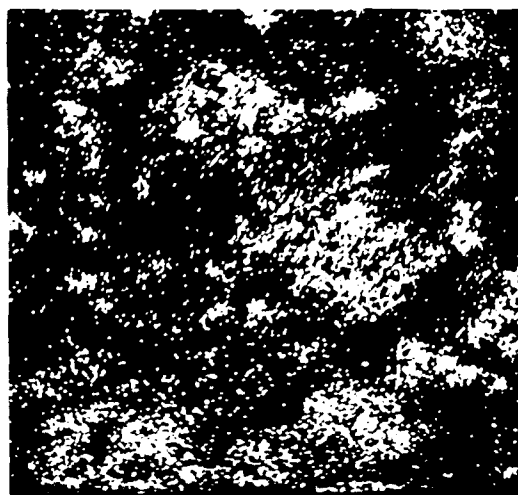
Electron Microprobe (280 x)
iron
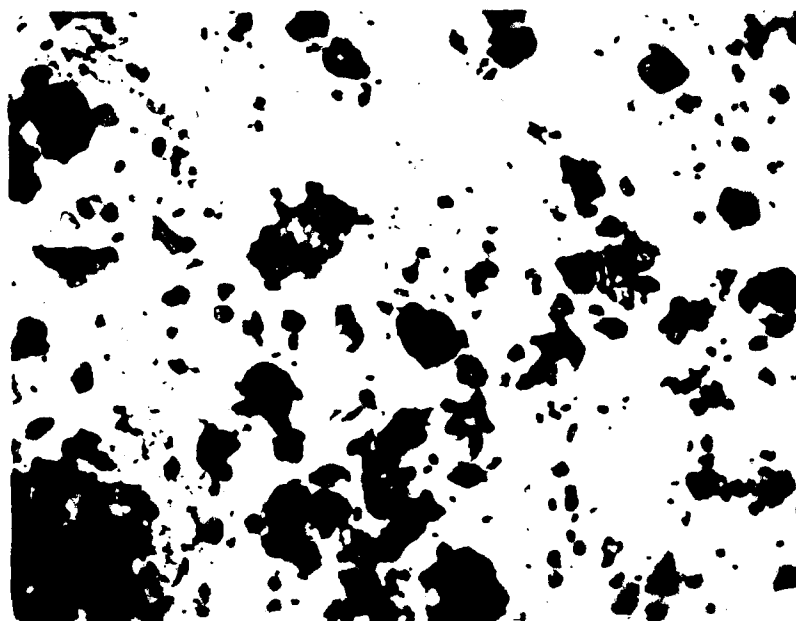
Photomicrograph (200 x) of particles
from Marcus Hook Shoal

Figure 46. Si and Fe Electron Microprobe and Microphotographs
of Marcus Hook Sediment.
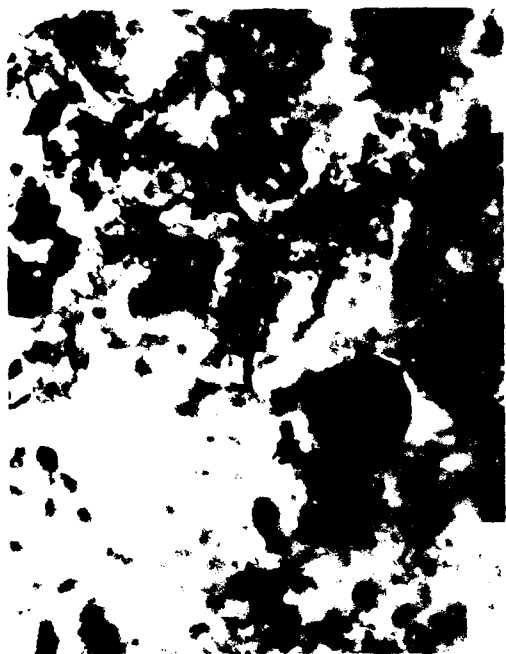
Non-treated Heavy Mineral Fraction (−44 + 20μ)   HCl−treated Heavy Mineral Fraction (−44+20μ)

Figure 47. Photomicrographs of dispersed and flocculated sediment in the minus 10 micron fraction at Marcus Hook shoal and comparison of heavy mineral fractions in upper silt-size showing iron oxide impregnation of the diatom Coscinodiscus sp. (lower left) and removal of iron oxide by acid leach (lower right).

reveals the disc-shaped particle as the more abundant *(Consinodiscus sp.)* diatom variety occurring in the shoal.

Chemical analysis of the silt fraction (+2 micron size) and clay fraction (-2 micron size) of Marcus Hook sediment by the dithionite iron method reveals respectively 3.61 percent Fe_2O_3 and 4.67 percent Fe_2O_3. Similar size fractions for Mifflin and Pea Patch Island shoals are respectively 2.38 and 4.33 percent Fe_2O_3 and 2.28 and 4.13 percent Fe_2O_3. Thus, it is apparent that the hydrous iron oxide increases with decreasing sieve size. Particles greater than 74 micron size contain 3.07 percent Fe_2O_3 at Marcus Hook shoal, 1.41 percent Fe_2O_3 at Mifflin shoal, and 1.79 percent Fe_2O_3 at Pea Patch Island shoal; such occurence is in the main as coatings on the particles with Marcus Hook particles containing nearly double that found in other shoal areas.

IRON OXIDE AND HEAVY METAL ASSOCIATION

Heavy metal analysis of the dithionite iron method leachates reveals that from a quarter to a total of the heavy metals known to occur in the entire samples is contained in these leachates. Nearly all the mercury, zinc, and chromium occur in the leachates while lesser amounts of lead, copper, and nickel are associated with this leachate. From the foregoing, it is strongly suggested that the amorphous iron scavengers the heavy metals to a strong degree. Marcus Hook sediment containing the greater concentration of amorphous hydrous iron oxide also contains a higher concentration of heavy metals than the other shoal sediments. Organic matter and possibly clay minerals probably concentrate the rest of the heavy metals.

The role of hydrous iron oxide appears especially important in the flocculation process of Marcus Hook shoal. The "flocs" are aggregates of finer particles of silt-size which move together at zero electrophoretic mobility and consists of clay, organics, and hydrous ferric oxide coated particles held together by cohesive forces. The iron oxide, by altering the electrophoretic mobility of quartz, one of the most abundant materials in the estuary, may be instrumental along with other coating in bringing about the formation of flocs.

SOURCE OF SEDIMENTS IN DELAWARE ESTUARY

INTRODUCTION

The Delaware River from the confluence of the Schuylkill River to Pea Patch Island is experiencing extensive shoaling with the maximum shoaling rate occuring in the Marcus Hook Range. The sources of the sediments in the shoals can be shown to be from the upland watershed and from mans' activities. Virtually none of the entrapped sediment in the river estuary is from the bay as shown by diatom evaluations and detailed clay mineral analysis.

The lower bay area has experienced extensive sedimentation from the sea ward direction. Contributing source areas appear to be the New Jersey coast and Delaware coast readily delineated by their heavy mineral suite and textural parameters. Unlike the river estuary trapping fine grained silt and clay, the lower bay is receiving sand-size sediment from the high energy zones experienced in the coastal areas.

Sediments brought into the bay in the vicinity of Cape May and Cape Henlopen are mixed with the bay sediments and strong currents in the deep channel probably sweeps the sediments seaward in a southeasterly direction along the Delaware submarine channel onto the continental shelf. It is also apparent in the embayed portion of the estuary that wave action is winnowing fines from the central bay area and depositing the fines in the shallower bay margins.

DELAWARE RIVER SHOALS

An approximation of the tons of sediment deposited annually in the 3 major shoal areas of Delaware River in relation to the source area is presented in Table 19. In the evaluation of source areas, it is assumed that, depending on the specific shoal area, between 15 and 30 percent of the shoal material is biogenous matter and precipitated industrial effluents. The remainder of the shoal sediment (70 to 85 percent) is from upland discharge and consists of sand, silt, clay, organic vegetation, and anthracite coal.

In an earlier section it was shown that, based on sediment discharge data (U. S. Geological Survey, Water Resources Data Report, 1969, and U.S. Army Corps of Engineers Data, 1969) and the composition analysis of suspended samples from streams that approximately 47,700 tons of chlorite and 34,-500 tons of kaolinite were delivered annually to

Marcus Hook shoal. This ratio of chlorite to kaolinite was found to be relatively similar to that found in analysis of 257 suspended sediment samples during the 23 July 1969 tidal cycle and thus providing corroborative evidence that the clay is from the upland watershed rather than from a seaward direction. The kaolinite is more abundant than chlorite in Piedmont source streams whereas chlorite tends to dominate over kaolinite in Coastal Plain streams tributary to the Delaware Estuary. In Delaware Bay, chlorite is more abundant than kaolinite from all the streams since Coastal Plain formations rim the bay; bottom sediments also reflect this dominance of chlorite over kaolinite in the bay area. The chlorite to kaolinite ratio in bottom and suspended sediment is a parameter useful in relating the sediments to their source areas. Thus the similarity of Marcus Hook shoal sediments to that of the upland watershed and the marked difference existing seaward of mile 49 at the null point is in strong support of the view that virtually none of the shoaling material is from the bay or Atlantic ocean.

Since amorphous hydrous iron, organic matter from sewage, and diatoms are local occurrences in proximity to the shoaling area, estimates of annual contributions are based on the known annual shoaling rate determined from U. S. Army Corps of Engineers, Philadelphia District, dredging records times the weight percent of that material found in the shoal.

Example: Diatoms in Marcus Hook Shoal from Estuary Source

$$\text{Annual Marcus Hook shoal rate (tons/yr)} \times \text{Weight \% diatoms} = \text{Annual diatoms in Marcus Hook (tons/yr)}$$

Estimates are listed in Table 19 for each of the major shoaling areas.

The source of anthracite coal is listed as the Schuylkill River for all shoal locations since

this material has a point source from the anthracite coal fields drained by the Schuylkill River.

The heavy minerals have been cited pre-

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TABLE 19
ANNUAL TONS OF SEDIMENT TO MAJOR SHOALS IN DELAWARE RIVER FROM SOURCE AREAS

Constituent	Fort Mifflin	Marcus Hook	Pea Patch Is.	Source
Quartz	269,800	246,000	264,700	Watershed; silt size largely from Pleistocene rock flour.
Feldspar	50,400	141,600	59,500	Watershed; sand size 6X greater from Piedmont; silt size from Pleistocene rock flour.
Mica	2,700	1,000	6,700	Watershed; largely from Piedmont source in Pea Patch Island Shoal.
Heavy Minerals	1,600	1,000	5,600	Watershed; hornblende and garnet largely from Piedmont source
Organic Matter	31,300	80,300	15,900	Watershed; Sewage, Industry and Eutrophication effects in estuary.
Anthracite Coal	29,700	54,200	15,400	Anthracite Coal Fields in Schuylkill River Watershed.
Diatoms	48,900	180,700	61,600	Predominantly estuary source and a result of eutrophication.
Amorphous Iron Oxide	7,400	31,100	9,200	Marcus Hook source largely from industry; watershed predominant in other shoals.
Clay Minerals				
Illite	46,700	161,700	36,400	Watershed clay mineral.
Chlorite	22,000	47,700	14,600	Watershed clay mineral.
Kaolinite	13,200	34,500	18,200	Watershed predominant Piedmont source.
Montmorillonite	6,200	21,200	3,600	Watershed clay mineral.
Miscellaneous	1,100	3,000	1,500	Watershed
TOTALS TONS/YEAR	531,000	1,004,000	513,000	

viously with 5 times as many heavy minerals, rich in garnet and hornblende, from a Piedmont fluvial source as compared to the Coastal Plain streams for the same length of river estuary.

In this analysis, it is concluded that there is essentially insignificant material from the seaward direction; diatom species are especially significant to this conclusion as cited earlier.

DELAWARE BAY DEPOSITS

It has been effectively demonstrated by hydrodynamic evaluations and historic surveys as well as heavy mineral data that marine sand is invading the lower embayed portion of the estuary. As cited earlier, Fairchild (1966) has estimated from U. S. Army, Corps of Engineers data that 200,000 cubic yards of sediment per year from the eroding southern New Jersey coast and shelf is being transported in a southwesterly direction around the capes into the lower bay and on the shoals off Cape May while, Turner (1968), has estimated that northward longshore transport from the Delaware coast around Cape Henlopen is 450,000 cubic yards per year. This investigation tends to agree with the observa-

tions and estimates but has also demonstrated that (a) mixing of sediments does not take place across the capes and (b) sediment tends to leave the bay by the Delaware submarine channel. The sediment movement into the bay in close proximity to the capes has been demonstrated by several investigators and corroborative evidence exists in heavy mineral dispersal patterns delineated in this investigation. Feldspar distribution patterns, heavy-mineral dispersal patterns, and hydrodynamic evaluations through the water column in vicinity of the capes indicate that sediment drift is seaward along the Delaware submarine channel. Oostdam (1971) may have demonstrated this in showing that there is a net seaward flux of suspended sediments in vicinity of the capes (2.9 to 10.1 x 10^9 Kgs/yr).

SUMMARY AND CONCLUSIONS

Analysis of 140 bottom sediment samples and more than 300 suspended samples from tributary streams, the Delaware estuary and the continental shelf in vicinity of the capes has been made in order to determine the mechanisms effecting deposition and to evaluate the probable sources of the shoal materials. The suspended solids from the watershed, diatom production, industrial and municipal pollutants are trapped within the estuary. Approximately 40 percent of these suspended solids are deposited in Marcus Hook Range which is situated at the vicinity of mean salinity intrusion into the estuary. The materials comprising Marcus Hook are predominantly silts and clays with unusually high concentrations of biogenous matter, clay, and toxic materials than exist in the other shoals.

Analysis of upland discharge materials reveals differences in clay minerals from the Piedmont and Coastal Plain source streams with kaolinite ratios higher in the former and chlorite

in the latter source areas. An evaluation of the clay minerals in 257 samples taken at various depths through the water column for a complete tidal cycle on 23 July, 1969 shows an assemblage compatable with contributions measured from suspended samples discharging into the Delaware River between Trenton and the bay. Anthracite coal has a point source from the Schuylkill River as delineated by dispersal patterns. Diatoms reach peak values in the Marcus Hook shoal area and examination of species from this shoal and contrasting freshwater and marine environments reveals a diatom suite unique to the river estuary which is compatible with pollution conditions in this portion of the estuary. The high proteinaceous content of the organic matter reflects major sewage contributions in local shoals. Amorphous iron oxides and heavy metal concentrations are also associated with major shoal sites. Net transport of sand-size sediment is reflected by heavy mineral distribution patterns; this is especially diagnostic to

sediment transport directions reflected by sillimanite dispersal in vicinity of the capes where sediment is being actively transported into the lower bay margins while seaward transport appears apparent via the Delaware submarine channel carved during the Pleistocene. Feldspar distribution reflects similar dispersal as diagnostic sillimanite for Delaware Bay source sediments.

Source area representation of materials in Marcus Hook shoal based on current shoaling rates is summarized below. The materials in Marcus Hook shoal are especially unique in being finer in texture than the other shoals with a median diameter of 6 microns and only a few percent ranging up to fine sand size. This shoal is unique in that electrophoretic mobility measurement indicate that flocculation is the dominant process and analysis of thin films coating silt particles suggest that iron oxide and organic matter may be as influential as the cations from seawater incident with the salinity intrusion to this point.

1. Quartz and feldspar of silt-size constitute respectively 24.5 percent and 14.1 percent of the sediment and are largely derived from Pleistocene deposits in the watershed. The pulverizing action of the continental glacier, incident to the region during the Pleistocene, resulted in generation of rock flour which is available from "blanket" deposits overlying older geologic formations in the watersheds.

2. Clay minerals constitute 26.4 percent of the shoal and fractional amounts include 61 percent illite, 18 percent chlorite, 13 percent kaolinite, and 8 percent montmorillonite. These materials are generated in the main by weathering processes in the watershed.

While illite is more evenly represented in all source areas, kaolinite and chlorite were found to vary in relation to source regions. Streams draining the Coastal Plain between Trenton and Marcus Hook shoal contain sediment with 1.0 parts kaolinite to every 1.5 parts chlorite, whereas, Piedmont source streams contain 1.0 parts chlorite to every 1.5 parts kaolinite. The sediments above Trenton contain 1.0 parts kaolinite to every 1.3 parts chlorite. Thus the kaolinite to chlorite content of the shoal is influnced by the Piedmont source kaolinite from the relatively Pleistocene-free surfaces between Trenton and Marcus Hook as observed in the kaolinite representation of the shoal. It was also found that the chlorite kaolinite ratio for 257 suspended samples taken during the tidal cycle of 23 July 1969 at Marcus Hook averages 1.4 which is in fair agreement with the 1.3 ratio from the watershed discharge.

3. Diatom tests of amorphous opaline composition comprise about 18 percent of Marcus Hook shoal. Study of the diatom species reveal that they are predominantly brackish water varieties that occur in the estuary and the siliceous frusticles are deposited with the sediment after the diatom dies. The presence of such large amounts of diatoms in the estuary as compared to but a few percent found in the bay sediment is attributed to eutrophication conditions of the estuary. Analysis of historic dredge spoil from Marcus Hook area between 1946 and 1962 for diatoms reveals nearly 45 percent less than contemporary dredge spoil samples. Man's

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increased sewage and industrial waste discharge to the estuary may have doubled the quantity of diatoms to this shoaling site since the last decade although the distinct possibility exists that improved dredging methods may be responsible for the apparent increase in diatom quantities.

4. Organic matter in Marcus Hook shoal averages 8 percent and includes all amorphous organic compounds except anthracite coal. The major portion of this material is believed to be finely divided sewage since DTA analysis discloses that most of this material is less than 10 micron size and chemical analysis of the solvent extractable organic material is shown to be largely proteinaceous matter. The strongly polluted condition of the estuarine waters, as evident by high pathogen content and dissolved oxygen in amounts less than 2 ppm, also supports the view that material otherwise capable of being oxidized or assimulated by natural processes in the river is being retained and deposited in the bottom sediment.

5. Anthracite coal constitutes 5.4 percent of the shoal from a source encompassing the anthracite coal fields of the Schuylkill River Watershed. Studies in the lower Schuylkill River, as part of this investigation, indicate a 43 percent reduction of coal in the Schuylkill River sediments since pollution control measures were initiated in 1952. While the source of this anthracite coal must be listed as a consequence of man's activities, it is also an example of effective control in the decrease of pollution in this estuary.

6. Amorphous hydrous iron oxide comprises 3.1 percent of the Marcus Hook shoal material. The amorphous hydrous iron oxide, determined by the sodium dithionite method, does not include the iron in high temperature oxides, clay minerals, or ferromagnesian silicates; the values obtained thus reflect only low temperature sedimentary iron and that precipitated as ferric hydroxide from acid effluent discharge. Half of this iron accumulation is attributed to industry if the 1.8 percent found in the lower Schuylkill River is taken as a maximum watershed accumulation value; this river drains a watershed containing Triassic red beds as well as receiving runoff from coal fields in which pyrite is oxidized to the amorphous hydrous iron oxide. The greater amorphous hydrous oxide occurrence at Marcus Hook than in other shoal areas is of special interest since electrophoretic mobility measurements and electron microprobe studies indicate that particle surfaces contain thin films of this iron and thereby give the particles a more favorable electrophoretic value for flocculation.

7. Other sediments in Marcus Hook shoal consists of detrital heavy minerals, mica, slag, calcite, phosphate, heavy metals, insecticides and minor others. The heavy minerals of sand size contain 36 percent hornblende and 16 percent garnet in the transparent fraction and reflect a strong fluvial Piedmont source since these streams carry abundant hornblende and garnet derived from the crystalline gneiss and schist of the area. Highest phosphorus values ap-

pear in Marcus Hook shoal as a result of diatom accumulations and impoundment of sewage from nearby Philadelphia. Slag is of minor occurrence and represents industrial detritus. The heavy metals and DDT, although relatively insignificant in volume representation of the shoal, are important to environmental considerations because of their toxic qualities and Marcus Hook shoal represents the largest concentration of these materials in the estuary.

The Fort Mifflin and Pea Patch Island shoals are considerably smaller than Marcus Hook shoal with annual sediment to the shoals respectively 531,000 and 513,000 tons. The flocculation process is less evident in these shoals and the average grain size is larger with appreciable sand fractions; median diameters for Fort Mifflin and Pea Patch Island shoals are respectively 50 and 80 microns; Marcus Hook shoal material has a median diameter of 6 microns and but 2 percent sand fraction. Differences in proportional amounts of materials in these shoals as compared to Marcus Hook is mainly a function of grain size but for some biogenous materials it is also a function of distance from the source and the polluted nature of the estuary. Relative differences to Marcus Hook is summarized as follows:

1. Quartz is proportionally twice as abundant in these shoal areas than at Marcus Hook shoal mainly as a function of grain size; quartz in the sand fraction ranges between 80 and 95 percent. Feldspar, on the other hand, is approximately 20 percent less represented in Pea Patch Island shoal and 30 percent less in Fort Mifflin shoal than in Marcus Hook shoal; this proportional increase at Marcus

Hook shoal is attributed to the local input of feldspar rich sediment from Chester Creek and the fact that feldspar is higher in the glacially derived silt-size sediments.

2. Clay minerals are relatively twice as abundant at Marcus Hook than at Pea Patch or Fort Mifflin shoals because of grain size differences cited and the favorable physiochemical and hydraulic conditions existing at Marcus Hook that favor flocculation as a shoaling mechanism.

3. Anthracite coal has a dispersal from the Schuylkill River source area with least representation in Pea Patch Island shoal. Approximately 29,700 tons are deposited annually in Fort Mifflin shoal and 15,400 tons annually in Pea Patch Island shoal.

4. Organic matter at Fort Mifflin and Pea Patch Island shoals is respectively 5.9 and 3.1 percent of the shoal as compared to 8.0 percent at Marcus Hook shoal and the nature of the organic matter stands in sharp contrast. Fort Mifflin shoal has the highest "fatty acid" content attributed to the highest proportion of raw sewage from the Philadelphia sewage outfalls in close proximity. Polluted conditions of the estuary as measured by dissolved oxygen and fecal coliform content and reflected in Eh values, extend beyond Marcus Hook shoal and thus both Fort Mifflin and Marcus Hook shoals contain appreciable undigested "organic detritus" from sewage. At Pea Patch Island shoal the organic accumulation is observed as mainly vegetation from marshes along the

banks of this more seaward portion of the estuary; the vegetation is easily observed because of its larger size.

5. Diatoms at Fort Mifflin and Pea Patch Island shoals are respectively 48 and 30 percent proportionally less in the sediment than the high at Marcus Hook shoal. Maximum representation at Marcus Hook shoal is attributed to grain size, proximity to sewage outfalls, and hydrodynamic factors effecting deposition.

6. Iron oxide at Fort Mifflin and Pea Patch Island shoal is generally half as concentrated as at Marcus Hook shoal. This appears related to proximity to source as well as physiochemical factors favoring flocculation at this site.

7. Heavy metal concentration is generally associated with the scavagening effect that iron oxide has on these materials and it is not surprising therefore that highest concentrations are generally found in Marcus Hook shoal. Some exceptions, related to proximity to source, include the following:

    (a) Highest lead values in excess of 300 ppm occur in Schuylkill River bottom sediment.

    (b) Zinc values in excess of 1000 ppm occur in Schuylkill and Christina Rivers. A dispersal pattern to a "point" source in Christina River is found in suspended samples of the water column.

    (c) Mercury ranges up to 5 ppm in bottom sediment nearest Pea Patch Island shoal but values of 3 and 4 ppm are widespread in the estuary.

The suspended load in the Delaware estuary generally averages about 45 ppm with volatile matter, largely organic, averaging about 25 ppm. At Marcus Hook shoaling area, measurements at hourly intervals through the water column during a complete tidal cycle on 23 July 1969 discloses an average suspended sediment load of 30 ppm near the surface and an average suspended load of 93 ppm in the lower level of the water column. Proportional representation of the silt and clay fraction of 257 samples was similar in proportion and fractional values to that found in the shoal. Actual control of organic matter and other x-ray amorphous materials are lacking from this investigation because of the amount of sample required for analysis. Future studies of the water column should include large freeze dried samples of the upper and lower layers of the water column during phases of the tidal cycle and in relation with upland discharge to ascertain the role of dissolved effluents and sewage that become impounded in the sediment from local source areas and are the function of mans' activities. Evaluations of nitrogen and phosphorus has demonstrated variations in relation to distance from sewage outfalls and discharge variations from the watershed; preliminary studies indicate that eutrophication is occurring as a result of sewage and is responsible for excessive diatom populations found in the river estuary.

Long term net transport direction of sand-size sediment from source areas in the watershed and from the continental shelf area has been established in the Delaware estuary by delineation of four heavy mineral provinces as follows:

1. A fluvial Piedmont source exists in the upper river estuary characterized by a

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hornblende-garnet heavy-mineral suite extending along the river estuary to mile 49. The Piedmont source area between Trenton and the bay is relatively free of Pleistocene blanket deposits and contributes a volume of transparent heavy minerals 5 times as great as the Coastal Plain streams discharging for the same linear distance along the river estuary. The Piedmont streams drain crystalline rocks (schists and gneiss) rich in garnet and hornblende and control points from Trenton to the bay show the steady increase in these minerals toward the bay. Coastal Plain streams impoverished in these minerals are not in control because of their smaller contributions.

2. The upper and central bay areas is characterized by "full" heavy mineral suite i.e. heavy-minerals of all stability ranges and abundant sillimanite. Sillimanite is in similar proportions in this heavy-mineral suite of mixed Coastal Plain and Piedmont source materials and thus maintains a similar value while less resistant Piedmont minerals (hornblende and garnet) are somewhat reduced in value as are likewise the stable minerals (zircon, rutile, and tourmaline) of the Coastal Plain formations. The "Delaware Bay" heavy mineral province extends the full length of the western bay area. The main source around the bay appears to be Pleistocene formations and local other Coastal Plain formations. A recent investigation of 7 bottom samples in the southwest corner of Delaware Bay for heavy minerals by Strom (1972) provides corroborative evidence for including this southwestern bay

area in the "Delaware Bay" heavy mineral province. The shelf and coastal area of Delaware is also part of this heavy mineral province (see Figure 27).

3. The lower east and central bay area contains a heavy-mineral suite of mixed "Delaware Bay" and glacially-derived continental shelf sands. Sillimanite in this mixed suite ranges from 4 to 8 percent and pyroxene attains highest values (4 percent) of the bay area. This heavy mineral province is the smallest province delineated and is actually a "mixed" province existing between the Delaware Bay province and the glacially derived continental shelf heavy mineral province off the New Jersey coast (see Figure 27). This zone is five miles wide with the Delaware submarine channel the southern boundary and the landward boundary nearly 10 miles into the lower bay area.

4. The continental shelf and coastal area off New Jersey contains a heavy-mineral suite relatively impoverished in sillimanite and enriched in pyroxene as compared to the Delaware Bay heavy-mineral province. The sillimanite is generally less than 4 percent and pyroxenes generally average 8 percent; other heavy minerals are similar to the heavy mineral provinces. This heavy mineral suite is from glacially derived sediments and eroding coast transported in a southerly direction to vicinity of Cape May. In vicinity of Cape May some of the sediment is transported into the bay and some deposited on the shoals fronting the capes.

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The hydrodynamic currents and sediment drift is from the shelf into the bay from the New Jersey coast around Cape May and from the shelf into the bay from the Delaware coast around Cape Henlopen. Feldspar distribution along Pleistocene surfaces and heavy mineral provinces provide corroborative evidence of the foregoing and in addition indicated that net transport is seaward along the Delaware submarine channel and the western side of the bay to the shelf area and thence south toward the Maryland coast and shelf area.

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GLOSSARY

Technical terms not in ordinary use, and words used in the report in a special sense, are defined below. Definitions used are in part from the current American Geologic Institute glossary of geology and related sciences, glossary of coastal engineering terms (Allen, 1972), and American Public Health Association (1965), as well as other current texts in specialized areas used in this study.

AMORPHOUS MATERIALS—Materials without definite crystalline structure.

AMPHIBOLE—A mineral group of the common rock forming minerals. Includes hornblende, tremolite and actinolite which also occurs as detrital heavy minerals in sediment.

ANTHRACITE COAL—A compact, dense coal with viterous to submetallic luster, hardness of 2 to 2.5, specific gravity 1.4 to 1.8, with fixed carbon content varying between 80 to 90 percent.

ATOMIC ABSORPTION—Chemical technique capable of detecting metals in sensitivity ranges of 1 ppm.

AUGITE—A green mineral of the pyroxene group common in basic igneous rock and occurring in sediment. This is one of the less resistant heavy minerals.

BATHYMETRY—The measurement of depths of water in oceans, seas, and lakes; also information derived from such measurements.

BAY — A recess in the shore or an inlet of a sea between two capes or headlands, not as large as a gulf but larger than a cove.

BIGHT(coastal)—A long, gradual bend or gentle curve, or a slight, crescent-shaped indentation, in the shoreline of an open coast or of a bay; it may be larger than a bay, or it may be a segment of or a feature smaller than a bay.

BIOGENOUS—A term referring to materials formed by organic processes.

BUFFER—A substance which tends to resist changes in pH of a solution.

CANAL—A artificial watercourse cut through a land area for such uses as navigation and irrigation.

CAPE—A relatively extensive land area jutting seaward from a continent or large island which prominently marks a change in, or interrupts notably the coastal trend; a prominent feature.

CATION EXCHANGE CAPACITY—The property of exchange capacity in clays measured in terms of milliequivalents per 100 g.

CHANNEL—(1) A natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water. (2) The part of a body of water deep enough to be used for navigation through an area otherwise too shallow for navigation. (3) A large strait, as the English Channel. (4) The deepest part of a stream, bay or strait through which the main volume or current of water flows.

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CHLORITE GROUP—A term used for a group of platy hydrous silicates of aluminum, ferrous iron, and magnesium which are closely related to the micas. Generally of greenish color, they are common in low-grade metamorphic rocks and occur both as a detrital heavy mineral and clay-mineral.

CHLORITOID—A dark-green, brittle mica found in metamorphic rock and sometimes occurring as a detrital heavy mineral.

CLAY—As a textural term denotes material *finer than two micron size.*

CLAY MINERAL—The clay minerals are finely crystalline hydrous silicates with a *crystal structure of the two-layer type* (kaolinite) or three layer type (montmorillonite) in which silicon and aluminum ions have tetrahedral coordination with respect to oxygen while aluminum, ferrous and ferric iron, magnesium, chromium, lithium, manganese and other ions have octahedral coordination with respect to oxygen or hydroxyl. Exchangeable cations may be on the surfaces of the silicate layers, in an amount determined by the excess negative charge within the composite layer. These cations usually are calcium and sodium but may also be potassium, magnesium, hydrogen, etc. The most common clays belong to the kaolinite, illite, montmorillonite, and attapulgite groups.

CLAY SIZE—Material finer than 2 micron size.

COAST—A strip of land of indefinite width (may be several miles) that extends from the shoreline inland to the first major change in terrain features.

COASTAL AREA—The land and sea area bordering the shoreline.

COASTAL PLAIN—The plain composed of horizontal or gently sloping strata of clastic materials fronting the coast, and generally representing a strip of sea bottom that has emerged from the sea in recent geologic time.

COASTLINE—(1) Technically, the line that forms the boundary between the COAST and the SHORE. (2) Commonly, the line that forms the boundary between the land and the water.

COLIFORM GROUP—Predominant bacteria in sewage and river water.

CONTINENTAL SHELF—The zone bordering a continent and extending from the low water line to the depth (usually about 100 fathoms) where there is a marked or rather steep descent toward a greater depth.

CULM—A vernacular term variously applied, according to the locality to carbonaceous shales, or to fissile varieties of anthracite coal.

CURRENT, LITTORAL—Any inshore current landward of the breaker zone and in the littoral zone caused primarily by wave action, e.g., longshore current, rip current.

CURRENT LONGSHORE—The littoral current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

DEPTH—The vertical distance from a specified tidal datum to the sea floor.

DETRITAL—Same as clastic. Material derived from pre-existing igneous, sedimentary, or metamorphic rock.

DETRITUS—Matter worn from rocks by mechanical means.

DIATOM—A microscopic plant (one of the algae) that secretes a siliceous skeleton or test.

DISSOLVED OXYGEN—The amount of oxygen dissolved in water.

DISSOLVED SOLIDS—See salinity

DITHIONITE METHOD—Chemical method for determining the low temperature iron including the hydrous amorphous varieties.

DOWNDRIFT—The direction of predominant movement of littoral materials.

DTA—Abbreviation for differential thermal analysis.

EBB CURRENT—The tidal current in a seaward direction usually associated with the decrease in the height of the tide.

EBB TIDE—The period of tide between high water and the succeeding low water; a falling tide.

EFFLUENT—A liquid, solid, or gaseous waste product discharged or emerging from an industrial process.

Eh (Redox Potential)—The Eh (Redox Potential) is a quantitative expression of the electron-escaping tendency or the state of oxidation or reduction of water or sediment systems and can be measured in volts. This environmental parameter has been used to describe changes in composition, chemical activity, biological populations, diagenesis, color, and other properties of recent sediments.

ELECTRON DIFFRACTION PATTERNS— Patterns obtained by use of an electron microscope for studying the structure of surface films on small particles. The advantage over x-ray diffraction is the shorter wave lengths and greater scatter of electrons enabling thin film study possible.

ELECTRON MICROPROBE—Capable of examining small areas, 1 to 300 microns in diameter by x-ray fluoresence.

ELECTRON MICROSCOPE—A microscope which employs a stream of high-speed electrons in place of a light beam and electromagnetic or electrostatic fields act as lenses to form the image. The image is made visible by impingement of the electrons in the focal plane on a fluorescent screen or photographic emulsion. Magnifications usually in the range 5000—20,000 X.

ELECTROPHORETIC MOBILITY—The velocity of colloidal particle in an electrical field gradient.

ENDOTHERM—The peak on a DTA pattern resulting from an endothermic (adsorption of heat) reaction.

EPIDOTE—A mineral common in metamorphic rocks and in the heavy mineral fraction of sediment.

EUTROPHICATION—The intentional or unintentional enrichment of water with nutrients.

EXOTHERM—The peak on a DTA pattern resulting from an exothermic (heat generating) reaction due to oxidation of material.

EROSION—The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

ESTUARY—The part of a river that is affected by tides.

FECAL COLIFORM—Pathogenic bacteria from sewage.

FINES—Material less than 74 microns in size.

FLOC—A felted mass formed in a liquid medium by the aggregation of a number of fine suspended materials.

FLOCCULANT—A substance that induces or promotes flocculation.

FLOCCULATION—The process whereby fines tend to aggregate into lumps.

FLOOD CURRENT—The tidal current toward shore or up a tidal stream, usually associated with the increase in the height of the tide.

FLOOD TIDE—The period of tide between low water and the succeeding high water; a rising tide.

GARNET—Minerals formed in contact metamorphism or in medium ranked meta-

morphic zones. Common as a detrital heavy mineral.

GLAUCONITE—A green mineral, closely related to the micas and essentially a hydrous potassium iron silicate. Commonly occurs in sedimentary rocks of marine origin.

HEAVY LIQUIDS—A general term applied to a group of heavy organic liquids used for determination of the specific gravity of minerals or for the separation of minerals having respectively, lower and higher specific gravities than the liquid used. Examples are bromoform and methylene iodide.

HEAVY METALS—Salts of metals which become trapped as pollutants in bottom sediments and are not readily removed by natural processes. A characteristic feature as heavy metals are the toxic effects to the acquatic animals in the environment. Some of the heavy metals include nickel, zinc, mercury, lead, cadmium.

HEAVY MINERALS—Detrital minerals of high specific gravity which are separated in the laboratory from minerals of lesser specific gravity by heavy liquids such as bromoform.

HORNBLENDE—A green mineral of the amphibole group that commonly occurs in schists, gneisses, and amphibolites and is a prominent constituent of many detrital sediments. This mineral is also one of the less resistant minerals of the heavy-mineral suites.

ILMENITE—A black opaque detrital heavy mineral found in sediment.

INORGANIC NITROGEN—Nitrogen of of NH_3, NO_2, and NO_3 in water samples.

KJELDAHL METHOD—Chemical determination of nitrogen by which organic material is decomposed and its nitrogen converted to ammonia.

KYANITE—A colorless to pale blue, elongate mineral of high rank metamorphic zones and relative common as a detrital heavy mineral in such regions.

LEACHATE—Chemical term for certain materials in solution dissolved from a larger mass by slow washing operation.

LITTORAL DRIFT—The sedimentary material moved in the littoral zone under the influence of waves and currents.

LITTORAL TRANSPORT—The movement of littoral drift in the littoral zone by waves and currents.

LITTORAL TRANSPORT RATE —Rate of transport of sedimentary material parallel to the shore in the littoral zone. Usually expressed in cubic yards (meters) per year. Commonly used as synonymous with LONGSHORE TRANSPORT RATE.

LITTORAL ZONE—In beach terminology, an indefinite zone extending seaward from the shoreline to well l.vond the breaker zone.

LOAD—The quantity of sediment transported by a current. It includes the suspended load of small particles, and the bedload of large particles that move along the bottom.

LONGSHORE TRANSPORT RATE—Rate of transport of sedimentary material parallel to the shore. Usually expressed in cubic yards (meters) per year. Commonly used as synonymous with LITTORAL TRANSPORT RATE.

MAGNETITE—A black opaque magnetic heavy mineral.

MAGNETIC SLAG—A magnetic particle from industrial waste discharge.

MARSH—An area of soft, wet or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

MASS SPECTROMETER—Separates gaseous ions of different mass and charge by action of electrical and magnetic fields.

MASSIF—A massive topographic and structural feature in an orogenic belt, commonly formed of rocks more rigid than those of its surroundings.

MICA—A mineral group, consisting of phyllo-silicates with sheetlike structures and characterized by very perfect basal cleavag. Induces muscovite, biotite, and others.

MEAN HIGH WATER (MHW)—The average height of the high waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value. All high water heights are included in the average where the type of tide is either semidiurnal or mixed.

MEAN LOW WATER (MLW)—The average height of the low waters over a 19-year period. For shorter periods of observations, corrections are applied to eliminate known variations and reduce the results to the equivalent of a mean 19-year value.

MEDIAN DIAMETER—The diameter which marks the division of a given sand sample into two equal parts by weight, one part containing all grains larger than that diameter and the other part containing grains smaller.

MICROBIOLOGICAL—Pertaining to very small living matter and its processes.

MICROORGANISM—Minute living matter.

MICROGRAMS/LITER (ug/1)—Equivalent to 1 part per billion.

MICRON—A unit of length equal to one-millionth of a meter and usually denoted by the symbol u.

MILLIGRAMS/LITER (mg/1)—Equivalent to 1 part per million (ppm).

MILLIGRAMS/1000 GRAMS (mg/1000 g)—Equivalent to 1 ppm of dry solids.

NITROGEN (Organic) Nitrogen combined in organic molecules such as proteins, amines, and amino acids.

NITROGEN (Inorganic) Nitrogen of dissolved NH_3, NO_2, and NO_3 in the water column.

NON-FILTERABLE SOLIDS—See suspended load.

NUTRIENT—Any inorganic or organic compound used to sustain plant life. e.g. silicates for diatoms.

OFFSHORE—(1) In beach terminology, the comparatively flat zone of variable width, extending from the breaker zone to the seaward edge of the Continental Shelf. (2) A direction seaward from the shore.

OFFSHORE CURRENT—(1) Any current in the offshore zone. (2) Any current flowing away from shore.

ORGANIC DETRITUS—The particulate remains of disintegrated plants and animals.

ORGANIC MATTER—The organic material that shows as the 300—400°C exotherm on DTA.

OXYGEN DEMAND—Oxygen required for oxidationof inorganic matter of for stabilization of decomposable organic matter by aerobic bacteria.

PALIMPSET SEDIMENT—A sediment which exhibits petrographic attributes of an earlier depositional environment and in addition petrographic attributes of a later environment.

PATHOGENS—Pathogenic or disease-producing organisms.

PETROGRAPHIC MICROSCOPE—Polarizing microscope which make use of the optical characteristics of the minerals for study and identification of sediment.

pH— Hydrogen ion index which is the exponent of 10 with sign reversed, in the hydrogen ion concentration.

PHI GRADE SCALE—A logarithmic transformation of the Wentworth grade scale for size classifications of sediment grains based on the negative logarithm to the base 2 of the particle diameter. $\log_2 d$.

POINT—The extreme end of a cape, or the outer end of any land area protruding into the water, usually less prominent than a cape.

POLLUTION—The result of discharging normally foreign material into surface waters.

PROVINCE—A large area or region unified in some way and considered as a whole. An example is a heavy mineral province.

PYROXENE—One of the common rock forming mineral groups. Includes augite, diopside, and hypersthene commonly found as heavy minerals in sediment.

RELICT SEDIMENT—A sediment that had been deposited in equilibrium with its environment, but that is now unrelated to its present environment even though it remains unburied by later sediments; e.g. a land-laid or shallow-marine sediment occurring in deep water (as near the seaward edge of the continental shelf).

ROCK FLOUR—Very finely ground rock material of silt and clay size formed by the abrasive action of glaciers. It consists predominantly of angular unweathered mineral fragments and thus, does not possess the cohesion characteristic of fine-grained materials composed of clay minerals.

RUTILE—A red to reddish brown mineral common as an accessory mineral in igneous rock and one of the more resistant heavy minerals in sands.

SALINITY—For the purposes of this investigation, the total quantity of dissolved solids in sea water measured by weight in parts per thousand.

SCOUR—Removal of underwater material by waves and currents, especially at the base or toe of a shore structure.

SEDIMENTATION—The act or process of depositing sediment from suspension in water.

SEM—Abbreviation for scanning electron micrograph.

SHOAL (noun)—A detached elevation of the sea bottom, comprised of any material except rock or coral, which may endanger surface navigation.

SHOAL (verb)—(1) To become shallow gradually. (2) To cause to become shallow. (3) To proceed from a greater to a lesser depth of water.

SHORE—The narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a beach.

SHORELINE—The intersection of a specified plane of water with the shore or beach. (e.g., the highwater shoreline would be the intersection of the plane of mean high water with the shore or beach.) The line delineating the shoreline on U. S. Coast and Geodetic Survey nautical charts and

surveys approximates the mean high water line.

SILLIMANITE—A colorless, elongate, mineral formed in high rank metamorphic zones. Common as a detrital heavy mineral.

SILT—Sediment between 74 and 2 micron size.

SPIT—A small point of land or a narrow shoal projecting into a body of water from the shore.

SPOIL BANKS—Embankments of dumped material dredged from a channel which lies near the area.

SPECIES—A classification group having only minor details of difference among themselves.

SPRING TIDE   A tide that occurs at or near the time of new or full moon (syzygy), and which rises highest and falls lowest from the mean sea level.

STAUROLITE—A brown mineral formed in medium rank metamorphic rock and a common detrital heavy mineral.

STREAM— (1) A course of water flowing along a bed in the earth. (2) A current in the sea formed by wind action, water density differences, etc. (Gulf Stream).

SURF—The wave activity in the area between the shoreline and the outermost limit of breakers.

SURF ZONE —The area between the outermost breaker and the limit of wave uprush.

SUSPENDED LOAD—(1) The material moving in suspension in a fluid, being

kept up by the upward components of the turbulent currents or by colloidal suspension. (2) The material collected in or computed from samples collected with a suspended load sampler. (A suspended load sampler is a sampler which attempts to secure a sample of the water with its sediment load without separating the sediment from the water.) Where it is necessary to distinguish between the two meanings given above, the first one may be called the "true suspended load".

SUSPENDED SOLIDS—See suspended load.

TEST—The external shell, secreted exo-skeleton, or other hard or firm covering or suppporting structure of many in-vertebrates and diatoms.

THERMOGRAVIMETRIC ANALYSIS—A record of the change in weight of a sample as the temperature is raised.

TIDAL RISE—The height of tide as referred to the datum of a chart.

TIDE The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting upon the rotating earth. Although the ac-companying horizontal movement of the water resulting from the same cause is also sometimes called the tide, it is preferable to designate the latter as TIDAL CURRENT, reserving the name TIDE for the vertical movement.

TOPOGRAPHY The configuration of a surface, including its relief, the position of its streams, roads, building, etc.

TOURMALINE—A mineral occurring commonly in granite petmatites and commonly one of the more resistant heavy minerals in sediment.

TGA—Abbreviation for thermogravimetric analysis.

WASTE—Any material which is of no further utility to the particular process involved.

X-RAY DIFFRACTION—A method of identifying crystalline substances by means of the scattering of x-rays by the constituent atoms to form characteristic patterns.

X-RAY FLUORESCENCE—A method for identification of elements in a sample by bombarding the sample with x-rays and the use of a crystal to transmit the characteristic radiation of various elements at a given angle to a counter for graphic display on a strip chart.

ZETA POTENTIAL—The potential caused by ionic charges surrounding finely divided particles in suspension. It is the difference between the charge layer rigidly held by the particles and the ions in the "bulk of the suspending liquid", and is a measure of the net effective charge on the surface of the particles.

ZIRCON—One of the more common resistant heavy minerals found in sediment. Commonly colorless and with well defined tetragonal crrstals.

ANNEX A

COMPOSITION OF BOTTOM SEDIMENTS
DELAWARE ESTUARY AND VICINITY

ANNEX A. COMPOSITION OF BOTTOM SEDIMENT. DELAWARE ESTUARY AND VICINITY

Contents

Table

COMPOSITION AND TEXTURE OF BOTTOM SEDIMENT

The composition of the bottom sediment is reported as sand-size (material greater than 74 microns) and fines (material less than 74 microns) and fines (material less than 74 microns) because it is convenient to separate the material at the 200 sieve size in relation to techniques necessary for identification of mineral composition. It is also convenient to compare similar size fractions for correlation purposes in source evaluation investigations. The materials greater than 44 micron size were identified by means of the petrographic and binocular microscope while the fines, less than 44 micron size were identified by a combination of techniques including x-ray diffraction, differential thermal analysis, mass spectrograph, scanning electron microscope, and analytical chemical techniques. A general summary of the composition and textures in the Delaware estuary between Trenton and the Capes is presented in Table 1.

The material greater than 44 micron size, identified by the petrographic microscope, was computed as a statistical "point count" for the several sieve sizes and a weighted average computed; this weighted average is listed in Table 2. Only the heavy minerals are reported as weight percent since these minerals were determined by the "sink float" method. Individual heavy mineral species in turn were computed as a statistical "point count" and this data appears for each sample location in Annex B.

The fines are materials less than 44 micron size and the highest concentrations of fines occur in the major shoal areas comprised of organic clayey silts. The fines are listed for individual sample locations in Table 3.

The texture description of the various bottom sediment samples as based on the cumulative grain size curve is listed in Table 4.

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TABLE 1

AVERAGE TEXTURE AND COMPOSITION OF BOTTOM SEDIMENT IN DELAWARE RIVER FROM TRENTON TO THE CAPES

Constituents	Delaware River North of Trenton	Schuyl-kill River	Delaware River			Delaware River Shoals			Delaware Bay	
			North of Phila-delphia	Phila. to Wilmington	Wilmington to Ship John Light	Fort Mifflin	Marcus Hook	Pea Patch Island	Ship John Light to Capes	At the Capes
					TEXTURE					
% Total Sample +44 micron	80	28	25	45	37	20	2	53	81	98
% Total Sample -44 micron	20	72	75	55	63	80	98	47	19	2
				AVERAGE % COMPOSITION +44 MICRON SIZE						
Quartz	87.0	62.0	84.0	79.7	70.8	78.2	74.0	64.9	86.2	96.2
Feldspar	2.0	3.0	1.6	1.9	6.2	3.4	17.2	11.0	3.6	3.3
Mica	3.0	4.5	2.4	1.8	2.1	2.4	2.1	2.6	1.2	Trace
Coal	2.0	27.0	2.0	2.0	1.0	5.0	2.0	0.5	–	–
Heavy Minerals	4.0	3.0	2.0	3.0	3.0	1.5	3.5	2.0	3.5	0.5
Other	2.0	0.5	8.0	11.6	16.9	9.5	1.2	19.0	5.5	–
				AVERAGE % COMPOSITION -44 MICRON SIZE						
Quartz	66.0	40.0	51.0	41.4	38.9	38.1	23.0	38.7	51.8	77.3
Feldspar	3.0	10.0	11.5	12.4	12.8	12.0	14.0	11.8	16.3	11.2
Organics	5.0	19.0	7.8	5.8	2.0	5.9	8.0	6.3	2.5	0.7
Diatoms	Trace	2.0	3.5	12.0	9.0	12.5	18.8	11.5	1.7	Trace
Fe_2O_3	1.9	2.0	0.9	1.4	1.1	1.2	3.0	0.8	0.5	0.3
Clay	26.0	21.0	21.0	22.3	26.2	20.8	27.0	28.5	21.2	7.1
Coal	0.1	6.0	0.1	1.0	0.3	2.1	2.0	0.1	–	–
				AVERAGE % CLAY FRACTION						
Illite	50	65	57	65	65	53	61	50	59	72
Chlorite	26	18	29	15	20	25	18	20	26	23
Kaolinite	19	11	8	15	10	15	13	25	8	3
Montmorillonite	5	6	6	5	5	–	8	5	7	2
Number Samples	4	13	25	20	11	6	12	6	15	3

NOTES: 1. Schuylkill River samples based on 13 samples from Fairmount Dam.
2. Delaware River north of Philadelphia includes field samples S-35, R-232, S-34, R-233, and S-1.
3. Delaware River from Philadelphia to Wilmington includes field samples S-33, R-1, R-15, R-22, R-35, R-36, R-48, R-32, R-52, R-65, R-80, S-31, S-30, R-124, R-13, R-153, S-22, R-167, and R-23.
4. Delaware River from Wilmington to Ship John Light includes field samples R-181, S-24, R-188, S-25, R-200, S-16, S-15, R-222, S-14, R-231, and S-26.
5. Detailed analysis of each sample is listed in U.S.C.E., South Atlantic Division Laboratory Petrographic Report of 1 September 1969.
6. Average clay fraction for shoal samples is based on the Flocculation Investigation, SAD Lab. Petrographic Report of 3 Oct. '69 and average diatom content on "Limited Investigation of the Concentration and Source of Diatoms in Delaware Estuary and Vicinity", SAD Lab. report of March 1970.
7. Other in -44 micron size fraction includes organic matter, calcite, glauconite, pebbles, and industrial slag.

TABLE 2
COMPOSITION OF SAND-SIZE SEDIMENT IN BOTTOM SAMPLES OF TRIBUTARY RIVERS AND DELAWARE ESTUARY BETWEEN TRENTON, NEW JERSEY AND THE CAPES

% Composition by Point Count

Sample Control Number	Field Sample Number	Quartz	Feldspar	Mica	Coal	Shell	Organics	Heavy Minerals	Diatoms	Rock Pebbles	Others
				Ranges North of Philadelphia							
RB1	S-1	87.0	2.0	3.0	2.0	–	–	6.0	Tr	–	Tr
RB35	S-35	66.5	1.4	1.1	1.1	–	–	1.8	–	27.5	Tr
RB306	R-232	94.0	2.0	2.0	–	–	–	2.0	–	Tr	Tr
RB34	S-34	92.8	1.8	2.7	1.0	Tr	Tr	1.7	–	–	Tr
RB307	R-233	81.9	1.0	3.1	4.9	Tr	Tr	1.9	–	–	*Tr
				Ranges South of Confluence of Delaware and Schuylkill River							
RB33	S-33	96.4	1.3	Tr	Tr	–	–	1.3	–	–	*1.0
RB75	R-1	91.0	3.0	3.0	1.0	–	Tr	2.0	–	Tr	Tr
RB88	R-14	89.3	2.0	1.0	1.0	–	–	6.7	–	–	Tr
RB89	R-15	68.1	2.0	1.4	3.5	5.0	18.0	2.0	–	–	Tr
RB96	R-22	72.2	3.4	2.4	5.0	Tr	10.0	7.0	Tr	Tr	*Tr
RB109	R-35	86.4	5.0	1.1	3.5	–	2.0	2.0	–	–	Tr
RB110	R-36	82.0	6.0	2.0	4.0	Tr	3.0	3.0	–	–	Tr
RB122	R-48	88.0	5.0	2.0	1.0	–	1.0	3.0	–	–	Tr
RB132	S-32	88.0	5.0	2.0	1.0	–	1.0	3.0	–	–	Tr
RB126	R-52	73.1	1.8	1.0	T:	Tr	19.5	3.6	–	Tr	Tr
RB139	R-65	81.8	9.5	2.0	4.7	–	Tr	2.0	–	–	Tr
RB154	R-80	83.5	6.8	4.1	1.8	–	2.3	1.5	–	–	Tr
RB31	S-31	73.8	2.3	1.1	7.0	–	Tr	2.9	–	11.5	*Tr
RB30	S-30	56.2	1.6	1.0	Tr	–	38.2	3.0	1.0	–	Tr
RB198	R-124	74.0	17.2	2.1	1.3	–	2.4	3.0	–	–	Tr
RB306	R-139	87.8	5.5	1.8	Tr	–	1.0	3.9	–	–	Tr
RB227	R-153	80.9	9.2	1.9	Tr	–	5.0	3.0	–	–	Tr
RB22	S-22	80.9	9.2	1.9	Tr	–	5.0	3.0	–	–	Tr
RB241	R-167	80.1	5.7	1.1	7.6	Tr	2.7	2.8	–	–	Tr
RB23	S-23	59.6	3.4	2.3	1.8	Tr	31.6	1.3	Tr	–	Tr

TABLE 2 (Continued)

Sample Control Number	Field Sample Number	Quartz	Feldspar	Mica	Coal	Shell	Organics	Heavy Minerals	Diatoms	Rock Pebbles	Others
					Ranges South of Confluence of Delaware and Schuylkill River						
RB255	R-181	78.5	6.5	1.0	–	–	10.0	2.0	Tr	2.0	Tr
RB24	S-24	90.0	2.4	3.1	Tr	Tr	2.1	2.4	Tr	–	Tr
RB304	R-188	84.2	7.9	1.6	Tr	Tr	3.3	3.0	Tr	–	Tr
RB25	S-25	85.5	2.5	1.0	1.0	–	7.1	2.9	Tr	–	Tr
RB268	R-200	62.1	4.7	1.0	Tr	Tr	28.5	3.7	Tr	32.2	1.0
RB16	S-16	61.8	2.4	Tr	Tr	–	–	2.6	Tr	–	*Tr
RB15	S-15	44.0	6.3	2.3	28.8	11.5	5.0	2.3	Tr	–	Tr
RB294	R-222	64.9	11.0	2.6	Tr	Tr	14.4	7.1	Tr	–	*Tr
RB14	S-14	67.4	2.1	2.0	–	–	Tr	3.4	Tr	23.8	Tr
RB299	R-231	83.4	3.2	2.2	Tr	–	6.7	4.5	Tr	–	Tr
RB26	S-26	57.1	19.1	6.7	Tr	–	10.0	3.6	Tr	–	2.0
					Tributary Rivers to Delaware Estuary						
TB2	S-2	67.0	3.0	2.0	25.0	–	–	3.0	Tr	–	Tr
TB3	S-3	72.0	5.0	10.0	7.0	–	–	6.0	Tr	–	Tr
TB4	S-4	71.0	6.0	8.0	Tr	–	–	15.0	Tr	–	Tr
TB11	S-11	70.9	9.3	3.7	3.7	Tr	6.8	5.0	Tr	–	*Tr
TB7	S-7	74.9	1.4	Tr	Tr	–	3.8	2.9	Tr	12.8	*2.2
TB8	S-8	81.1	2.7	1.0	1.0	1.8	5.0	3.6	Tr	2.7	1.0
TB9	S-9	91.9	Tr	Tr	2.6	–	Tr	2.8	Tr	–	2.4
TB10	S-10	69.1	1.0	3.5	2.0	–	–	14.6	Tr	10.0	1.0
TB13	S-13	44.3	1.7	4.1	1.6	–	–	4.1	Tr	46.0	Tr
TB17	S-17	49.3	4.9	Tr	2.3	–	2.2	2.0	Tr	36.5	2.6
TB18	S-18	87.8	4.3	Tr	–	2.2	1.5	1.0	Tr	Tr	Tr
TB19	S-19	10.5	Tr	Tr	Tr	5.6	13.3	1.0	Tr	–	Tr
TB20	S-21	24.6	1.6	Tr	Tr	73.9	17.8	1.9	Tr	10.3	Tr
TB28	S-28	58.2	2.7	Tr	Tr	56.5	Tr	2.2	Tr	2.0	Tr
TB27	S-27	77.0	4.0	–	Tr	28.2	–	1.0	–	2.0	15.0
TB29	S-29	50.0	Tr	1.0	–	15.0	–	1.0	–	30.0	2.0

TABLE 2 (Continued)

Sample Control Number	Field Sample Number	Quartz	Feldspar	Mica	Coal	Shell	Organics	Heavy Minerals	Diatoms	Rock Pebbles	Others
						Delaware Bay Locations					
BB36	B-1	90.5	3.5	Tr	Tr	1.0	Tr	5.0	Tr	–	Tr
BB37	B-2	80.0	10.0	4.0	Tr	4.0	Tr	5.0	Tr	–	Tr
BB38	B-3	68.2	3.0	1.4	Tr	26.4	Tr	1.0	Tr	–	Tr
BB39	B-4	85.9	3.0	2.0	Tr	2.7	Tr	6.4	Tr	–	*Tr
BB41	B-6	80.7	3.4	Tr	Tr	11.5	1.0	3.4	Tr	–	*Tr
BB42	B-7	81.0	3.4	2.8	Tr	6.0	Tr	6.8	Tr	–	Tr
BB43	B-8	88.0	2.0	1.0	Tr	3.3	Tr	4.7	Tr	–	Tr
BB44	B-9	90.9	3.8	Tr	Tr	1.8	Tr	3.5	Tr	–	Tr
BB45	B-10	97.1	2.9	Tr	Tr	Tr	Tr	Tr	Tr	–	Tr
BB46	B-11	96.3	3.7	Tr	Tr	Tr	Tr	Tr	Tr	–	Tr
BB47	B-12	95.6	2.7	Tr	Tr	1.1	Tr	1.7	Tr	–	*Tr
BB50	B-15	92.2	2.8	1.8	Tr	1.9	Tr	2.1	Tr	–	Tr
BB51	B-16	93.5	2.8	Tr	Tr	1.9	Tr	1.8	Tr	–	Tr
BB52	B-17	85.0	2.8	1.4	4.0	2.0	Tr	4.8	Tr	–	Tr
						Beaches (MHW) – Delaware Bay					
CB54	BS-1	94.2	1.3	–	–	–	–	3.5	–	–	1.0
CB55	BS-2	94.2	1.2	–	–	–	–	3.6	–	–	1.0
CB56	BS-3	97.5	2.5	–	–	–	–	Tr	–	–	–
CB57	BS-4	97.7	2.3	–	–	–	–	Tr	–	–	–
CB58	BS-5	97.8	2.2	–	–	–	–	Tr	–	–	*Tr
CB59	BS-6	99.0	1.0	–	–	–	–	Tr	–	–	–
CB60	BS-7	99.0	1.0	–	–	–	–	Tr	–	–	–
CB61	BS-8	97.9	2.1	–	–	–	–	Tr	–	–	Tr
CB62	BS-9	96.4	3.6	–	–	–	–	Tr	–	–	Tr
CB63	BS-10	96.4	3.6	–	–	–	–	Tr	–	–	–
CB64	BS-11	96.8	3.2	–	–	–	–	Tr	–	–	–
CB65	BS-12	91.4	3.0	Tr	Tr	Tr	–	5.6	–	–	*Tr

TABLE 2 (Concluded)

Beaches (MHW) – Delaware Bay

Sample Control Number	Field Sample Number	Quartz	Feldspar	Mica	Coal	Shell	Organics	Heavy Minerals	Diatoms	Rock Pebbles	Others
CB66	BS-13	94.1	2.9	Tr	Tr	Tr	–	3.0	–	–	*Tr
CB67	BS-14	96.4	2.1	Tr	Tr	Tr	–	1.5	–	–	–
CB68	BS-15	96.7	3.3	Tr	Tr	–	–	Tr	–	–	–
CB69	BS-16	–	–	–	–	–	–	–	–	–	–
CB70	BS-17	93.2	3.7	Tr	Tr	–	–	3.1	–	–	–
CB71	BS-18	95.3	2.2	Tr	Tr	Tr	–	2.5	–	–	–
CB72	BS-19	93.5	6.5	–	–	–	–	Tr	–	–	–
CB73	BS-20	91.2	4.6	–	–	Tr	–	4.2	–	–	–
CB74	BS-21	97.8	2.2	–	–	–	–	Tr	–	–	–

* – Slag and magnetic slag.

NOTES:
1. Other includes glauconite, slag, and other miscellaneous materials.
2. Sample locations are shown on Figure 3.
3. Per cent composition of sand-size fraction is based on statistical point count of the several size fractions.
4. Glauconite in sample TB27 averages 9% of the sand fraction; slag in this sample averages 6%.

TABLE 3
COMPOSITION OF AMORPHOUS AND CRYSTALLINE MATERIALS IN MINUS 44 MICRON FRACTION OF SEDIMENT FROM DELAWARE ESTUARY BOTTOM SAMPLES

Sample Control Number	Field Sample Number	Amorphous Material (Weight %)						Crystalline Material (Weight %)					
		Fe$_2$O$_3$	Diatoms	Organics	Quartz	Feldspar	Horn-blende	Illite	Chlorite	Kaolinite	Montmor-illonite	Calcite	Other
				Special Study Samples – Delaware River									
RB306	R-232	0.9	15.0	7.8	35.5	11.5	2.3	17.1	5.2	2.6	1.3	Tr	0.8
RB75	R-1	1.0	8.0	7.8	48.0	12.5	1.7	12.0	3.7	1.9	0.9	Tr	2.5
RB88	R-14	2.5	7.0	6.4	47.1	12.4	1.8	13.8	4.2	2.1	1.1	Tr	1.6
RB89	R-15	1.6	3.0	5.0	58.9	9.9	2.7	11.2	3.4	1.7	0.9	Tr	1.7
RB96	R-22	1.1	1.5	3.5	53.8	15.0	1.9	13.8	4.3	2.1	1.1	Tr	1.9
RB109	R-35	1.7	5.0	3.7	44.2	15.2	2.7	16.2	5.0	2.5	1.2	0.8	1.8
RB110	R-36	1.7	4.5	4.7	50.5	8.9	2.7	16.4	5.0	2.5	1.3	Tr	1.8
RB122	R-48	0.9	2.0	6.3	53.0	11.0	1.8	14.5	4.5	2.2	1.1	0.9	1.8
RB126	R-52	0.5	7.0	4.5	47.8	11.4	1.8	15.5	4.9	2.4	1.2	0.9	2.1
RB139	R-65	2.6	2.0	9.8	47.4	14.6	1.7	12.6	3.9	1.9	1.0	0.9	1.7
RB154	R-80	0.8	8.0	1.1	47.4	12.6	1.8	17.2	5.3	2.7	1.3	0.9	0.9
RB198	R-124	1.1	9.0	3.1	36.9	18.2	1.7	17.4	5.4	2.7	1.3	0.9	2.3
RB218	R-139	2.9	13.0	4.8	39.7	11.9	1.6	15.4	4.7	2.4	1.2	Tr	2.4
RB227	R-153	0.9	9.0	3.4	41.6	14.7	1.8	17.0	5.2	2.6	1.3	0.9	1.6
RB241	R-167	1.2	12.0	9.6	47.8	5.7	0.8	13.2	4.1	2.0	1.0	0.8	1.8
RB255	R-181	0.9	7.0	1.9	43.4	12.8	1.8	19.8	6.1	3.0	1.5	0.9	0.9
'3304	R-188	0.2	12.0	2.5	45.4	13.0	1.7	14.5	4.5	2.2	1.1	0.9	2.0
RB268	R-200	2.4	20.0	2.4	37.1	9.3	1.5	16.3	5.0	2.5	1.2	Tr	2.3
RB290	R-222	0.8	5.0	1.1	48.7	11.1	1.9	18.5	5.7	2.9	1.4	Tr	2.9
RB299	R-231	1.2	Tr	1.9	49.9	14.7	1.9	17.0	5.2	2.6	1.4	1.0	3.2
				Marcus Hook Shoal									
*	MH	2.8	10.0	8.0	33.4	14.3	2.0	17.1	5.3	2.6	1.3	1.5	1.7
				Schuylkill River									
**	SR	1.8	2.0	18.8	40.0	10.3	0.6	14.4	5.2	1.7	1.6	1.2	0.4

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TABLE 3 (Continued)

Sample Control Number	Field Sample Number	Amorphous Material (Weight %)			Quartz	Feldspar	Horn- blende	Crystalline Material (Weight %)					
		Fe$_2$O$_3$	Diatoms	Organics				Illite	Chlorite	Kaolinite	Monmor- illonite	Calcite	Other
					Delaware River and Tributaries								
RB-1	S-1	1.9	Tr	—	66.0	3.0	2.0	15.0	8.0	2.0	1.0	—	1.1
TB-2	S-2	—	Tr	—	58.0	8.0	2.0	20.0	6.0	2.0	3.0	—	1.0
TB-3	S-3	—	Tr	—	64.0	7.0	2.0	15.0	9.0	2.0	1.0	—	1.0
TB-4	S-4	—	Tr	—	69.0	5.0	4.0	12.0	6.0	1.0	2.0	—	1.0
TB-5	S-5	2.7	Tr	7.3	41.0	7.0	Tr	22.0	11.0	4.0	Tr	—	5.0
TB-6	S-6	3.6	3.0	6.2	45.4	15.0	Tr	15.0	6.0	2.0	2.0	Tr	1.8
TB-7	S-7	10.1	7.0	6.2	44.9	11.0	1.0	9.0	5.0	2.0	Tr	Tr	3.8
TB-8	S-8	2.7	4.0	10.0	39.3	12.0	1.0	15.0	8.0	5.0	Tr	—	3.0
TB-9	S-9	5.1	Tr	5.0	44.9	12.0	2.0	15.0	8.0	4.0	Tr	—	4.0
TB-10	S-10	4.1	5.0	1.2	46.9	10.0	Tr	22.0	7.0	2.0	Tr	—	1.8
TB-11	S-11	3.0	3.0	1.2	56.0	8.0	1.0	15.0	8.0	2.0	1.0	Tr	1.8
TB-12	S-12	2.9	6.0	4.1	47.1	16.0	2.0	11.0	5.0	2.0	2.0	Tr	1.9
TB-13	S-13	3.3	Tr	5.9	38.7	12.0	2.0	24.0	9.0	4.0	Tr	—	1.1
RB-14	S-14	1.2	2.0	1.7	51.8	17.0	3.0	12.0	7.0	1.0	2.0	—	1.3
RB-15	S-15	2.3	3.0	5.1	49.7	15.0	3.0	11.0	6.0	1.0	2.0	Tr	1.9
RB-16	S-16	1.0	3.0	8.7	39.0	10.0	1.0	20.0	12.0	2.0	2.0	Tr	1.3
TB-17	S-17	1.2	8.0	6.1	55.8	5.0	2.0	10.0	6.0	1.0	3.0	—	1.9
TB-18	S-18	1.6	10.0	3.7	42.4	15.0	1.0	15.0	9.0	1.0	Tr	—	1.3
TB-19	S-19	1.7	2.0	5.0	44.3	12.0	1.0	18.0	8.0	1.0	Tr	2.0	6.0
TB-20	S-20	2.4	6.0	6.2	34.6	20.0	Tr	15.0	7.0	1.0	3.0	Tr	4.8
TB-21	S-21	1.1	4.0	6.1	48.9	15.0	2.0	12.0	5.0	2.0	Tr	Tr	3.9
RB-22	S-22	1.4	5.0	2.8	51.6	17.0	3.0	11.0	5.0	2.0	Tr	Tr	1.2
RB-23	S-23	1.3	4.0	4.1	46.7	20.0	1.0	10.0	9.0	2.0	Tr	Tr	1.9
RB-24	S-24	1.8	4.0	3.9	55.2	1.2	1.0	12.0	6.0	1.0	1.0	Tr	2.1
RB-25	S-25	1.8	4.0	5.0	45.2	16.0	2.0	12.0	8.0	2.0	2.0	Tr	2.0
RB-26	S-26	1.1	8.0	5.1	41.9	18.0	2.0	11.0	7.0	2.0	1.0	Tr	1.9
TB-27	S-27	2.0	8.0	2.5	46.0	15.0	1.0	12.0	8.0	2.0	2.0	Tr	1.5
TB-28	S-28	2.4	10.0	3.8	49.6	12.0	1.0	10.0	7.0	2.0	1.0	Tr	1.2
TB-29	S-29	3.0	1.0	8.4	47.0	12.0	1.0	12.0	8.0	2.0	2.0	Tr	3.6
RB-30	S-30	1.7	12.0	6.3	45.3	11.0	1.0	11.0	6.0	1.0	2.0	Tr	2.7

TABLE 3 (Concluded)

Sample Control Number	Field Sample Number	Amorphous Material (Weight %)			Crystalline Material (Weight %)								
		Fe$_2$O$_3$	Diatoms	Organics	Quartz	Feldspar	Hornblende	Illite	Chlorite	Kaolinite	Montmorillonite	Calcite	Other
					Delaware River and Tributaries								
RB-31	S-31	2.4	2.0	5.1	49.6	15.0	2.0	15.0	5.0	1.0	1.0	Tr	1.0
RB-32	S-32	2.6	1.0	6.0	50.4	16.0	2.0	12.0	6.0	2.0	1.0	Tr	1.0
RB-33	S-33	2.1	2.0	6.2	46.9	18.0	1.0	12.0	8.0	1.0	1.0	Tr	1.8
RB-34	S-34	1.3	Tr	11.0	36.7	22.0	1.0	13.0	6.0	2.0	4.0	2.0	1.0
RB-35	S-35	1.7	1.0	4.5	55.3	8.0	1.0	15.0	9.0	2.0	1.0	Tr	1.5
					Delaware Bay								
BB-36	B-1	0.6	5.0	2.0	53.0	20.0	2.0	8.0	4.0	1.0	1.0	Tr	3.4
BB-37	B-2	0.5	5.0	2.4	50.0	18.0	3.0	7.0	4.0	2.0	2.0	2.0	4.1
BB-38	B-3	0.6	3.0	2.6	52.0	15.0	3.0	9.0	3.0	1.0	1.0	1.0	3.8
BB-39	B-4	0.7	1.0	0.3	55.0	16.0	3.0	12.0	5.0	1.0	1.0	3.0	2.0
BB-40	B-5	0.5	1.0	1.6	56.0	15.0	2.0	10.0	4.0	1.0	Tr	7.0	1.9
BB-41	B-6	0.4	1.0	7.1	48.0	12.0	4.0	12.0	7.0	3.0	4.0	Tr	3.5
BB-42	B-7	0.6	1.0	0.5	53.0	22.0	4.0	11.0	4.0	1.0	1.0	Tr	1.9
BB-43	B-8	0.5	Tr	3.3	50.0	23.0	4.0	12.0	5.0	1.0	Tr	Tr	1.2
BB-44	B-9	0.6	1.0	5.9	45.0	22.0	2.0	14.0	5.0	1.0	2.0	Tr	1.5
BB-45	B-10	0.5	Tr	0.5	67.0	12.0	2.0	8.0	2.0	Tr	1.0	6.0	1.0
BB-46	B-11	0.4	Tr	Tr	75.0	10.0	1.0	6.0	2.0	Tr	Tr	5.0	0.6
BB-47	B-12	0.3	Tr	1.6	65.0	15.0	1.0	8.0	3.0	1.0	Tr	3.0	2.1
BB-48	B-13	0.1	2.0	1.6	60.0	12.0	2.0	11.0	5.0	1.0	1.0	3.0	1.3
BB-49	B-14	0.6	Tr	0.9	61.0	15.0	2.0	12.0	4.0	2.0	1.0	3.0	1.5
BB-50	B-15	0.5	Tr	0.9	50.0	17.0	2.0	12.0	7.0	2.0	2.0	Tr	3.6
BB-51	B-16	0.3	3.0	Tr	55.0	10.0	1.0	15.0	8.0	3.0	1.0	5.0	1.7
BB-52	B-17	0.7	8.0	3.1	41.0	15.0	2.0	18.0	8.0	1.0	2.0	Tr	1.2
BB-53	B-18	0.2	6.0	5.9	43.0	10.0	2.0	15.0	9.0	3.0	3.0	Tr	2.9

* – Average of 20 samples from Marcus Hook Shoal.   ** Average of 12 samples from N. Fairmount Lock and Dam Reservoir.

NOTES: 1. Organics based on loss on ignition minus dehydration loss by the Train Method. The Train Method consists of heating the sample, previously heated to 110°C for 90 minutes and collecting the evolved water in a Schwartz drying tube containing anhydrone.

2. Diatoms determined by differential caustic leach method compared to a standard curve; amorphous hydrous iron by dithionite method.

3. Crystalline materials computed from x-ray diffraction analysis.

4. Other crystalline materials include glauconite, pyroxene, magnetite, garnet, epidote, ilmenite, etc. which seldom exceed trace amounts per mineral specie but collectively commonly constitute a few per cent of the fines.

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TABLE 4
SEDIMENT DESCRIPTION OF BOTTOM SAMPLES BASED ON PERCENTILE MEASUREMENTS FROM THE CUMULATIVE GRAIN-SIZE CURVE

Sample Control Number	Field Sample Number	Weight "Sand" Fraction >74 micron size	Percent "Silt–Clay" Fraction <74 micron size	Quartiles (mm)			Md ϕ	Sediment Description
				Q_1	Q_2	Q_3		
			Ranges North of Philadelphia					
RB1	S-1	100.0	–	–	–	–	–	Sand
RB35	S-35	93.0	7.0	0.17	0.22	0.31	1.09	Sand
RB306	R-232	37.2	62.8	0.28	0.50	0.90	0.50	Sand
RB34	S-34	45.0	55.0	–	–	–	–	–
RB307	R-233	98.7	1.3	–	–	–	–	–
			Ranges South of Confluence of Delaware and Schuylkill Rivers					
RB33	S-33	87.0	13.0	0.120	0.180	0.300	1.69	Silty Sand
RB75	R-1	93.2	6.8	0.060	0.085	0.140	1.24	Sand
RB88	R-14	85.2	14.8	0.055	0.085	0.200	1.78	Sand
RB89	R-15	83.4	16.6	0.061	0.100	0.280	1.66	Silty Sand
RB96	R-22	88.7	11.3	0.017	0.060	0.130	2.03	Silty Sand
RB109	R-35	66.5	33.5	0.002	0.011	0.035	3.25	Silty Sand
RB110	R-36	32.4	67.6	–	0.110	–	–	Clayey Silt
RB122	R-48	92.9	7.1	–	0.140	–	1.66	Sand
RB132	S-32	98.0	2.0	–	0.140	–	1.59	Sandy Silty Clay
RB126	R-52	57.7	42.3	–	0.035	0.020	1.59	Sandy Silty Clay
RB139	R-65	52.5	47.5	0.008	0.095	0.250	2.42	Sandy Silt
RB154	R-80	7.1	92.9	0.004	–	–	1.69	Clayey Sand
RB31	S-31	98.0	2.0	–	–	–	–	–
RB30	S-30	25.0	75.0	–	–	–	–	Silty Clay
RB198	R-124	17.5	82.5	0.001	0.003	0.014	4.13	Sandy Silty Clay
RB306	R-139	48.5	51.5	0.001	0.045	0.014	2.24	Silty Clay
RB227	R-153	30.4	69.6	–	0.005	–	3.89	Silty Clay
RB22	S-22	3.0	97.0	–	–	–	–	Sandy Silt
RB241	R-167	18.6	81.4	–	–	–	–	Sandy Silty Clay
RB23	S-23	12.0	88.0	0.003	0.015	0.035	–	–
RB255	R-181	22.7	77.3	–	–	–	–	Clayey Silt
RB24	S-24	52.0	48.0	0.001	0.050	0.100	–	Sandy Silty Clay
RB304	R-188	2.5	97.5	0.001	0.004	0.015	2.16	Silty Clay
RB25	S-25	25.0	75.0	–	0.015	–	3.98	Clayey Silt
RB268	R-200	44.0	56.0	0.001	0.020	0.065	2.16	Silty Silt
RB16	S-16	79.0	21.0	–	–	–	–	Sandy Silt
RB15	S-15	90.0	10.0	–	–	–	–	–
RB294	R-222	22.6	77.4	0.004	0.025	0.055	2.66	Clayey Silt
RB14	S-14	97.0	3.0	–	–	–	–	–
RB299	R-231	13.0	87.0	0.001	0.006	0.020	3.76	Silty Clay
RB26	S-26	72.0	28.0	–	–	–	–	–

TABLE 4 (Concluded)

Sample Control Number	Field Sample Number	Weight "Sand" Fraction >74 micron size	Percent "Silt–Clay" Fraction <74 micron size	Quartiles (mm)			Md φ	Sediment Description
				Q_1	Q_2	Q_3		

Tributary Rivers to Delaware Estuary

Sample Control Number	Field Sample Number	Weight "Sand" Fraction >74 micron size	Percent "Silt–Clay" Fraction <74 micron size	Q_1	Q_2	Q_3	Md φ	Sediment Description
TB2	S-2	100.0	–	–	–	–	3.98	Sand
TB3	S-3	100.0	–	–	–	–	3.69	Sand
TB4	S-4	100.0	–	–	–	–	3.82	Sand
TB11	S-11	62.0	38.0	–	–	–	–	Silty Sand
TB7	S-7	97.0	3.0	–	–	–	–	Sand
TB8	S-8	96.0	4.0	–	–	–	–	Sand
TB9	S-9	96.0	4.0	–	–	–	–	Sand
TB10	S-10	98.0	2.0	–	–	–	–	Sand
TB13	S-13	98.0	2.0	–	–	–	–	Sand
TB17	S-17	99.0	1.0	–	–	–	–	Sand
TB18	S-18	95.0	5.0	–	–	–	–	Sand
TB19	S-19	97.0	3.0	–	–	–	–	Sand
TB20	S-21	88.0	12.0	–	–	–	–	Silty Sand
TB28	S-28	94.0	6.0	–	–	–	–	Sand
TB27	S-27	48.0	52.0	–	–	–	–	Sandy Silt
TB29	S-29	99.0	1.0	–	–	–	–	Sand

Delaware Bay

Sample Control Number	Field Sample Number	Weight "Sand" Fraction >74 micron size	Percent "Silt–Clay" Fraction <74 micron size	Q_1	Q_2	Q_3	Md φ	Sediment Description
BB-53	B-18	8.0	91.0	–	0.003	0.01	2.40	Silty Clay
BB-48	B-13	92.0	8.0	0.260	0.460	0.70	0.56	Sand
BB-36	B-1	99.0	1.0	0.710	0.980	1.50	0.01	Sand
BB-37	B-2	85.0	15.0	0.066	0.085	0.130	1.78	Silty Sand
BB38	B-3	94.0	6.0	0.120	0.150	0.28	1.37	Sand
BB39	B-4	96.0	4.0	0.090	0.130	0.15	1.47	Sand
BB41	B-6	36.0	64.0	0.002	0.010	0.06	0.33	Sandy Silty Clay
BB42	B-7	99.0	1.0	0.065	0.080	0.10	1.82	Silty Sand
BB43	B-8	80.0	20.0	0.048	0.067	0.95	1.95	Sandy Silt
BB44	B-9	53.0	47.0	0.019	0.450	0.09	2.24	Sandy Silt
BB45	B-10	98.0	2.0	0.400	0.450	0.55	0.58	Sand
BB46	B-11	99.5	0.5	0.026	0.460	0.70	0.56	Sand
BB49	B-14	–	–	0.250	0.350	0.45	0.76	Sand
BB50	B-15	93.0	7.0	0.130	0.180	0.30	1.24	Sand
BB51	B-16	97.0	3.0	0.120	0.250	0.65	0.76	–
BB52	B-17	87.0	13.0	0.028	0.080	0.13	1.65	Silty Sand
BB40	B-5	92.0	8.0	–	0.300	–	0.87	Sand

TABLE 5
SEDIMENTARY PARAMETERS OF DELAWARE BAY BEACH AND PROFILE SAMPLES

Beach and Sample No.	Quartiles in Microns			Median Diameter ϕ in Units	Sediment Description
	Q_1	Q_2	Q_3		
NEW JERSEY BEACHES					
Seabreeze 1	624	451	340	1.15	Sand
2	574	445	340	1.16	Sand
3	1320	958	574	0.08	Sand
4	758	570	435	0.89	Sand
5	616	403	287	1.31	Sand
6	616	432	287	1.23	Sand
7	500	357	233	1.48	Sand
8	406	316	203	1.74	Sand
Thompson 1	660	536	379	0.87	Sand
2	536	518	500	0.95	Sand
3	536	518	500	0.95	Sand
4	278	233	218	2.07	Sand
5	287	233	203	2.11	Sand
6	450	287	203	1.82	Sand
7	500	354	250	1.50	Sand
8	177	308	203	1.66	Sand
Miami 1	379	330	287	1.60	Sand
2	406	354	308	1.50	Sand
3	–	1231	707	−0.30	Sand
4	268	218	189	2.17	Sand
5	536	287	177	1.78	Sand
6	–	576	165	0.93	Sand
7	165	109	54	3.20	Silty Sand
8	82	67	54	3.94	Clayey Sand
DELAWARE BEACHES					
Broadkill 1	379	308	250	1.68	Sand
2	354	287	218	1.82	Sand
3	1000	467	308	1.07	Sand
4	758	574	406	0.84	Sand
5	500	354	250	1.50	Sand
6	379	189	154	2.40	Sand
7	987	616	233	0.66	Sand
8	–	–	574	–	Sand
Bowers 1	–	555	406	0.85	Sand
2	–	574	406	0.80	Sand
3	–	1320	595	−0.30	Sand
4	1072	536	379	0.93	Sand
5	574	354	250	1.53	Sand
6	536	308	102	1.70	Sand
7	77	63	54	4.04	Sandy Silt
8	95	77	72	3.68	Silty Sand
Pickering 1	987	733	536	0.45	Sand
2	574	406	308	1.26	Sand
3	812	536	354	0.94	Sand
4	–	933	616	0.08	Sand
5	308	125	54	3.00	Silty Sand
6	483	406	144	1.30	Sand
7	60	51	44	4.32	Sandy Silt
8	72	54	47	4.22	Sandy Silt
Woodland 1	435	366	330	1.45	Sand
2	500	424	330	1.27	Sand
3	780	707	616	0.50	Sand
4	379	330	233	1.6	Sand
5	354	233	177	2.10	Sand
6	233	196	165	2.34	Sand
7	–	500	250	1.00	Sand
8	574	319	117	1.65	Sand

NOTES:
1. Q_1 is the quartile at the 25% point on the cumulative curve.
2. Q_2 is the quartile at the 50% point on the cumulative curve, and is called the median diameter (md).
3. Q_3 is the quartile at the 75% point on the cumulative curve.

ANNEX B

HEAVY MINERAL ANALYSES

ANNEX B. HEAVY MINERAL ANALYSES

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HEAVY MINERAL ANALYSIS

LABORATORY PROCEDURE

The heavy minerals were separated along with the sand fraction from the bottom sediment samples by wet sieving through a 325 mesh sieve. This fraction was then dried and screened and a cumulative curve made of the sand fraction to determine the median diameter. The material greater than 40 sieve size was then removed and a 25 gram representative sample obtained from this fraction between 50 and 450 microns size for heavy mineral separation in bromoform by the sink-float method. The heavy minerals were collected and washed with acetone several times and dried. The percent heavy minerals was determined and a hand magnet used to separate the magnetite from the other heavy minerals. The remaining heavy minerals were sieved into the following sieve fractions +80, +100, +200, and +325. The percent of each fraction was determined and a 300 count of transparent heavy minerals accomplished by means of the petrographic microscope; the amount of mica and opaques were also estimated and recorded. Where the fraction of heavy minerals was less than 10 percent of the volume, a 100 count was performed. The average weighted average is recorded in the tables of this appendix for each sample location.

SPECIAL TECHNIQUES

In addition to standard microscopic techniques, magnetic separation, x-ray diffraction, and chemical analysis were employed to aid in the identification of the minerals. In cases where positive differentiation between two similar minerals was difficult microscopically, it was possible to utilize the difference in magnetic susceptibility of the minerals for identification. In this study, the Franz Isodyamic Magnetic Sepa-

rator proved to be extremely beneficial in differentiating between several difficult minerals. For example, actinolite with its higher iron content, was more susceptible to a magnetic force than was tremolite, which is rich in magnesium. It was found that after screening and passing the heavy mineral fraction (less the magnetic opaque fraction) through the magnetic separator at a front tilt angle of 25°, and a side tilt angle of 20°, the actinolite separated from the sample when 0.8 amps was passed through the magnet, but that it took 1.2 amps to attract the tremolite with the same front and side tilt angles. In the same manner, aggregates of sillimanite, which were difficult to identify, were readily separated by their lack of magnetic susceptibility since they contain no iron. Further separation of heavy mineral fractions was also effected by methylene iodide of 3.2 specific gravity. The weights of each fraction was recorded and the weighted percent of a pure mineral fraction obtained by this mineral beneficiating technique. X-ray diffraction analysis was accomplished on pure mineral fractions for verification of petrographic identification in this process the complete representative sample was pulverized and passed through a 200 sieve and the powder press method of sample preparation accomplished before the minerals were scanned with x-rays at 2 degrees 2θ per minute on a Phillips x-rays diffraction unit with a copper target tube.

OPAQUE HEAVY MINERALS

The opaque heavy minerals were divided in this study into two fractions-magnetic opaques and non-magnetic opaques. The magnetic opaques were separated from the heavy-mineral sample by a hand magnet, and were found to contain magnetite and iron slag. The magnetic slag was generally more abundant in the larger

sieve sizes and sparsely represented in the finer sieve sizes. The magnetite was about equally distributed throughout all sieve sizes. More than half of the heavy-mineral fraction are magnetic opaques in the New Castle Range;the Cohansey River, the C& D Canal, and the Murderkill River. Although predominantly magnetite, this fraction contained from trace amounts to several percent magnetic slag.

The non-magnetic opaque heavy-mineral fraction, in decreasing order of abundance, included ilmenite, leucoxene, and hematite. As with the magnetic opaques, the amount of non-magnetic opaques varied throughout the estuary with no apparent fixed trend.

The concentration of heavy minerals and the various fractions are listed in Table 1 for specific sample locations shown in Figure 3 of the appendix.

TRANSPARE*.'T HEAVY MINERALS (MINUS MICA)

The percentage of heavy minerals in the 44 to 420 micron size range were determined by subtracting the volume estimate of opaque heavy minerals and mica from the total heavy mineral fraction. The transparent heavy minerals in order of decreasing abundance are:hornblende, garnet, zircon, staurolite, epidote, sillimanite, tourmaline, pyroxene, kyanite, and minor other. Characteristics of the more abundant transparent heavy minerals are listed below:

> Amphibole: For convenience in this reconnaissance all amphiboles have been grouped together. Hornblende greatly predominates with small amounts of actinolite and tremolite often present in addition. The hornblende varies in both color and the intensity of color; most is green and

there are lesser amounts of brown and blue-green. The amphiboles retain their characteristic cleavage-controlled prismatic shape but terminations vary from ragged to relatively rounded.

> Garnet:The garnets include the colorless, pink, green and brown varieties. Some well-shaped garnets were found, but the majority of the garnets were well-rounded and smooth. The garnets range from 6% to 38% of the Delaware River heavy-mineral suite and locally in the tributaries range up to 49% of the transparent fraction. The garnets were easily counted because of the isotropic property under crossed nicols and relatively high index of refraction.

> Zircon: Zircon is the most common of the stable heavy minerals. It varies in appearance from nearly clear euhedra to rounded, cloudy, fractured grains. The greatest number group midway between these extremes, being colorless, subangular and subrounded, and usually retaining some evidence of their original prismatic habit. Most appear to be broken rather than worn. An average of 1 to 2 percent of the zircon grains are pink;a very few are tan.

> Staurolite: Staurolite is especially abundant from locations in some of the Coastal Plain sediments of the upper estuary and is relatively abundant throughout the estuary. It is usually brown in color with a characteristic birefringence color and commonly is pleochroic; inclusions are common in this mineral.

Epidote: Epidote tends to occur in irregular but roughly equidimensional grains or, much more rarely, in crude prisms. Color varies from very pale green, almost colorless, through yellow-greens to rather yellow varieties. High birefrigence is characteristic of this mineral type. Both clinozoisite and zoisite present in trace amounts to a few percent are included in the epidote group in this investigation.

Sillimanite: The sillimanite examined occurs in colorless, usually prismatic grains. Less common are more or less tabular grains flattened parallel to 001 which could easily be misidentified except that they yield acute bisectrix interference figures showing the distinctive small 2V of sillimanite. The fibrous variety, fibrolite, is included here and comprises between 10 and 20 percent of the total sillimanite.

Tourmaline:The tourmaline is characteristic of an igneous source and relatively persistent between a few and several percent in all the samples. Pleochroism and elongate shape are the most diagnostic identifying properties of this mineral. Yellow to brown pleochroism is by far the more common but minor blue and pink varieties were also observed.

Kyanite: The kyanite occurs as a colorless to pale blue, elongate to tabular mineral more common in the larger sieve sizes.

Rutile: A red to reddish brown mineral common as an accessory mineral in igneous rock and one of the more stable heavy minerals.

Pyroxenes: Both clinopyroxenes and orthopyroxenes were represented in the river and tributaries with orthopyroxenes, the more abundant. The clinopyroxene was predominantly augite with trace amounts of diopside, and the orthopyroxenes were normally hypersthene with an occasional crystal of enstatite. Hypersthene was distinguished from enstatite by more pleochroism, and from the clinopyroxenes by parallel extinction.

Chloritoid: Bow-tie structured chloritoid comprises up to 1% of the heavy-mineral suite. This mineral is easily recognized because of its characteristic structure.

Other: Minerals of this category occur in amounts ranging from trace amounts to as much as a few percent locally. In general order of decreasing abundance, they include rutile, apatite, monazite, wollastonite, sphene, and corundum.

STABILITY ORDER OF TRANSPARENT HEAVY MINERALS

Several interpretations regarding the stability of heavy minerals exist in the literature but few agree on relative degree on all. Groot and Glass (1960) published a list where common agreement regarding relative chemical stability of heavy minerals exist as follows:

Zircon
Rutile } Very stable
Tourmaline

Staurolite
Kyanite } Moderately stable
Garnet

Hornblende } Least stable
Augite

To this list could be added several other heavy minerals and especially sillimanite which is placed in accordance with the findings of Neiheisel (1962, p. 371 and Dryden and Dryden 1964, p. 94) as one of the moderate to very stable minerals chemically but considerably less in rank on the scale of resistance to mechanical abrasion. Sillimanite remains persistant throughout the Delaware River estuary and Delaware Bay except in vicinity of the capes. Sillimanite is especially important in this investigation where Delaware Bay sediments mix with the continental shelf sediments of considerable abrasive history and glacial origin.

FULL VERSUS LIMITED
HEAVY-MINERAL SUITE

Strom (1972) summarizes the various definitions and interpretations given the "full" and "limited" heavy-mineral suite given wide use by Owens and Sohl (1969) and others. In its most liberal usage the terms refer to the resistance of the heavy minerals to destruction by chemical agencies. Thus a "full" heavy-mineral suite might contain some of the least stable heavy minerals previously described i.e. augite and hornblende while the "limited" heavy-mineral suite would contain only the more

resistant heavy minerals such as zircon, rutile, and tourmaline and possibly some of the moderately stable mineral species but impoverished in less stable mineral species.

Thus the Coastal Plain sediments older than Pleistocene contain a generally "full" heavy-mineral suite and the Piedmont sediments contain the "limited" heavy-mineral suite. This concept is important in relating source areas.

TEXTURAL ASPECTS

In any comparison with the heavy mineral studies conducted by previous investigators it is necessary to consider the similarity of size range of heavy minerals studied since some of the heavy minerals vary in proportional amounts with size. Most of the previous investigations by Jordan and Groot (1962), Groot and Blass (1960), Owens and Sohl (1969), and McMaster (1954) are in the 62 to 500 micron size range;Strom (1972) in the southwest Delaware Bay cover a variety of ranges. This investigation considers only those heavy minerals between 44 and 420 micron size and is thus comparable with most investigations. Between 44 and 74 micron size, more stable heavy minerals such as zircon and rutile are generally higher, however, the quantity of heavy minerals in this fraction is generally on the order 10% of the heavy mineral fraction. A useful index to differences in heavy minerals that may be caused by size differences is in the median diameters listed in Annex A.

TABLE 1
COMPOSITION OF TRANSPARENT HEAVY-MINERAL FRACTION IN SEDIMENT OF TRIBUTARIES RIVER, DELAWARE ESTUARY, DELAWARE BAY AND CONTINENTAL SHELF

Field Location	% Heavy Minerals	% Opaque Fraction	% Transparent Fraction	Hornblende	Actinolite	Tremolite	Clinopyroxene	Hypersthene	Sillimanite	Kyanite	Staurolite	Garnet	Zircon	Rutile	Epidote	Tourmaline	Chloritoid	Other
TRIBUTARY STREAMS																		
Delaware River N. of Trenton																		
S-1	6.0	40	60	27	2	2	2	2	7	1	3	8	26	4	10	2	Tr	4
Brandywine Creek																		
S-4	15.0	33	67	29	3	–	–	3	3	Tr	6	49	1	1	3	Tr	–	2
Mantua Creek																		
S-7	2.9	86	14	11	Tr	–	Tr	2	8	4	20	4	33	6	3	8	–	1
Rancocas Creek																		
S-8	3.6	66	34	8	1	–	–	1	16	4	6	8	28	7	9	9	–	3
Crosswick Creek																		
S-9	2.0	76	24	5	–	–	Tr	2	11	3	37	7	23	3	2	5	–	2
Chester River																		
S-10	14.6	46	54	51	1	–	Tr	2	8	4	4	10	11	3	2	2	–	2
Christina River																		
S-11	5.0	52	48	47	2	Tr	1	2	13	2	6	9	10	2	2	1	Tr	3
Neshaminy Creek																		
S-13	4.1	49	51	32	2	–	1	1	9	3	8	35	3	1	Tr	2	–	3
C & D Canal																		
S-17	2.0	70	30	10	Tr	–	Tr	3	13	5	33	8	13	4	2	4	1	4
Murderkill River																		
S-18	0.3	85	15	9	3	3	1	2	10	7	10	4	33	3	8	4	–	3
St. Jones River																		
S-19	1.0	75	25	8	Tr	–	1	1	15	7	9	3	39	3	8	3	Tr	3
Leipsic River																		
S-20	4.5	90	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mispillion River																		
S-21	1.9	41	59	28	3	–	Tr	2	8	3	4	11	18	2	14	3	–	4
Salem River																		
S-27	1.0	62	38	9	Tr	–	Tr	1	12	4	22	7	31	6	2	2	–	4
Maurice River																		
S-28	2.2	28	72	17	Tr	–	Tr	2	14	2	14	5	33	4	3	3	–	3
Cohansey River																		
S-29	2.0	71	29	2	–	–			6	3	15	4	59	2	3	3	–	3
Schuylkill River (Average of 13 Samples)																		
S-3	3.0	65	35	37	–	2	4	2	7	5	Tr	9	11	3	11	6	–	3
DELAWARE ESTUARY																		
R232	2.0	10	90	24	1	Tr	1	1	6	2	8	38	8	1	4	3	–	3
R233	3.0	40	60	52	1	–	1	1	3	1	3	17	6	3	5	4	–	3
S34	2.0	20	80	33	1	–	1	2	7	1	6	17	22	2	2	3	–	3
S35	1.4	27	73	39	1	Tr	Tr	1	9	2	10	16	11	2	4	2	–	3
R1	2.0	25	75	32	2	Tr	2	7	9	2	8	16	8	2	5	3	1	3
R14	6.7	33	67	34	3	Tr	1	6	10	2	6	14	10	3	4	4	–	2
R15	2.0	33	67	35	4	1	1	4	11	3	4	10	13	4	4	4	–	3
R22	7.0	25	75	28	3	Tr	1	6	9	2	7	13	15	2	8	4	–	2
R35	2.0	25	75	40	5	Tr	1	3	8	1	3	12	14	2	4	4	–	3
R36	3.0	17	83	34	4	Tr	1	4	8	1	5	13	14	2	6	4	–	4

TABLE 1 (Continued)

Field Location	% Heavy Minerals	% Opaque Fraction	% Transparent Fraction	Hornblende	Actinolite	Tremolite	Clinopyroxene	Hypersthene	Sillimanite	Kyanite	Staurolite	Garnet	Zircon	Rutile	Epidote	Tourmaline	Chloritoid	Other
R48	3.0	15	85	34	2	Tr	1	7	8	1	5	14	12	2	7	3	2	2
R52	3.6	75	25	28	2	Tr	1	3	10	2	7	6	33	2	4	1	Tr	2
R65	2.0	15	85	30	2	–	3	5	8	3	6	14	18	3	2	3	Tr	3
R80	1.5	24	76	40	4	–	1	3	7	4	3	10	17	2	4	3	–	2
S30	0.3	18	62	36	4	–	1	3	7	3	3	12	19	2	3	2	–	3
R124	3.0	14	86	36	4	–	1	2	6	4	3	16	19	2	3	1	Tr	3
R139	3.9	13	87	34	3	Tr	2	5	7	3	6	13	17	2	2	3	–	3
R153	3.0	10	96	43	3	–	1	3	8	3	2	13	19	1	1	2	Tr	1
R167	2.8	8	92	37	5	–	1	1	12	5	4	11	14	2	4	2	Tr	2
R181	2.0	69	31	48	3	–	Tr	2	11	3	4	7	14	2	3	2	Tr	1
R188	3.0	13	87	50	3	–	Tr	2	8	3	2	10	15	2	1	2	Tr	2
R200	3.7	9	91	51	3	–	1	2	6	4	2	11	14	1	1	1	Tr	3
R222	7.1	6	94	46	2	–	1	2	6	3	1	14	18	1	2	2	Tr	2
R231	4.5	19	81	43	2	–	2	1	7	3	5	10	17	3	4	2	–	1
DELAWARE BAY																		
B-1	5.0	2	98	55	3	–	–	3	6	1	2	6	9	9	2	1	–	2
B-2	2.5	3	97	59	2	Tr	1	2	7	1	2	10	7	5	2	2	–	–
B-3	2.1	10	90	46	2	1	2	2	7	1	4	11	6	11	2	2	–	2
B-4	6.4	2	98	45	3	2	1	3	6	1	1	20	8	6	1	1	–	2
B-5	1.2	20	80	40	2	2	2	2	6	3	4	13	8	12	2	2	–	2
B-6	3.2	63	37	13	1	Tr	Tr	1	5	1	9	10	5	45	2	5	Tr	3
B-7	6.8	5	95	34	3	2	1	1	10	1	2	–	6	6	Tr	2	Tr	2
B-8	3.5	3	97	44	3	–	2	2	10	2	1	16	7	9	1	2	1	–
B-9	0.5	5	95	53	3	1	1	3	10	Tr	Tr	13	7	6	Tr	2	–	1
B-10	0.8	15	85	26	2	Tr	1	1	7	3	17	24	7	8	Tr	3	–	2
B-11	0.8	44	56	13	2	–	1	1	6	4	23	23	6	15	Tr	5	–	1
B-12	0.3	33	67	31	2	–	2	1	13	5	12	6	7	8	2	7	–	4
B-13	0.9	31	69	40	2	Tr	1	1	5	1	6	22	5	12	1	2	–	2
B-14	1.4	21	79	31	3	Tr	1	2	8	2	8	20	8	10	1	4	–	2
B-15	2.1	13	87	39	3	1	1	3	4	Tr	2	25	6	10	1	3	–	2
B-16	1.8	19	81	40	2	1	1	2	6	2	3	20	6	12	1	3	–	2
B-17	4.8	10	90	44	3	1	1	2	6	1	3	16	9	9	1	2	–	2
B-18	3.9	60	40	19	2	Tr	1	1	6	2	15	16	5	27	1	3	–	2

TABLE 1 (Continued)

Field Location	% Heavy Minerals	% Opaque Fraction	% Transparent Fraction	Hornblende	Actinolite	Tremolite	Clinopyroxene	Hypersthene	Sillimanite	Kyanite	Staurolite	Garnet	Zircon	Rutile	Epidote	Tourmaline	Chloritoid	Other
DELAWARE BAY BEACH AT MHW																		
BS-1	3.5	25	75	13	2	–	Tr	1	14	4	33	14	4	2	5	5	–	3
BS-2	3.6	68	32	2	–	–	–	–	6	2	40	17	24	2	2	3	–	2
BS-3	0.5	48	52	2	–	–	–	–	16	3	45	17	4	1	2	8	–	3
BS-4	0.3	30	70	7	2	–	–	1	19	4	21	8	20	3	6	6	–	3
BS-5	0.1	82	18	4	–	–	–	–	36	6	21	4	9	2	6	8	–	4
BS-6	0.2	89	11	3	Tr	2	–	–	17	3	20	4	31	5	3	10	–	2
BS-7	0.3	50	50	11	2	–	–	2	22	3	19	5	18	5	4	7	–	2
BS-8	1.4	84	16	3	Tr	Tr	–	1	13	3	31	9	26	3	2	5	–	4
BS-9	0.3	71	29	6	–	–	–	1	15	5	34	10	12	3	3	9	–	2
BS-10	0.2	50	50	4	1	–	–	2	16	2	18	16	24	1	4	10	–	2
BS-11	0.9	50	50	14	3	–	–	2	8	3	15	23	18	5	4	3	–	2
BS-12	5.6	40	60	30	3	–	–	2	10	2	5	12	12	2	17	3	–	2
BS-13	3.0	30	70	44	3	–	1	3	7	2	3	19	5	1	8	2	Tr	2
BS-14	1.2	50	50	9	1	–	–	2	8	3	18	21	19	8	5	4	–	2
BS-15	5.6	40	60	31	2	Tr	2	Tr	17	2	18	3	8	2	7	5	–	3
BS-16	0.8	–	–	9	2	Tr	Tr	1	5	2	9	10	43	4	8	4	Tr	3
BS-17	1.1	78	22	5	2	1	–	1	5	3	9	9	41	6	14	2	–	2
BS-18	2.5	82	18	7	1	–	–	Tr	15	2	34	8	19	2	7	3	–	2
BS-19	0.6	68	32	16	1	Tr	1	Tr	25	3	18	2	18	2	7	3	–	2
BS-20	0.5	80	20	12	3	–	–	1	20	2	5	4	24	4	20	3	–	2
BS-21	0.6	27	73	28	3	Tr	Tr	2	12	3	10	13	10	2	9	6	Tr	2
CONTINENTAL SHELF																		
C-93 Top	2.0	40	60	55	2	1	–	3	2	1	3	14	9	2	7	2	–	3
C-93 4'	2.4	50	50	40	2	2	1	3	4	1	3	20	9	2	6	5	–	2
C-95 Top	0.8	50	50	15	1	1	1	1	4	4	15	37	12	1	1	5	–	2
C-100 Top	8.1	50	50	5?	1	2	1	1	3	1	6	18	23	3	4	3	–	3
C-108 Top	1.5	40	60	2?	1	3	2	1	2	6	9	27	12	2	5	5	–	3
C-123 Top	1.6	80	20	2?	2	1	1	3	6	3	18	20	10	1	3	4	–	2
C-132 5'	0.3	30	70	2?	2	1?	1?	2	12	8	28	10	2	1	Tr	12	–	2

TABLE 1 .(Concluded)

Field Location	% Heavy Minerals	% Opaque Fraction	% Transparent Fraction	Hornblende	Actinolite	Tremolite	Clinopyroxene	Hypersthene	Sillimanite	Kyanite	Staurolite	Garnet	Zircon	Rutile	Epidote	Tourmaline	Chloritoid	Other
C-152 Top	4.4	30	70	23	2	1	Tr	4	4	1	7	21	24	4	4	3	–	2
C-152 1'	1.6	40	60	27	2	Tr	Tr	2	7	2	9	16	17	4	5	4	–	2
C-167 Top	2.0	40	60	19	2	3	1	1	4	3	27	19	6	2	1	10	–	2
C-167 5'	2.0	40	60	26	1	1	1	1	2	2	11	18	21	2	6	5	–	3
C-170 Top	2.8	40	60	41	2	1	1	2	4	2	6	20	11	2	5	2	–	2
C-171 Top	5.2	40	60	33	1	1	1	2	2	1	3	18	25	4	5	2	–	2
C-171 6'	2.0	20	80	11	2	2	1	1	20	3	24	5	14	3	5	7	–	2
C-173 Top	3.9	50	50	48	1	2	1	1	2	2	5	12	9	4	5	5	--	3
C-182 Top	1.7	40	60	30	2	1	1	1	7	3	6	16	15	3	6	2	–	3
C-183 Top	1.2	50	50	28	2	1	1	2	2	2	10	19	15	2	5	4	–	3
C-183 5'	1.7	40	60	27	2	1	1	2	8	2	10	17	14	3	6	5	–	2
REHOBOTH BEACH (Average of 3 samples)																		
C-308, 9, & 10	0.8	40	60	30	2	3	1	1	13	2	15	11	5	1	8	5	Tr	3

NOTES: 1. Mica ranges between trace amounts and 3% of the transparent heavy mineral fraction; this mineral is not reported with the transparent heavy-mineral suite.

2. Other includes apatite, sphene, andalusite, monazite, wollastonite, topaz, corundum, and minor others.

3. Epidote includes clinozosite and zosite; clinopyroxene includes augite and diopside.

4. Continental Shelf samples have median diameter range between 0.19 and 0.50 mm except for C-167-Top (0.55 mm) and C-171-6' (0.80 mm).

5. All sample locations are shown in Figure 3.

TABLE 2
COMPOSITION OF TRANSPARENT HEAVY-MINERAL FRACTION IN BEACH PROFILE AND OFFSHORE SAMPLES OF DELAWARE BAY.

Field No.	Location	Horn-blende	Ac-tinolite	Tremo-lite	Clino-pyroxene	Hyper-sthene	Sill-imanite	Ky-anite	Staur-olite	Garnet	Zircon	Rutile	Epi-dote	Tour-ma-line	Other
	Sea Breeze Beach, N. J.														
1	Dune	4	2	—	Tr	Tr	15	2	20	4	30	5	6	9	3
2	Beach, M.H.W.	5	1	Tr	1	1	20	4	22	2	30	2	3	6	3
3	Beach, M.W.	8	1	—	1	Tr	6	2	17	2	48	5	2	5	3
4	Beach, M.L.W.	16	1	Tr	Tr	Tr	10	4	17	1	32	6	2	8	3
5	Offshore, 3 ft.	7	1	1	1	1	18	3	13	2	33	6	5	6	3
6	Offshore, 6 ft.	10	1	—	Tr	1	14	4	20	3	31	6	3	5	2
7	Offshore, 9 ft.	11	2	Tr	Tr	1	15	2	18	7	32	2	2	5	3
8	Offshore, 12 ft.	19	2	Tr	Tr	1	20	2	12	10	20	4	5	3	2
	Thompson Beach, N. J.														
1	Dune	12	2	Tr	—	Tr	13	3	17	12	20	4	7	7	3
2	Beach, M.H.W.	16	1	1	2	1	20	7	20	4	7	2	3	13	3
3	Beach, M.W.	9	1	1	2	1	19	5	28	9	10	4	3	4	4
4	Beach, M.L.W.	14	1	1	Tr	1	15	3	30	8	13	1	4	7	2
5	Offshore, 3 ft.	9	1	Tr	1	1	16	4	32	9	13	1	3	7	3
6	Offshore, 6 ft.	9	2	1	Tr	1	15	2	23	11	24	4	2	4	2
7	Offshore, 9 ft.	14	1	Tr	1	1	15	3	20	8	24	2	4	5	2
8	Offshore, 12 ft.	8	1	Tr	—	2	15	3	26	14	16	2	7	4	2

TABLE 2 (Continued)

Field No.	Location	Horn-blende	Ac-tinolite	Tremo-lite	Clino-pyroxene	Hyper-sthene	Sill-imanite	Ky-anite	Staur-olite	Garnet	Zircon	Rutile	Epi-dote	Tour-ma-line	Other
	Miami Beach, Villas, N. J.														
1	Dune	1	1	Tr	1	1	19	7	19	3	23	9	3	10	3
2	Beach, M.H.W.	11	1	1	1	1	22	3	19	2	24	3	4	5	3
3	Beach, M.W.	2	Tr	Tr	1	1	21	3	13	10	30	5	5	6	3
4	Beach, M.L.W.	2	1	Tr	1	1	14	2	26	3	34	2	2	9	3
5	Offshore, 3 ft	6	1	Tr	1	1	8	2	25	7	35	4	4	3	3
6	Offshore, 6 ft.	5	2	Tr	1	1	13	2	7	1	48	5	8	4	3
7	Offshore, 9 ft.	32	3	1	1	1	12	1	6	14	13	2	8	3	3
8	Offshore, 12 ft.	32	1	Tr	1	2	6	1	3	20	16	5	9	2	2
	Woodland Beach, Del.														
1	Dune	16	1	1	Tr	1	34	4	19	9	5	Tr	1	6	3
2	Beach, M.H.W.	7	1	1	1	1	7	3	28	13	25	3	4	3	3
3	Beach, M.W.	18	2	1	—	1	25	3	18	6	18	2	2	2	2
4	Beach, M.L.W.	17	2	1	1	1	16	2	16	9	20	2	7	4	2
5	Offshore, 3 ft	8	1	1	1	1	13	1	6	4	50	4	5	3	2
6	Offshore, 6 ft.	25	3	1	1	1	20	2	8	4	21	1	6	4	3
7	Offshore. 9 ft.	38	2	Tr	1	Tr	6	Tr	6	11	24	1	7	2	2
8	Offshore, 12 ft.	32	2	Tr	1	Tr	5	Tr	2	23	24	3	5	1	2

TABLE 2 (Continued)

Pickering Beach, Del.

Field No.	Location	Horn-blende	Ac-tinolite	Tremo-lite	Clino-pyroxene	Hyper-sthene	Sill-imanite	Ky-anite	Staur-olite	Garnet	Zircon	Rutile	Epi-dote	Tour-ma-line	Other
1	Dune	35	2	2	1	1	34	5	3	2	2	2	5	3	3
2	Beach, M.H.W.	27	3	1	Tr	1	30	4	14	2	4	Tr	8	4	2
3	Beach, M.W.	15	4	2	1	1	20	1	8	3	22	3	13	4	3
4	Beach, M.L.W.	51	2	1	Tr	Tr	4	Tr	1	11	19	1	8	Tr	2
5	Offshore 3 ft.	27	2	Tr	1	1	18	3	7	4	22	1	11	1	2
6	Offshore, 6 ft.	33	2	2	Tr	1	8	1	5	10	22	3	6	4	3
7	Offshore, 9 ft.	38	2	3	1	2	7	1	Tr	16	20	2	4	1	3
8	Offshore, 12 ft.	44	2	Tr	1	1	7	1	1	17	14	1	8	1	2

Bowers Beach, Del.

Field No.	Location	Horn-blende	Ac-tinolite	Tremo-lite	Clino-pyroxene	Hyper-sthene	Sill-imanite	Ky-anite	Staur-olite	Garnet	Zircon	Rutile	Epi-dote	Tour-ma-line	Other
1	Dune	12	2	1	1	1	25	5	25	9	4	Tr	5	7	3
2	Beach, M.H.W.	13	2	2	1	1	21	3	13	4	18	1	14	4	3
3	Beach, M.W.	23	3	2	1	1	6	2	6	4	27	4	15	3	3
4	Beach, M.L.W.	16	2	1	1	1	14	3	5	4	29	2	14	5	3
5	Offshore, 3 Ft.	14	1	2	1	2	12	1	21	8	20	3	8	4	3
6	Offshore, 6 Ft	43	1	Tr	–	Tr	10	1	4	7	20	4	5	2	3
7	Offshore, 9 Ft	40	1	1	1	1	11	Tr	1	15	19	2	9	2	2
8	Offshore, 12 Ft.	38	2	2	1	2	10	Tr	1	11	21	2	6	2	2

TABLE 2 (Concluded)

Broadkill Beach, Del.

Horn-blende	Ac-tinolite	Tremo-lite	Clino-pyroxene	Hyper-sthene	Sill-imanite	Ky-anite	Staur-olite	Garnet	Zircon	Rutile	Epi-dote	Tour-ma-line	Other
20	2	1	Tr	1	26	5	5	13	7	1	11	5	3
18	3	5	1	1	26	4	11	2	9	2	10	10	3
30	2	1	Tr	1	15	4	10	9	20	1	10	5	2
6	1	1	Tr	1	9	1	11	7	46	5	8	2	2
14	2	Tr	Tr	2	34	2	11	3	6	2	14	7	3
9	1	2	Tr	Tr	10	1	11	10	36	4	9	4	3
5	3	3	Tr	1	8	1	2	10	20	1	11	5	3
5	1	1	Tr	Tr	16	2	14	6	28	1	11	2	3

... in order of decreasing abundance include andalusite, chloritoid, sphene, apatite, monazite, wollastonite, topaz, ... miscellaneous types.

... scovite, biotite, and phlogopite) is not included in transparent heavy-mineral fraction.

... fraction includes epidote and minor occurrences of zoisite and clinozosite.

... includes the variety fibrolite.

... al point-count was performed on each sieve-size constituting more than 10% of the heavy minerals; each ... sieve-size fraction was weighted for the point-count of each mineral and the average composition determined.

INITIAL
SAMPLE

A

20° Front Slope
15° Side Slope
0.3 amps

Magnetic   Non- Magnetic

B

20° Front Slope
15° Side Slope
0.4 amps

Methylene Iodide
Separation
Sp.Gr. 3.3

Specific Gravity   Specific Gravity
3.3   3.3

C   D

20° Front Slope
15° Side Slope
0.5amps

Magnetic   Non-Magnetic

20° Front Slope
25° Side Slope
0.6 amps

20° Front Slope
25° Side Slope
0.8amps

Magnetic Non-Magnetic   Magnetic Non-Magnetic

E

20° Front Slope
25° Side Slope
0.65 amps

H

20° Front Slope
25° Side Slope
1.0 amps

Magnetic Non Magnetic

F   G

I

20° Front Slope
25° Side Slope
1.3 amps

Magnetic   Non-Magnetic

20° Front Slope
25° Side Slope
5 amps

Magnetic   Non Magnetic

NOTES 1 A is magnetite removal
with hand magnet

Percent Tourmaline Fraction - Delaware Bay

DELAWARE BEACHES — Woodland, Pickering, Bowers, Broadkill

NEW JERSEY BEACHES — Sea Breeze, Thompson, Miami Beach Villas

% Tourmaline Fraction

Beach — Off Shore
Dune
MHW
MW
Beach and Bay Profile Locations

Bay Bottom Samples
River Bottom Samples
Beach and Profile Samples

% Zircon Fraction

DELAWARE BEACHES — Woodland, Pickering, Bowers

NEW JERSEY BEACHES — Sea Breeze, Thompson, Miami Beach Villas

Heavy Mineral Concentration, Delaware Bay

Percent Epidote Fraction, Delaware Bay

FIGURE 3-B. Percent heavy mineral concentration and percent epidote in transparent heavy-minerals of sand fraction from sediments of Delaware Bay.

D-A084 364   ARMY ENGINEER DISTRICT PHILADELPHIA PA
              LONG RANGE SPOIL DISPOSAL STUDY. PART III. SUB-STUDY 2. NATURE,--ETC(U)
              DEC 73   J NIEHEISEL

UNCLASSIFIED   NL

3 OF 3
AD A
A084 364
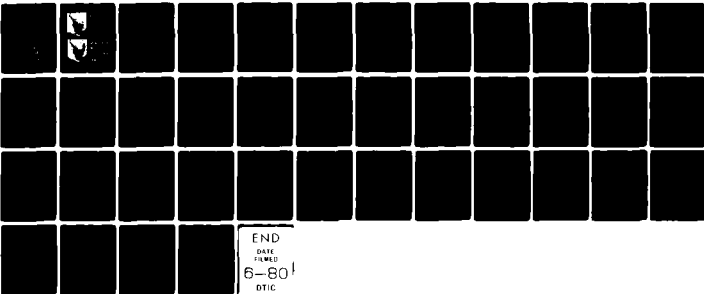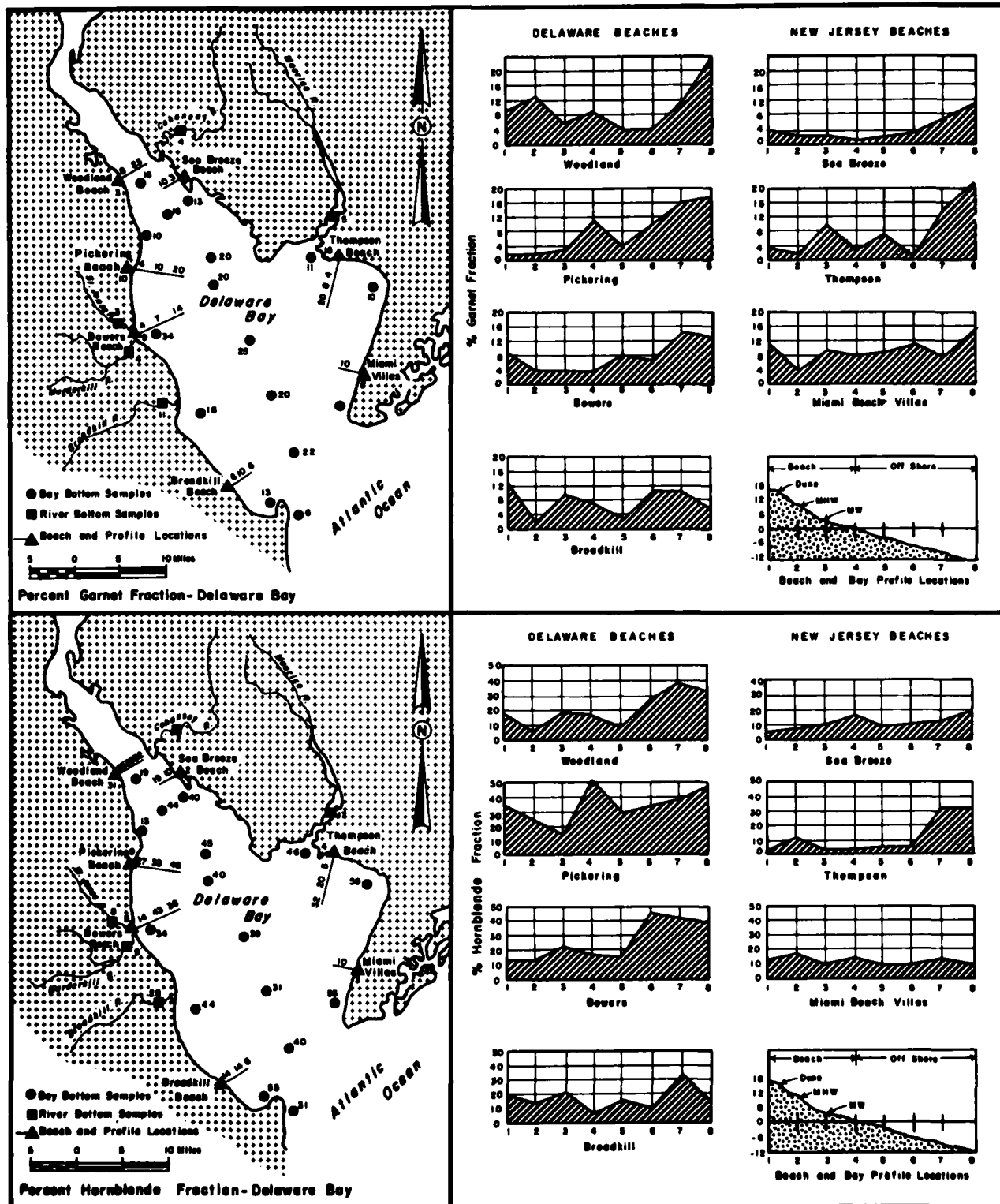
FIGURE 4-9. Percent of hornblende and garnet in transparent heavy-mineral suite of sand fraction from bottom and beach samples of Delaware Bay.
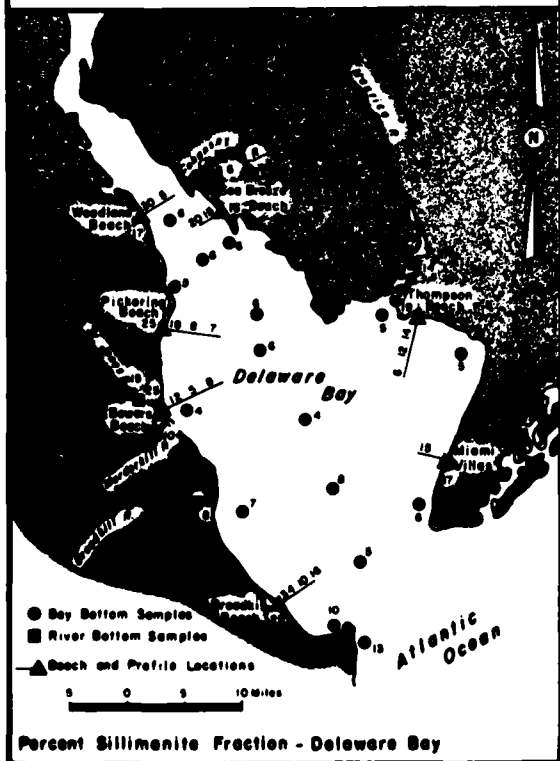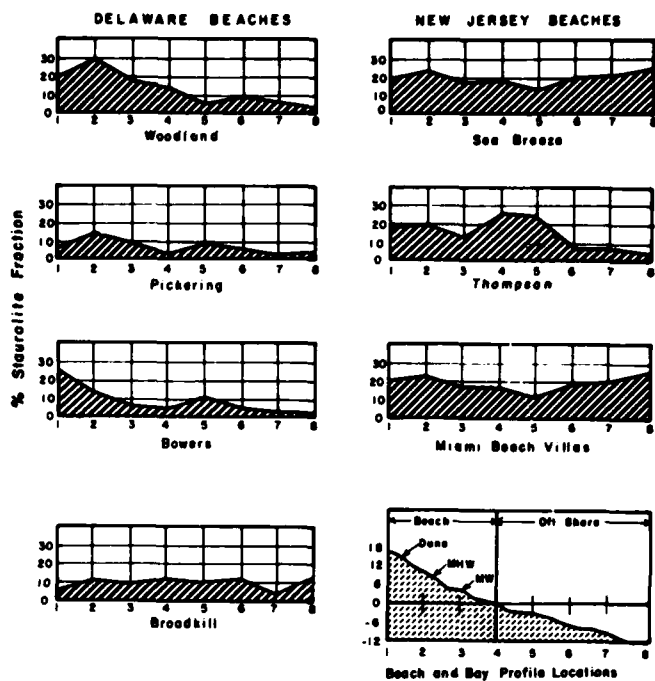
FIGURE 5-B. Percent sillimanite and staurolite in transparent heavy-mineral suite of sand fraction from bottom and beach samples of Delaware Bay.

ANNEX C

SUSPENDED SEDIMENTS OF
DELAWARE ESTUARY

ANNEX C.   SUSPENDED SEDIMENTS OF DELAWARE ESTUARY

Contents

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Figure

SUSPENDED SEDIMENTS OF DELAWARE ESTUARY

Suspended samples were collected from tributary rivers to the Delaware estuary and within the estuary from the water column simultaneously at regular intervals during a tidal cycle at 3 stations each at location 90 + 000, 124 + 000, and 180 + 000 on 23 July 1969 (see Figure 1C).

TRIBUTARY STREAMS

Samples were taken during periods of higher than average discharge after relatively complete shower coverage of the respective portion of the watershed so that the river sample reflects the general nature of the sediment contributed from runoff conditions.

A pint of water from 3 depth locations in streams tributary to Delaware River and Delaware Bay was obtained by Philadelphia District personnel at 20 minute intervals for a period of one hour during greater than average discharge of the respective streams during the spring, summer, and fall of 1969. The samples were further processed at the South Atlantic Division Laboratory for suspended solids and composition analysis. The suspended solids were collected on a 0.5 micron millipore filter and the weight of the suspended solids was determined as parts per million. The millipore with the suspended solids was then subjected to a beam of x-rays from a Phillips x-ray diffraction unit and the crystalline material approximated from the resulting peak intensities of the diffractograms. Organic matter was determined by washing the residue on the millipore filter into a composite sample and the sample treated with hydrogen peroxide; the weight loss was computed to percent organic matter.

Although the material collected on the millipore filter was too small for size analysis, an approximation of size is possible from evaluation of materials from the x-ray diffractograms. Quartz and feldspar are almost entirely silt-size with minor amounts of fine sand-size and the clay minerals area of clay-size, thus, the composition estimate is also an index to size.

The approximate percent of crystalline material as determined from x-ray diffractogram analysis was based on the intensity values of diagnostic reflections. The multiplication factor assigned peak intensities was determined by synthetic admixtures of the materials for the first approximation. The weighted averages of the following evaluations from the x-ray diffractogram was used to approximate the percent of crystalline materials:

a. Feldspar was computed as one times the 3.21 A peak intensity.

b. Quartz was computed as three times the 4.26 A peak intensity.

c. Illite was computed as two times the 10 A peak intensity.

d. Chlorite was computed as one times the 3.54 A peak intensity. The 14.5 A peak intensity after glycol treatment was also used to verify the chlorite.

e. Kaolinite was computed as one times the 3.58 A peak intensity. The 7.15 A peak intensity was also used as a check after chlorite had been evaluated.

f. Montmorillonite was computed as one times the 17 A peak intensity of the glycolated sample. Values seldom exceeded more than 5% of the clay fraction.

The mineral evaluation lacks the accuracy possible if the clay had been separated from the silt fraction, however, the small amount of sample available did not allow for application of such a preferred technique. This method was relatively inexpensive and permitted evaluations of significant trends in mineral composition which could be used in analysis of multiple samples through the tidal cycle.

In nearly all cases, the predominant clay mineral to the estuary was illite, and this mineral is also the most abundant clay mineral in the bottom sediment of Delaware estuary and bay. Kaolinite is locally the most abundant clay mineral in tributary streams draining the crystalline Piedmont formations; Chester Creek (Figure 1) situated south of Philadelphia contains relatively more kaolinite than other clay minerals. While kaolinite is generally more abundant than chlorite in the Piedmont streams, this mineral tends to be more abundant than kaolinite in the suspended samples from the headwaters of the Delaware River and the streams draining the Coastal Plain formations.

The organic content varies between 3 and 22% of the suspended material and appears to be largely vegetable matter (grass, etc.) but could contain high sewage content in locations of sewage outfalls near large population areas.

DELAWARE RIVER

The suspended load of 23 July 1969 is listed in Table 2 for the 9 sample locations in the river during the tidal cycle. The near bottom suspended sediment load is substantially greater than the near surface suspended sediment load at all locations; surface samples average between 20 and 82 ppm while near bottom samples average between 40 and 284 ppm, depending on location and position during the tiday cycle. The sediment load in the dredged river channel is greater, on the average, than the point locations nearer the river banks. Table 2 of the Appendix contains a summary of this data.

The general composition of the suspended matter from Delaware River consists of fractional components approximately 5 to 26 organics, 10-40 percent clay minerals, 50-70 percent silt and minor amorphous matter. The organic matter could be further fractionated into diatoms, anthracite coal, vegetable matter, sewage, and delineation of specific chemical components. Each fraction could be used to identify the source area and provide dispersal patterns for sediment transport analysis but the present investigation is limited in such detail because of the limited amount of suspended sediment available in the samples.

TABLE 1
SUSPENDED LOAD AND APPROXIMATE COMPOSITION OF SUSPENDED SEDIMENT SAMPLES
FROM TRIBUTARY STREAMS TO DELAWARE RIVER AND BAY

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmo-rillonite
Piedmont Tributary Streams												
Delaware River (Above Trenton)	1520	1.0	67.1	—	82	18	94	6	70	12	12	6
		2.4	63.3	8	70	30	94	6	57	20	20	3
		9.5	64.4	—	70	30	90	10	53	21	21	5
	1540	1.0	65.0	—	76	24	85	15	42	26	26	6
		2.4	65.2	12	80	20	88	12	33	33	26	8
		9.5	62.0	—	77	23	94	6	42	35	17	6
	1600	1.0	64.6	16	70	30	90	10	52	30	12	6
		2.4	65.8	—	65	35	93	7	50	30	15	5
		9.5	64.7	—	60	40	90	10	41	31	22	6
	Average		64.7	12	72	28	91	9	50	26	19	6
Neshaminy Creek Penn. 11 Jul 69	1500	1.0	33.6	—	77	23	87	13	43	35	17	5
		2.8	29.5	5	85	15	85	15	33	17	45	5
		11.2	17.0	—	78	22	95	5	37	11	41	11
	1520	1.0	32.8	—	62	38	85	15	60	17	17	6
		2.8	30.8	7	73	27	90	10	55	20	20	5
		11.0	14.3	—	58	42	87	13	50	14	31	5
	1540	1.0	33.5	—	64	36	95	5	52	14	26	8
		2.7	25.2	2	75	25	95	5	54	10	30	6
		10.7	14.4	—	60	40	94	6	45	15	34	6
	Average		25.7	4	70	30	90	10	48	17	29	6
Pennypacker Creek Penn. 4 Sept. 69	1240	1.0	210	—	79	21	90	10	58	20	20	2
		4.2	173	—	76	24	88	12	48	25	25	2
	1300	1.0	231	3	71	29	85	15	71	12	12	5
		4.0	187	—	74	26	80	20	65	20	10	5
	1320	1.0	254	—	67	33	76	24	74	9	9	8
		3.7	198	—	79	21	84	16	55	28	14	3
	Average		209	3	74	26	84	16	62	19	15	4

TABLE 1. (Continued)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmorillonite
Frankford Creek Penn. 20 July 69	1240	2.0	34	–	64	36	80	20	64	22	11	3
	1300	1.0	47	–	58	42	73	27	70	14	14	2
	1320	2.0	57	20	60	40	–	–	60	18	17	5
		1.0	32	–	70	30	88	12	50	25	17	8
		2.0	33	–	61	39	82	18	82	7	7	4
		Average	41	20	63	37	81	19	66	17	13	4
Upper Schuylkill River 27 June 69	1020	1.0	20.0	–	60	40	88	12	50	20	25	5
		3.0	21.4	–	62	38	85	15	50	20	25	5
		10.1	14.5	–	50	50	92	8	66	15	15	4
	1040	1.0	26.9	14	70	30	90	10	55	15	25	5
		3.0	18.0	–	60	40	91	9	30	21	41	8
		10.1	15.0	10	70	30	90	10	61	15	15	9
	1100	1.0	20.3	–	60	40	85	15	55	25	12	8
		3.0	18.2	–	65	35	92	8	68	18	9	5
		10.1	13.5	–	45	55	98	2	58	17	17	8
		Average	18.7	12	47	53	90	10	55	18	20	7
Schuylkill River	1400	1.0	–	14	–	–	–	–	–	–	–	–
		7.2	19.0	–	74	26	95	5	62	15	15	8
		28.8	16.3	–	60	40	95	5	39	28	28	5
	1420	1.0	–	–	–	–	–	–	–	–	–	–
		7.3	7.9	–	68	32	88	12	50	22	22	6
		29.2	–	–	–	–	–	–	–	–	–	–
	1440	1.0	–	–	–	–	–	–	–	–	–	–
		7.3	19.1	–	53	47	82	18	59	18	18	5
		29.0	18.0	–	50	50	95	5	61	17	17	5
		Average	16.0	14	61	39	91	9	54	20	20	6

TABLE 1. (Continued)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmorillonite
Chester Creek	1320	1.0	64.8	12	52	48	90	10	38	15	41	6
		2.0	64.9	—	50	50	85	15	30	15	45	10
		6.2	62.2	—	65	35	95	5	25	20	50	5
27 June 69	1340	1.0	60.3	9	70	30	96	4	27	32	30	11
		2.0	73.2	—	60	40	94	6	32	24	32	12
		5.2	65.6	—	56	44	90	10	22	30	40	8
	1400	1.0	87.2	12	55	45	90	10	27	36	25	12
		2.0	86.3	—	55	45	90	10	37	26	25	12
		5.0	81.1	—	62	38	92	8	34	30	30	6
		Average	71.8	11	58	42	91	9	30	25	35	10
Brandywine Creek	1340	1.0	79.0	2	88	12	95	5	24	24	47	5
		2.0	10.7	—	52	48	82	18	57	10	30	3
		9.0	32.0	—	75	25	90	10	45	20	31	4
9 July 69	1400	1.0	52.0	6	70	30	90	10	52	12	32	4
		2.0	42.8	—	65	35	90	10	47	23	23	7
		8.6	25.2	—	64	36	80	20	36	26	30	8
	1420	1.0	38.4	6	62	38	95	5	35	20	40	5
		2.0	36.1	—	60	40	93	7	48	12	35	5
		8.6	27.2	—	63	37	84	16	58	7	35	2
		Average	49.2	4	67	33	89	11	45	17	33	5
Christina River	1440	1.0	46.0	20	62	38	99	1	39	33	23	5
		5.0	47.1	—	65	35	90	10	50	15	30	5
		20.0	33.9	—	70	30	94	6	42	20	20	18
9 July 69	1500	1.0	44.8	15	60	40	93	7	50	30	15	5
		5.0	42.5	—	63	37	88	12	43	22	15	20
		20.0	35.2	—	81	19	94	6	36	36	10	18
	1520	1.0	44.6	12	76	24	91	9	32	45	15	8
		5.0	39.3	—	70	30	93	7	56	22	11	11
		20.0	46.9	—	85	15	96	4	60	18	18	4
		Average	42.2	16	70	30	93	7	45	27	17	11

TABLE 1. (Continued)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmo-rillonite
Delaware Coastal Plain Streams										
C & D Canal	1220	1.0	44.2	14	70	30	92	8	40	26	25	9
26 June 69		7.0	39.2	–	55	45	80	20	47	28	15	10
		28.4	25.8	–	50	50	60	40	65	15	15	5
	1240	1.0	66.8	13	78	22	80	20	35	45	14	6
		7.0	35.8	–	58	42	75	25	57	32	7	4
		28.2	31.6	–	80	20	75	25	55	30	7	8
	1300	1.0	43.2	16	60	40	80	20	44	40	12	4
		7.2	33.7	–	65	35	85	15	60	25	9	6
		28.8	32.4	–	65	35	82	18	53	34	9	4
	Average		39.1	14	65	35	79	21	51	30	13	6
C & D Canal	1620	1.0	50	14	85	15	89	11	73	9	9	9
5 Sept 69		7.4	38	–	68	32	79	21	80	11	6	3
		29.6	31	–	75	25	86	14	83	7	7	3
	1640	1.0	40	13	73	27	81	19	77	11	6	6
		7.5	38	–	76	24	88	12	75	7	13	5
		30.0	28	–	62	38	67	33	77	9	9	5
	1700	1.0	38	16	67	33	91	9	73	9	9	9
		7.6	34	–	70	30	84	16	68	17	11	4
		30.1	27	–	63	37	63	37	77	9	9	5
	Average		36	14	65	29	81	19	75	10	9	5
Appoquinimink River	1320	1.0	109	–	77	23	82	18	74	13	7	6
		4.0	102	–	79	21	68	32	65	22	11	2
		16.0	89	–	76	24	90	10	82	8	8	2
27 Aug 69	1340	1.0	131	–	75	25	67	33	80	10	8	2
		3.9	126	6	76	24	85	15	75	12	10	3
		15.6	119	–	73	27	78	22	72	13	12	3
	1400	1.0	119	–	71	29	78	22	71	13	13	3
		3.8	118	–	75	25	83	17	75	11	10	4
		15.2	110	–	81	19	77	23	76	10	10	4
	Average		114	6	76	24	79	21	74	12	10	4

TABLE 1. (Continued)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmorillonite
Smyrna River	–	Composite	125.0	6	81	19	89	11	48	21	21	10
Leipsic River	1420	1.0	133.4	—	62	38	88	12	62	20	13	5
		3.0	135.9	—	62	38	87	13	60	21	14	5
		11.5	95.3	—	72	28	87	13	56	19	17	8
12 June 69	1440	1.0	168.1	—	69	31	80	20	63	17	13	7
		3.0	155.7	—	75	25	77	23	55	24	13	8
		11.0	160.3	—	77	23	84	16	54	26	10	10
	1500	1.0	167.0	—	81	19	85	15	66	13	13	8
		3.0	169.6	—	64	36	73	27	53	20	20	7
		11.0	154.5	—	76	24	80	20	60	26	6	8
		Average	148.9	—	71	29	73	27	59	21	13	7
St. Jones River	1320	1.0	37.7	10	82	18	94	6	53	20	20	7
		3.0	33.9	—	77	23	60	40	63	21	11	5
		10.0	47.6	—	70	30	83	17	55	16	24	5
13 June 69	1340	1.0	36.6	7	55	45	85	15	42	25	25	8
		3.0	35.8	—	64	36	88	12	38	27	27	8
		9.7	33.0	—	60	40	85	15	40	30	23	7
	1400	1.0	36.6	7	45	55	65	35	44	25	27	4
		3.0	36.0	—	74	26	85	15	53	26	16	5
		9.5	32.3	—	75	25	85	15	42	24	24	10
		Average	36.6	8	67	33	81	19	48	24	22	6
Murderkill River	1120	1.0	11.5	12	59	41	84	16	71	12	12	5
		2.0	11.4	—	64	36	92	8	46	23	23	8
		7.0	14.4	—	78	22	95	5	43	21	21	15
13 June 69	1140	1.0	12.8	—	65	35	81	19	70	13	12	5
		2.0	16.9	—	66	34	78	22	67	17	8	8
		7.2	14.7	—	70	30	91	9	82	8	5	5
	1200	1.0	18.1	—	59	41	81	19	56	22	17	5
		2.0	39.9	—	82	18	95	5	71	12	12	5
		6.5	21.0	—	60	40	90	10	60	25	10	5
		Average	17.9	12	67	33	86	14	63	17	13	7

TABLE 1. (Continued)

Tributary Stream	Time	Depth (ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material Silt	% Crystalline Material Clay	Silt Fraction (Rock Flour) Quartz	Silt Fraction (Rock Flour) Feldspar	Clay Mineral Fraction Illite	Clay Mineral Fraction Chlorite	Clay Mineral Fraction Kaolinite	Clay Mineral Fraction Montmorillonite
Mispillion River	1100	1.0	36.4	12	78	22	90	10	38	28	28	6
		2.0	34.6	—	84	16	90	10	35	25	32	8
		8.0	34.7	—	72	28	78	22	32	30	30	8
12 June 69	1120	1.0	36.1	7	83	17	70	30	43	25	25	7
		2.0	32.5	—	82	18	85	15	45	25	25	5
		7.3	34.1	—	80	20	72	25	30	30	30	10
	1140	1.0	36.0	6	80	20	75	25	33	28	32	7
		2.0	35.6	—	88	12	80	20	41	35	15	9
		7.2	36.3	—	85	15	82	18	50	30	15	5
		Average	35.1	8	81	19	80	20	39	28	26	7
Broadkill River	1540	1.0	9.7	23	47	53	78	22	62	23	11	4
		2.0	15.0	—	54	45	72	28	44	30	16	10
		8.0	11.5	—	48	52	92	8	55	20	20	5
20 June 69	1600	1.0	17.7	22	54	46	83	17	53	20	20	7
		2.0	11.4	—	60	40	96	4	60	15	15	10
		8.0	11.2	—	54	46	83	17	64	20	12	4
	1620	1.0	14.1	—	45	55	94	6	59	24	12	5
		2.0	12.6	—	55	45	55	45	62	15	15	8
		7.0	13.7	—	65	35	85	15	50	25	18	7
		Average	13.0	23	54	46	82	18	57	21	15	7
Louis and Rehobeth Canal	1440	1.0	7.1	—	46	54	65	35	72	15	6	7
		2.0	5.3	11	60	40	77	23	60	15	16	10
		6.0	7.5	—	55	45	60	40	72	16	4	8
	1500	1.0	6.9	—	45	55	80	20	66	14	10	10
20 June 69		3.0	7.0	—	34	66	95	5	70	15	9	6
		6.0	9.2	—	48	52	57	43	70	11	11	8
	1520	1.0	6.8	—	77	23	78	22	58	13	25	4
		3.0	7.2	—	40	60	85	15	73	15	7	5
		5.0	6.6	—	40	60	95	5	56	24	14	6
		Average	7.1	11	49	51	77	23	66	15	11	8

TABLE 1. (Continued)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmo-rillonite
Crosswick Creek	1420	1.0	67.1	12	75	25	94	6	42	26	26	6
		3.3	66.9	—	70	30	98	2	55	22	15	8
		13.2	67.8	—	75	25	95	5	53	30	11	6
	1440	1.0	63.4	12	70	30	83	17	40	35	20	5
		3.2	64.6	—	60	40	91	9	47	22	22	9
		13.0	64.8	—	70	30	96	4	52	25	18	5
	1500	1.0	71.0	11	58	42	94	6	53	20	20	7
		3.2	69.5	—	60	40	96	4	60	16	20	4
		13.0	72.7	—	62	38	97	3	60	20	15	5
		Average	67.5	12	67	33	94	6	51	24	19	6
Rancocas Creek	1400	1.0	31.0	—	74	26	90	10	84	5	9	2
		4.4	47.0	—	86	14	75	25	62	21	11	6
		17.6	35.0	—	85	15	94	6	81	8	8	3
22 Aug 69	1420	1.0	52.0	6	83	17	88	12	63	21	11	5
		4.6	45.0	—	75	25	88	12	56	21	21	2
		17.2	40.0	—	82	18	60	40	65	22	11	2
	1440	1.0	59.0	—	81	19	82	18	50	30	17	3
		4.3	48.0	—	74	26	92	8	78	12	6	4
		17.1	45.0	—	83	17	91	9	58	21	14	7
		Average	44.7	6	80	20	84	16	66	18	12	4
Cooper River	1440	1.0	26.0	—	74	28	94	6	70	12	12	6
		2.8	22.0	—	62	38	83	17	75	9	9	7
		11.8	17.0	—	56	44	63	37	78	7	7	8
21 Aug 69	1500	1.0	21.0	—	68	32	92	8	70	17	6	7
		2.8	20.0	10	68	32	79	21	85	6	6	3
		11.8	19.0	—	53	47	83	17	82	8	8	2
	1520	1.0	21.0	—	67	33	88	12	72	18	6	4
		16.7	21.0	—	59	41	68	32	64	20	13	3
		Average	19.0	10	63	37	81	19	74	12	9	5

TABLE 1. (Continued)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material Silt	Clay	Silt Fraction (Rock Flour) Quartz	Feldspar	Clay Mineral Fraction Illite	Chlorite	Kaolinite	Montmorillonite
Racoon Creek	1420	1.0	67.1	7	80	20	92	8	40	35	18	7
		3.3	67.2	—	82	18	85	15	42	30	21	7
		13.2	66.5	—	73	27	80	20	55	22	13	10
24 June 69	1440	1.0	71.0	10	83	17	78	22	40	27	27	6
		3.2	70.6	—	90	10	85	15	37	33	25	5
		13.0	67.6	—	75	25	87	13	38	28	28	6
	1500	1.0	73.8	8	80	20	65	35	50	22	22	6
		3.2	75.2	—	80	20	75	25	36	35	20	9
		13.0	70.2	—	81	19	93	7	52	20	20	8
	Average		69.9	8	80	20	82	18	43	28	22	7
Oldmans Creek	1020	1.0	53.4	13	72	28	87	13	57	14	14	15
		2.5	65.5	—	66	34	80	20	40	25	25	10
		10.0	50.4	—	63	37	90	10	58	16	21	5
24 June 69	1040	1.0	58.0	13	75	25	85	15	40	40	10	10
		2.5	55.6	—	60	40	82	18	47	23	23	7
		10.0	49.3	—	72	28	90	10	56	22	10	12
	1100	1.0	60.4	14	80	20	90	10	34	36	15	15
		2.5	52.5	—	80	20	80	20	43	23	24	10
		4.5	48.8	—	72	25	91	9	30	40	20	10
	Average		54.8	13	71	29	86	14	45	27	18	10
Salem River	1520	1.0	87.3	—	74	26	84	16	50	21	20	9
		4.0	87.2	—	75	25	75	25	33	30	30	7
		16.0	85.5	—	83	17	88	12	43	28	21	8
11 June 69	1540	1.0	87.9	—	65	35	85	15	60	23	12	5
		4.0	91.6	—	62	38	92	8	46	20	28	6
		16.0	87.7	—	70	30	75	25	40	25	25	10
	1600	1.0	92.0	10	65	35	80	20	40	25	25	10
		4.0	98.0	—	50	50	70	30	52	15	30	3
		16.0	96.3	—	65	35	94	6	30	33	30	7
	Average		81.4	10	68	32	83	17	44	24	25	7

TABLE 1. (Continued)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids Ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmo-rillonite
Big Timber Creek	1420	1.0	30.9	—	85	15	95	5	46	23	23	8
		3.6	29.5	—	78	22	96	4	53	26	13	8
		14.4	25.1	—	80	20	94	6	57	28	9	6
9 Jun 69	1440	1.0	27.5	10	70	30	80	20	37	35	17	11
		3.6	26.2	—	84	16	90	10	46	30	15	9
		14.4	29.3	—	75	25	89	11	46	30	15	9
	1500	1.0	26.9	8	83	17	95	5	50	25	16	9
		3.6	28.0	—	77	23	75	25	53	31	10	6
		14.4	22.1	—	67	33	93	7	40	35	20	5
		Average	27.3	9	78	22	90	10	48	29	15	8
Woodbury Creek	1040	1.0	31	—	84	16	91	9	78	10	10	2
		2.6	29	—	74	26	90	10	56	21	21	2
		10.4	27	—	66	34	83	17	66	13	13	8
21 Aug 69	1100	1.0	49	—	60	40	79	21	62	21	11	6
		2.6	29	9	61	39	83	17	84	8	4	4
		10.2	40	—	71	29	81	19	83	10	5	2
	1120	1.0	29	—	70	30	84	16	86	6	6	2
		2.5	28	—	64	36	77	23	57	22	17	4
		10.0	30	—	67	33	90	10	78	13	7	2
		Average	32	9	69	31	84	16	72	14	10	4
Mantus Creek	1420	2.0	33.0	2	60	40	72	28	54	21	15	10
		3.4	37.5	—	68	32	82	18	40	30	10	20
		13.6	32.2	—	65	35	88	12	60	25	10	5
27 May 69	1440	2.0	39.0	7	80	20	90	10	80	10	5	5
		3.3	21.7	—	55	45	86	14	75	15	5	5
		13.2	30.8	11	50	50	94	6	63	14	14	9
	1500	2.0	38.0	—	70	30	90	10	60	20	13	7
		3.2	39.1	—	65	35	85	15	55	27	12	6
		13.5	43.9	—	60	40	77	23	57	33	6	4
		Average	35.0	10	63	37	85	15	60	22	10	8

C-11

TABLE 1. (Concluded)

Tributary Stream	Time	Depth(ft) Above Bottom	Susp. Solids ppm	% Organic Matter	% Crystalline Material		Silt Fraction (Rock Flour)		Clay Mineral Fraction			
					Silt	Clay	Quartz	Feldspar	Illite	Chlorite	Kaolinite	Montmo-rillonite
Alloway Creek	1540	1.0	108.0	—	82	18	82	18	61	21	14	4
		4.4	98.0	—	86	14	68	32	58	19	19	4
		17.6	92.0	—	69	31	90	10	86	8	4	2
27 Aug 69	1600	1.0	109.0	6	75	25	67	33	62	22	11	5
		4.3	103.0	—	75	25	85	15	86	6	6	2
		17.7	100.0	—	76	24	78	22	80	6	12	2
	1620	1.0	145.0	—	90	10	78	22	69	13	13	5
		4.3	101.0	—	85	15	83	17	71	13	13	3
		16.8	88.0	—	67	33	77	23	55	24	18	3
	Average	—	104.8	6	78	22	79	21	70	15	12	3
Cohansey River		—	25.8	—	68	32	80	20	63	24	8	5
Maurice River	1640	1.0	63.7	—	75	25	83	17	50	23	16	11
		5.0	64.7	—	71	29	75	25	46	23	23	8
		20.0	68.0	—	79	21	79	21	37	29	29	5
19 June 69	1700	1.0	71.0	—	61	39	81	19	51	22	22	5
		5.0	71.0	—	67	33	84	16	44	28	16	12
		20.0	74.3	—	76	24	75	25	31	38	23	8
	1720	1.0	74.9	—	48	52	50	50	62	15	15	8
		5.0	78.3	—	77	23	75	25	33	31	31	5
		20.0	72.6	—	53	47	52	48	65	16	10	9
	Average		70.9	—	67	33	73	27	46	25	21	8

NOTES: 1. Approximate per cent silt (rock flour) and clay minerals is based on x-ray diffraction peak intensities of millipore filter residue from suspended samples. All quartz and feldspar is assumed to be silt or fine sand size and clay minerals are assumed to be less than 2 micron size.

2. Silt fraction (rock flour) as approximate sum of quartz and feldspar, is based on a weighted average of the quartz peak at 4.26 Å multiplied by three, and the feldspar peak at 3.21 Å times unity.

C-12

TABLE 2

SUSPENDED AND DISSOLVED SOLIDS, COMPOSITION AND VELOCITY
FOR LOCATIONS IN DELAWARE RIVER AT HOURLY INTERVALS ON 23 JULY 1969

Location 90+000, Point 1000

| Time in Hours | Height in Feet Above Bottom | Suspended Solids (PPM) | CRYSTALLINE MATERIAL (PPM) | | CLAY MINERALS (PPM) | | | | Dissolved Solids PPM | VELOCITY IN FT/SEC | ORGANICS IN PPM |
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmor-illonite			
0800	1	19	12	7	4	2	1	1	207	1.1	—
	2	18	12	6	—	—	1	—	203	0.9	—
	4	30	17	13	—	—	2	—	208	1.1	—
	8	28	22	6	—	—	1	—	189	1.1	—
	16	22	18	4	—	—	1	—	185	1.1	—
	32	19	10	9	7	1	1	Tr	185	1.1	—
0900	1	18	13	5	3	1	1	Tr	204	1.4	—
	2	20	13	7	—	—	—	—	196	1.1	—
	4	19	12	7	—	—	—	—	227	—	—
	8	19	12	7	—	—	—	—	236	1.0	—
	16	17	11	6	—	—	—	—	191	—	—
	32	18	15	3	2	1	1	Tr	187	1.3	—
1000	1	75	59	16	8	5	3	Tr	194	1.1	—
	2	60	46	14	—	—	4	—	212	1.2	—
	4	51	38	13	—	—	3	—	183	1.2	—
	8	31	19	12	—	—	2	—	196	1.5	—
	16	27	14	13	—	—	2	—	183	1.8	—
	32	19	16	3	2	1	1	Tr	194	2.2	—
1100	1	44	36	8	6	1	1	Tr	188	1.5	—
	2	33	25	8	—	—	1	Tr	192	—	—
	4	42	32	10	—	—	1	—	185	1.8	—
	8	36	26	10	—	—	2	—	189	—	—
	16	30	22	8	6	1	1	Tr	180	2.6	—
1200	1	33	27	6	4	2	1	Tr	180	2.4	—
	2	32	24	8	—	—	1	—	197	—	—
	4	28	22	6	—	—	1	—	188	2.1	—
	8	22	19	3	2	1	Tr	Tr	203	2.6	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1300	1	17	12	–	3	1	1	Tr	170	1.6	–
	2	24	–	6	–	–	1	–	174	2.1	–
	4	21	15	5	–	–	1	–	183	2.0	–
	8	20	15	9	–	–	1	–	159	1.5	–
	16	20	11	7	–	–	1	–	186	2.3	–
	32	9	25	7	1	Tr	Tr	Tr	166	2.3	–
1400	1	44	33	8	6	1	1	Tr	168	1.2	–
	2	39	31	8	–	–	2	–	178	1.4	–
	4	36	29	7	–	┊	–	–	169	1.6	–
	8	36	26	10	–	–	4	–	166	1.8	–
	16	32	–	–	–	–	–	–	159	2.4	–
	32	25	25	7	3	1	1	Tr	161	0.8	–
1500	1	136	94	42	20	11	11	1	162	0.6	–
	2	128	88	40	–	–	10	–	175	0.7	–
	4	105	80	25	–	–	4	–	175	0.8	–
	8	94	70	24	–	–	5	–	175	0.9	–
	16	61	48	13	–	–	3	–	172	1.1	–
	32	19	12	7	4	1	1	Tr	174	1.4	–
1600	1	69	52	17	11	3	3	1	168	0.6	–
	2	50	32	18	–	–	4	–	165	1.4	–
	4	31	20	11	–	–	2	–	161	1.0	–
	8	29	21	8	–	–	2	–	164	1.0	–
	16	15	13	5	2	1	1	Tr	173	1.0	–
1700	1	100	73	27	16	7	3	1	173	1.4	–
	2	85	62	23	–	–	3	–	172	1.7	–
	4	85	–	–	–	–	–	–	178	1.7	–
	8	76	–	–	–	–	1	–	182	1.9	–
	16	30	–	–	–	–	4	–	172	2.2	–
	32	18	8	10	3	1	6	Tr	170	2.2	–

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TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor-illonite			
1800	1	42	23	19	12	4	3	1	183	1.6	—
	2	41	—	—	—	—	—	—	176	2.0	—
	4	38	—	—	—	—	—	—	174	2.0	—
	8	39	—	—	—	—	—	—	166	2.2	—
	16	28	—	—	—	—	—	—	204	2.6	—
1900	1	33	24	9	4	2	2	Tr	175	1.7	—
	2	29	—	—	—	—	—	—	178	2.3	—
	4	31	22	—	—	—	2	—	177	2.0	—
	8	30	27	8	—	—	1	—	177	2.1	—
	16	34	—	7	—	—	1	—	155	2.4	—
	32	20	14	6	4	2	1	Tr	167	0.7	—
2000	1	39	31	8	4	2	1	Tr	186	1.2	—
	2	35	25	10	—	—	2	—	187	1.4	—
	4	34	23	11	—	—	1	—	189	1.3	—
	8	32	17	15	—	—	3	—	186	1.6	—
	16	31	24	7	—	—	1	—	194	1.6	—
	32	32	22	10	6	2	2	Tr	197	1.8	—
2100	1	39	32	7	2	2	2	Tr	193	0.5	—
	2	36	28	8	—	—	1	—	161	0.5	—
	4	33	28	5	—	—	1	—	194	0.5	—
	8	30	23	7	—	—	1	—	206	0.5	—
	32	35	19	16	11	2	1	1	189	0.5	5.4

Location 90+000, Point 2000

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor-illonite	Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
1000	1	60	50	10	5	2	2	1	186	1.1	—
	2	64	47	17	—	—	2	—	192	1.1	—
	4	46	39	7	—	—	1	—	186	1.1	—
	8	47	36	11	—	—	3	—	204	—	—
	16	27	16	11	—	—	2	—	200	—	—
	32	20	13	7	3	2	2	Tr	194	2.1	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	CRYSTALLINE MATERIAL (PPM)			CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
		Suspended Solids (PPM)	Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1100	1	37	27	10	6	1	1	Tr	193	–	–
	2	36	18	18	–	–	1	–	211	–	–
	4	37	27	10	–	–	1	–	195	–	–
	8	33	26	7	–	–	1	–	169	–	–
	16	35	20	15	–	–	2	–	186	–	–
	32	30	21	9	5	2	2	Tr	186	–	–
1200	1	35	29	6	4	1	1	Tr	166	–	–
	2	35	29	6	–	–	1	–	169	–	–
	4	35	16	19	–	–	3	–	169	–	–
	8	32	14	18	–	–	2	–	176	–	–
	16	30	–	–	–	–	–	–	176	–	–
	32	32	23	–	5	2	2	Tr	172	–	–
1300	1	35	25	10	7	1	1	Tr	198	–	–
	2	36	26	10	–	–	1	–	194	–	–
	4	35	27	8	–	–	1	–	187	–	–
	8	36	28	8	–	–	1	–	188	–	–
	16	35	24	11	7	–	1	–	216	–	–
	32	29	16	13	7	3	3	Tr	174	–	–
1400	1	54	39	15	9	3	2	1	184	1.1	–
	2	47	35	12	–	–	–	–	193	1.6	–
	4	42	26	16	–	–	–	–	184	1.8	–
	8	41	26	15	–	–	–	–	188	1.9	–
	16	34	–	–	–	–	–	–	189	2.2	–
	32	30	20	10	7	2	1	Tr	167	2.2	–
1500	1	54	34	20	8	8	4	1	159	–	–
	2	53	29	24	–	–	–	–	163	–	–
	4	56	43	13	–	–	–	–	157	–	–
	8	53	37	16	–	–	–	–	139	–	–
	16	50	35	15	–	–	–	–	165	–	–
	32	34	22	12	9	2	1	Tr	177	–	–

TABLE 2 ((Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1600	1	89	61	28	21	4	2	1	189	—	—
	2	64	43	21	—	—	—	—	163	—	—
	4	47	39	8	—	—	—	—	173	—	—
	8	28	30	17	—	—	—	—	183	—	—
	16	22	16	6	—	—	—	—	175	—	—
	32	23	15	8	6	1	1	Tr	172	—	—
1700	1	42	34	8	4	2	1	Tr	185	—	—
	2	42	32	10	—	—	—	—	183	—	—
	4	36	27	9	—	—	—	—	180	—	—
	8	30	20	10	—	—	—	—	190	—	—
	16	34	27	7	—	—	—	—	176	—	—
	32	18	15	3	1	1	1	Tr	188	—	—
1800	1	29	19	10	4	3	3	Tr	178	1.5	—
	2	38	31	7	—	—	1	—	182	2.0	—
	4	29	21	8	—	—	1	—	195	2.2	—
	8	26	21	5	—	—	1	—	181	2.5	—
	16	24	—	—	1	1	1	—	194	2.3	—
	32	30	22	8	7	1	1	Tr	192	2.8	—
1900	1	27	22	5	2	2	1	Tr	192	1.9	—
	2	29	22	7	—	—	1	—	201	1.7	—
	4	31	24	7	—	—	2	—	189	1.6	—
	8	27	—	—	—	—	—	—	170	2.4	—
	16	23	11	12	—	—	2	—	194	2.3	—
	32	35	17	—	12	2	2	Tr	178	2.5	—

Location 90+000, Point 3000

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite	Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
0900	1	15	8	7	5	1	1	Tr	185	1.0	—
	2	14	—	—	—	—	—	—	184	0.7	—
	4	10	6	4	—	—	4	—	174	1.5	—
	8	30	17	3	6	3	2	1	142	0.7	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1300	1	22	17	5	4	1	1	Tr	179	0.9	—
	2	21	11	10	—	—	2	—	182	1.2	—
	4	20	13	7	—	—	1	—	175	1.0	—
	8	18	13	5	2	1	1	Tr	177	1.1	3.2
1400	1	20	11	9	5	2	2	Tr	185	0.9	—
	2	20	12	8	—	—	2	—	167	0.9	—
	4	18	13	5	—	—	1	—	176	1.0	—
	8	17	11	6	3	2	1	Tr	168	1.0	—
1600	1	15	10	5	3	1	1	Tr	177	1.3	—
	2	15	10	5	—	—	1	—	165	1.4	—
	4	14	10	4	—	—	1	—	173	1.3	—
	8	13	11	4	2	1	1	Tr	165	1.4	2.1
1800	1	19	15	4	3	1	1	Tr	167	1.9	—
	2	17	12	5	—	—	1	—	166	1.8	—
	4	15	8	7	—	—	1	—	157	1.7	—
	8	16	11	8	3	1	Tr	Tr	172	1.9	2.4
1900	1	16	10	6	3	1	Tr	Tr	168	1.3	—
	2	16	—	—	—	—	Tr	—	186	1.4	—
	4	16	—	5	—	—	1	—	148	1.8	—
	8	16	11	—	3	1	1	Tr	176	1.9	3.2
	16				3	1	1	Tr	167	1.6	—
2000	1	19	12	7	5	1	1	Tr	193	0.8	—
	2	19	15	4	—	—	Tr	—	191	0.8	3.0
	4	16	11	5	—	—	Tr	—	207	0.8	—
	8	13	9	4	—	—	1	—	205	0.7	—
	16	12	7	5	3	1	1	Tr	180	0.9	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
2100	1	19	12	—	5	1	1	Tr	179	0.7	—
	2	13	12	7	—	—	1	—	154	0.7	—
	4	13	8	5	—	—	1	—	173	0.7	—
	8	12	8	5	—	—	1	—	219	0.8	—
	16	13	8	4	3	1	1	Tr	196	1.0	2.1

Location 124+000, Point 4000

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
0800	1	63	56	7	4	1	1	Tr	249	0.3	1.1
	2	35	29	6	—	—	1	Tr	244	0.3	—
	4	30	25	5	—	—	1	—	232	0.4	—
	8	27	22	5	—	—	Tr	—	251	0.7	—
	16	19	13	6	1	2	Tr	Tr	216	0.8	—
0900	1	101	82	19	11	4	4	1	269	1.0	1.9
	2	44	33	11	—	—	3	—	256	1.3	—
	4	32	14	18	—	—	2	—	279	1.3	—
1000	1	383	253	130	103	19	8	4	229	0.7	—
	4	64	53	11	—	—	1	—	248	1.5	—
	16	33	28	6	5	1	1	Tr	221	1.6	2.6
1100	1	104	78	26	21	3	2	1	214	1.1	—
	2	81	62	19	—	—	3	—	203	1.3	—
	8	44	32	12	—	—	2	—	214	1.6	—
	16	32	23	9	6	1	1	1	233	1.5	2.7
1200	1	134	103	31	23	3	3	3	188	1.3	3.5
	2	129	86	43	—	—	3	—	191	1.3	3.6
	4	79	57	22	—	—	2	—	214	1.5	—
	8	49	38	11	—	—	1	—	188	1.3	2.9
	16	37	28	9	5	2	2	1	182	1.3	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1300	1	104	60	44	34	5	3	1	207	0.9	1.8
	2	95	67	28	–	–	3	–	206	1.0	–
	4	56	36	20	–	–	2	–	183	1.2	–
	8	44	35	9	–	–	1	–	186	1.2	–
1400	1	169	96	73	46	17	5	3	184	0.4	10.3
	2	70	58	12	–	–	1	–	186	0.6	–
	4	49	32	17	–	–	1	–	179	0.8	–
	8	43	30	13	–	–	2	–	184	0.7	–
	16	35	28	7	5	1	1	1	189	0.6	–
1500	1	32	21	11	7	1	2	1	161	0.6	–
	2	28	18	10	–	–	1	–	171	0.8	–
	4	20	14	6	–	–	1	–	177	0.8	–
	8	17	10	7	–	–	1	–	167	0.9	–
	16	25	19	7	5	1	1	Tr	181	1.0	–
1600	1	105	69	36	28	3	3	1	208	1.3	–
	2	84	58	26	–	–	3	–	189	1.5	–
	4	55	44	11	–	–	3	–	179	1.5	–
	8	41	30	11	–	–	2	–	188	1.7	–
	16	19	12	7	6	1	1	Tr	182	1.7	–
1700	1	105	86	19	14	2	2	1	199	1.3	–
	4	64	40	24	–	–	5	–	206	1.3	–
	8	30	21	9	–	–	1	–	205	1.5	–
	16	50	30	20	12	6	2	1	236	1.5	–
1800	1	52	42	10	–	–	–	–	–	0.6	–
	2	67	50	17	–	–	2	–	190	0.6	–
	8	37	31	6	–	–	Tr	–	193	1.0	–
	16	31	22	9	4	3	1	Tr	223	1.2	–

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	CRYSTALLINE MATERIAL (PPM)			CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
		Suspended Solids (PPM)	Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor-illonite			
1900	1	27	15	12	8	1	2	Tr	210	0.5	–
	2	37	18	17	–	–	1	–	213	0.6	–
	4	57	34	23	–	–	5	–	190	0.5	–
	8	32	25	7	–	–	Tr	–	217	0.4	–
	16	34	23	11	5	3	3	Tr	204	0.6	–
2000	1	32	23	9	5	1	1	1	216	0.3	–
	2	33	21	12	–	–	1	–	221	0.3	–
	4	33	24	9	–	–	1	–	235	0.3	–
	8	37	32	5	–	–	1	–	208	0.3	–
	16	25	16	9	6	6	1	1	220	0.4	–
Location 124+000, Point 5000											
1000	1	437	354	84	52	13	13	4	273	1.1	–
	2	55	39	17	–	–	2	–	272	1.3	–
	4	36	25	11	–	–	1	–	255	1.3	–
	8	38	27	11	–	–	2	–	267	1.3	–
	32	16	9	7	5	1	1	Tr	261	1.5	–
1100	1	146	115	–	22	6	3	Tr	198	1.6	–
	2	172	136	36	–	–	3	–	220	1.5	8.9
	4	150	108	42	–	–	5	–	214	1.5	9.8
	8	115	84	31	–	–	6	–	219	1.7	10.4
	16	81	62	19	–	–	5	–	211	2.1	–
	32	70	53	17	11	4	2	1	169	2.3	–
1200	1	43	34	9	6	2	1	Tr	174	1.4	–
	2	27	6	–	–	–	1	–	181	1.6	–
	4	27	18	9	–	–	1	–	179	1.5	–
	16	29	21	8	–	–	1	–	175	1.9	–
	32	23	16	7	4	2	1	Tr	166	2.1	–

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmor-illonite			
1300	1	63	49	14	8	3	3	Tr	175	1.5	—
	2	52	37	15	—	—	2	—	158	1.4	—
	4	51	36	15	—	—	1	—	145	1.8	—
	8	46	31	15	—	—	3	—	179	1.3	—
	16	31	22	9	—	—	1	—	169	2.1	—
	32	20	14	6	3	1	1	Tr	166	2.2	—
1400	1	49	40	9	6	2	1	Tr	168	1.3	—
	8	37	28	9	—	—	1	—	159	1.8	—
	16	29	18	11	—	—	2	—	151	1.5	—
	32	26	15	11	5	3	2	1	147	1.8	—
1500	1	23	16	7	3	2	1	Tr	179	1.0	—
	2	19	10	9	—	—	1	—	175	0.9	—
	4	27	17	10	—	—	1	—	169	0.5	—
	8	21	15	6	—	—	1	—	171	1.0	—
	16	20	13	7	—	—	1	—	182	0.5	—
	32	18	9	9	6	1	1	Tr	178	0.7	—
1600	1	21	14	7	4	2	1	1	172	1.0	—
	4	33	16	17	—	—	1	—	184	1.3	—
	8	18	13	5	—	—	1	—	171	1.5	—
	16	15	8	7	—	—	1	—	173	1.5	—
	32	13	8	5	3	1	1	Tr	173	1.3	—
1700	1	47	33	14	9	2	2	Tr	151	1.6	—
	2	60	44	16	—	—	3	—	159	1.8	—
	4	54	36	18	—	—	2	—	187	1.6	—
	8	50	37	13	—	—	2	—	183	2.6	—
	16	38	24	14	—	—	1	—	184	2.6	—
	32	27	18	9	7	1	1	Tr	173	2.5	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1800	1	75	56	20	12	5	3	1	213	2.1	–
	2	32	28	4	–	–	1	–	191	1.6	–
	4	85	66	19	–	–	5	–	213	1.8	–
	16	60	37	23	–	–	4	–	221	2.6	–
	32	31	20	11	7	2	1	Tr	204	2.9	–
1900	1	197	124	73	49	10	10	4	243	1.7	–
	2	173	126	47	–	–	7	–	243	1.8	–
	8	152	91	61	–	–	12	–	241	2.1	–
2000	1	81	69	12	6	3	3	Tr	316	1.0	–
	2	116	96	20	–	–	2	–	317	1.3	3.6
	4	75	50	25	–	–	5	–	317	1.2	–
	8	72	45	27	–	–	5	–	303	1.5	–
	32	33	21	12	7	2	2	Tr	333	1.8	–

Location 124+000, Point 6000

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite	Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
0800	1	29	20	9	6	1	1	Tr	425	0.7	–
	2	27	22	5	–	–	1	–	399	0.7	–
	4	28	17	11	–	–	2	–	406	0.7	–
	8	14	9	5	–	–	Tr	–	436	0.6	–
	16	7	4	3	–	–	Tr	–	434	0.8	–
	32	21	13	8	5	2	1	Tr	413	0.7	–
0900	1	18	14	4	2	1	Tr	Tr	407	0.6	–
	2	18	12	6	–	–	1	–	406	0.6	–
	4	16	10	6	–	–	1	–	363	0.6	–
	8	17	12	5	–	–	1	–	371	0.6	–
	16	15	8	7	–	–	1	–	369	0.4	–
	32	16	10	6	3	1	1	Tr	407	0.6	–

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor- illonite			
1000	1	26	20	6	4	1	1	Tr	326	0.7	—
	2	21	15	6	—	—	1	—	325	0.8	—
	4	26	17	9	—	—	1	—	331	0.9	—
	8	16	12	4	—	—	Tr	—	340	1.1	—
	16	11	6	5	—	—	1	—	326	1.3	—
	32	10	6	4	3	1	1	Tr	324	1.5	—
1100	1	78	51	27	15	5	5	2	257	1.2	—
	2	71	43	28	—	—	1	—	244	1.3	—
	4	72	63	9	—	—	1	—	254	1.7	—
	8	68	52	16	—	—	3	—	256	1.7	—
	16	41	32	9	—	—	1	—	225	1.9	—
	32	27	19	8	6	1	1	1	227	2.0	—
1200	1	52	40	12	9	1	1	Tr	219	1.0	—
	2	45	37	8	—	—	1	—	186	1.7	—
	4	38	33	5	—	—	1	—	218	1.7	—
	8	27	22	5	—	—	1	—	204	2.1	—
	16	26	24	2	—	—	Tr	—	210	2.2	—
	32	21	15	6	4	Tr	Tr	Tr	206	2.5	—
1300	1	45	34	11	8	1	1	Tr	209	1.0	—
	2	42	35	7	—	—	1	—	207	1.0	—
	4	22	16	6	—	—	1	—	208	1.4	—
	8	35	29	6	—	—	1	—	201	1.5	—
	16	26	18	8	—	—	1	—	199	1.6	—
	32	25	21	4	3	1	1	Tr	180	1.9	1.3
1400	1	54	41	14	9	3	2	1	178	0.8	—
	2	47	38	9	—	—	1	—	184	1.0	—
	4	39	31	8	—	—	1	—	198	0.8	—
	8	30	25	5	—	—	1	—	198	1.1	—
	16	26	23	3	—	—	Tr	—	203	1.3	—
	32	24	20	4	2	1	1	Tr	180	1.3	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quarz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor- illonite			
1500	1	15	11	4	3	1	1	Tr	182	0.2	—
	2	21	15	6	—	—	1	—	179	0.3	—
	4	19	14	5	—	—	1	—	186	0.3	—
	8	20	13	7	—	—	1	—	176	0.2	—
	16	19	14	5	—	—	1	—	187	0.2	—
	32	20	13	7	4	1	Tr	Tr	173	0.4	—
1600	1	37	26	11	8	3	1	Tr	200	0.8	—
	2	29	20	9	—	—	1	—	217	0.8	—
	4	21	13	8	—	—	Tr	—	204	1.0	—
	8	20	11	9	—	—	1	—	205	1.0	—
	16	15	12	3	—	—	Tr	—	211	1.0	—
	32	13	8	5	4	1	Tr	Tr	206	1.0	—
1700	1	114	86	28	17	6	5	1	175	1.1	6.5
	2	72	53	19	—	—	4	—	182	1.1	—
	4	84	66	18	—	—	2	—	190	1.4	—
	8	68	59	9	—	—	2	—	178	1.6	—
	16	20	11	9	—	—	1	—	172	1.9	—
	32	13	10	3	2	1	Tr	Tr	163	2.2	—
1800	1	97	82	15	12	1	1	Tr	189	1.4	3.3
	2	99	88	11	—	—	2	—	185	1.7	—
	4	94	81	13	—	—	2	—	176	1.8	—
	8	57	50	7	—	—	1	—	185	2.5	—
	16	54	50	4	—	—	1	—	191	2.0	—
	32	32	24	8	6	1	1	Tr	173	2.4	—
2000	1	107	80	27	15	6	5	1	252	0.9	—
	2	87	64	23	—	—	4	—	275	0.7	—
	4	73	55	18	—	—	3	—	278	0.8	—
	8	50	42	8	—	—	1	—	288	0.8	—
	16	31	20	11	—	—	Tr	—	310	1.2	1.3
	32	24	18	6	4	2	1	Tr	317	1.6	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
					Location 180+000, Point 7000						
0900	1	68	48	20	14	3	1	1	1880	1.2	2.8
	2	51	29	22	–	–	1	–	1813	1.4	–
	4	36	20	16	–	–	2	–	1553	1.5	–
	8	27	14	13	–	–	2	–	1441	1.7	–
	16	25	15	10	7	2	2	1	1391	1.7	–
1000	1	83	68	15	10	2	2	Tr	1301	1.7	–
	2	182	120	68	–	–	4	–	1408	1.8	–
	4	87	68	19	–	–	4	–	1357	2.0	–
	8	87	56	31	–	–	3	–	1385	2.1	–
	16	63	43	20	12	4	3	1	1361	2.3	–
1100	1	107	68	39	25	10	3	1	1354	1.9	–
	2	108	68	40	–	–	2	–	1311	2.0	–
	4	99	53	46	–	–	2	–	1329	2.1	–
	8	113	70	43	–	–	3	–	1322	2.1	–
	16	85	45	40	35	2	2	1	1361	2.3	–
1200	1	112	84	28	17	5	5	1	875	1.8	–
	2	115	85	30	–	–	2	–	810	1.8	–
	4	133	80	53	–	–	11	–	829	1.9	8.9
	8	136	103	33	–	–	3	–	835	2.1	–
	16	121	98	23	13	7	2	Tr	806	2.0	–
1300	1	183	137	46	33	5	5	2	649	1.3	–
	2	167	124	43	–	–	3	–	693	1.4	–
	4	115	84	31	–	–	3	–	672	1.5	–
	8	120	94	26	–	–	2	–	675	1.8	–
	16	95	68	27	19	4	3	1	678	1.7	–

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	CRYSTALLINE MATERIAL (PPM)			CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
		Suspended Solids (PPM)	Silt Fraction (Quartz & Feldspar)	Clay Fraction (~2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1400	1	77	56	21	17	2	1	1	571	1.1	—
	2	56	42	14	—	—	1	—	580	1.4	—
	4	71	53	18	—	—	1	—	540	1.2	—
	8	49	37	12	—	—	1	—	560	1.4	4.0
	16	54	37	17	12	3	2	1	536	1.5	5.4
1500	1	30	23	7	5	1	1	Tr	602	.6	—
	2	27	22	5	—	—	1	—	593	.9	—
	4	26	17	9	—	—	2	—	599	.8	—
	8	24	17	7	—	—	Tr	Tr	594	.7	—
	16	23	12	11	10	1	Tr	Tr	603	.7	—
1600	1	97	65	31	15	7	7	1	776	1.4	—
	2	72	50	22	—	—	3	—	768	1.8	—
	4	66	55	11	—	—	3	—	778	1.6	—
	8	60	50	10	—	—	1	—	814	1.6	—
	16	62	48	14	10	2	1	1	767	.9	—
1700	1	145	106	39	28	7	3	1	982	1.4	1.3
	2	92	56	36	—	—	3	—	999	1.1	—
	4	113	69	44	—	—	6	—	1005	1.3	—
	8	92	57	35	—	—	3	—	1150	1.6	—
	16	112	74	38	27	4	4	2	1232	1.9	—
1800	1	173	125	48	40	5	2	2	1280	1.6	—
	2	131	110	21	—	—	3	—	1168	1.5	—
	4	160	134	26	—	—	5	—	1265	.8	—
	8	103	78	25	—	—	4	—	1274	1.1	—
	16	86	71	15	10	3	2	1	1268	.8	—
1900	1	216	153	63	50	6	6	2	1387	1.4	—
	2	97	76	21	—	—	2	—	1334	0.8	4.0
	4	121	90	31	—	—	2	—	1360	0.8	—
	8	119	84	35	—	—	4	—	1379	0.9	—
	16	84	45	39	35	3	1	1	1383	1.0	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor- illonite			
2000	1	94	59	35	29	3	1	1	1511	0.7	—
	2	94	60	34	—	—	1	—	1460	0.6	—
	4	86	63	23	—	—	2	—	1490	0.8	—
	8	75	59	16	—	—	2	—	1558	0.6	—
	16	60	47	13	9	2	2	1	1597	0.8	—
										0.7	

Location 180+000, Point 8000

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor- illonite			
0900	1	145	91	54	36	9	4	4	2160	0.9	5.8
	2	127	85	42	—	—	3	—	2234	1.3	4.2
	4	89	68	21	—	—	2	—	2067	1.1	3.4
	8	54	40	14	—	—	1	—	1943	1.3	—
	32	37	30	7	4	2	1	Tr	1583	1.4	—
1000	1	488	390	98	78	10	10	5	1482	1.4	—
	2	347	264	83	—	—	14	—	1638	1.4	—
	4	265	188	77	—	—	16	—	1588	1.8	17.0
	8	103	80	23	—	—	4	—	1579	2.1	—
	16	45	36	9	—	—	1	—	1478	2.4	3.0
	32	32	26	6	4	1	1	Tr	1458	1.8	—
1100	1	338	254	84	64	14	7	3	1493	1.6	—
	2	379	254	125	—	—	11	—	1508	1.5	—
	32	75	55	16	14	4	4	1	1256	3.2	—
1200	1	156	125	31	22	5	5	Tr	1025	2.0	—
	2	162	130	32	—	—	2	—	1029	2.0	—
	4	142	101	41	—	—	6	—	1042	2.4	9.4
	8	147	119	28	—	—	4	—	1026	2.6	7.2
	16	133	98	35	—	—	7	—	1031	3.1	—
	32	89	54	35	22	7	4	1	978	3.2	—

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TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1300	1	211	158	53	32	8	8	4	857	1.7	—
	2	208	139	69	—	—	10	—	915	2.0	—
	4	200	150	50	—	—	8	—	877	1.9	—
	8	195	152	43	—	—	8	—	831	2.3	—
	16	164	128	36	—	—	3	—	797	2.6	—
	32	119	80	39	30	5	2	2	836	2.9	—
1400	1	488	363	85	73	5	5	5	663	1.3	—
	2	384	319	65	—	—	4	—	638	1.3	—
	4	289	211	78	—	—	12	—	636	1.5	—
	8	158	107	51	—	—	5	—	677	1.4	—
	16	86	65	21	—	—	2	—	657	1.6	—
	32	47	30	17	8	4	3	1	617	1.8	—
1500	1	61	47	14	11	1	1	Tr	641	1.2	—
	8	44	34	10	—	—	1	—	555	1.0	2.5
	16	46	32	14	—	—	1	—	549	1.3	—
	32	42	31	11	8	1	1	1	577	1.0	—
1600	1	269	199	70	48	16	5	5	544	1.2	—
	2	262	186	76	—	—	8	—	612	1.5	—
	4	191	115	76	—	—	8	—	634	1.7	—
	8	146	114	32	—	—	3	—	630	1.8	—
	16	23	68	30	5	1	1	Tr	605	2.3	—
1900	1	124	71	53	37	6	6	4	1894	1.4	—
	2	119	93	26	—	—	2	—	1702	1.7	—
	16	81	53	28	—	—	5	—	1736	2.3	4.7
	32	47	28	19	14	2	2	Tr	1451	2.0	—
2000	1	292	216	76	58	12	6	3	2033	1.4	12.6
	2	171	118	53	—	—	7	—	2134	1.4	—
	4	117	91	26	—	—	2	—	2216	1.4	—
	16	45	34	11	—	—	1	—	1855	1.2	—
	32	38	29	8	3	2	1	Tr	1689	1.0	—

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	CRYSTALLINE MATERIAL (PPM)			CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
		Suspended Solids (PPM)	Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor-illonite			
					Location 180+000, Point 9000						
0800	1	57	42	11	9	3	2	1	2193	0.8	1.0
	2	45	36	9	–	–	1	–	2129	0.6	–
	4	42	32	10	–	–	1	–	2040	0.7	–
	8	42	32	10	–	–	1	–	2039	0.7	–
	16	39	31	8	–	–	2	–	1968	0.6	–
	20	30	23	17	4	1	1	Tr	1618	0.8	–
0900	1	70	55	15	8	3	3	1	2013	0.8	1.1
	2	57	46	11	–	–	1	–	1942	0.8	–
	4	49	35	14	–	–	2	–	1834	0.9	–
	8	36	21	15	–	–	3	–	1858	1.2	–
	16	38	31	7	–	–	1	–	1698	1.6	–
	20	36	23	9	5	1	1	Tr	1442	1.5	–
1000	1	157	119	38	33	2	2	Tr	1841	1.2	–
	2	156	97	59	–	–	3	–	1803	1.2	–
	4	139	75	64	–	–	6	–	1802	1.3	–
	8	118	61	57	–	–	1	–	1700	1.5	–
	16	64	48	16	–	–	2	–	1472	1.5	–
	20	53	32	21	6	1	3	Tr	1366	1.6	–
1100	1	401	305	96	72	8	8	4	1445	1.2	–
	2	373	310	63	–	–	4	–	1540	1.3	–
	4	288	202	86	–	–	12	–	1587	1.3	–
	8	163	124	39	–	–	3	–	1510	1.6	–
	16	66	46	20	–	–	2	–	1252	1.5	5.0
	20	59	42	17	14	1	1	1	1226	1.4	–
1200	1	308	222	86	71	6	6	3	1181	1.0	–
	2	231	162	69	–	–	7	–	1125	1.2	–
	4	148	80	68	–	–	6	–	1187	1.3	–
	8	69	51	18	–	–	3	–	1063	1.4	–
	16	50	38	12	–	–	2	–	1019	1.5	–
	20	48	36	12	6	3	2	Tr	1046	1.2	3.5

TABLE 2 (Continued)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (−2μ size)	Illite	Chlorite	Kaolinite	Montmorillonite			
1300	1	180	128	52	47	2	2	Tr	903	.9	—
	2	167	105	62	—	—	12	—	884	.8	—
	4	132	75	57	—	—	3	—	894	.8	—
	8	174	122	52	—	—	3	—	907	1.1	—
	16	149	97	52	—	1	1	—	826	1.1	—
	20	113	57	56	50	5	2	1	872	1.2	—
1400	1	96	76	20	9	5	5	1	743	0.7	—
	2	102	59	43	—	—	5	—	758	.7	—
	4	103	63	40	—	—	4	—	746	.7	—
	8	81	64	17	—	—	2	—	749	.8	—
	16	72	60	12	—	—	1	—	721	1.0	—
	20	55	36	19	5	3	1	—	747	.9	—
1500	1	224	186	38	25	9	4	2	966	1.3	—
	2	143	102	41	—	—	6	—	932	1.5	—
	4	69	59	10	—	—	1	—	919	1.6	—
	8	34	26	8	—	—	1	—	883	1.5	—
	16	23	16	7	—	—	2	—	896	1.7	—
	20	22	15	7	6	1	Tr	Tr	917	1.7	—
1600	1	60	43	17	11	3	3	1	959	1.6	—
	2	67	53	14	—	—	3	—	981	1.2	—
	4	52	30	22	—	—	2	—	978	1.9	—
	8	69	30	39	—	—	2	—	979	2.3	—
	16	90	48	42	—	—	3	—	1016	2.3	—
	20	70	37	33	20	7	5	1	1049	2.2	—
1700	1	329	234	95	76	10	3	3	1072	1.6	—
	2	241	176	65	—	—	2	—	1145	1.4	4.0
	4	79	55	24	—	—	2	—	1015	1.9	—
	8	45	34	11	—	—	1	—	972	2.2	—
	16	46	30	16	—	—	1	—	980	2.5	3.0
	20	43	37	6	4	1	1	Tr	981	2.8	3.3

TABLE 2 (Concluded)

Time in Hours	Height in Feet Above Bottom	Suspended Solids (PPM)	CRYSTALLINE MATERIAL (PPM)		CLAY MINERALS (PPM)				Dissolved Solids PPM	VELOCITY IN FT/SEC	ORGANICS IN PPM
			Silt Fraction (Quartz & Feldspar)	Clay Fraction (-2μ size)	Illite	Chlorite	Kaolinite	Montmor- illonite			
1800	1	92	64	28	19	5	3	1	1257	1.9	—
	2	90	54	36	—	—	3	—	1283	1.8	—
	4	78	52	26	—	—	2	—	1292	1.7	—
	8	83	60	23	—	—	2	—	1351	1.7	—
	16	89	65	24	—	—	3	—	1362	1.7	—
	20	67	54	13	40	12	3	3	1353	2.3	—
1900	1	76	65	11	8	2	2	1	1470	1.7	—
	2	93	53	40	—	—	2	—	1487	1.1	—
	4	89	58	31	—	—	3	—	1504	1.1	—
	8	87	70	17	—	—	2	—	1498	1.2	—
	16	71	54	17	—	—	3	—	1432	1.6	—
	20	49	38	11	5	3	2	1	1451	1.9	—
2000	1	75	62	13	11	1	1	1	1855	.9	—
	2	95	66	29	—	—	3	—	1912	.8	—
	4	82	66	16	—	—	2	—	1871	.7	—
	8	54	44	10	—	—	2	—	1824	.7	—
	16	49	38	11	—	—	1	Tr	1824	.8	—
	20	35	26	9	5	2	1		1706	.7	—

FIGURE I-C. Index map showing suspended sample locations in Delaware River

ANNEX D

METHODS OF ANALYSES

ANNEX D. METHOD OF ANALYSES

METHODS OF ANALYSIS

INTRODUCTION

A description of the techniques used in the Delaware estuary investigation is given here for comparison with the work of others whose methods may be somewhat different. Several of the techniques described, used to establish the quantitative values of amorphous and organic materials, include a combination of mass spectograms, differential thermal and thermogravimetric analysis. Flocculation studies also combine electron diffraction and the x-ray microprobe for evaluation of surface coatings on mineral surfaces.

GRAIN SIZE ANALYSIS

The grain size distribution of the sediment was performed by sieve and hydrometer analysis methods and a cumulative grain-size accumulation curve constructed to classify the sediment texture as well as for use in computation of sedimentary parameters. The upper clay-size limit used is that as defined by Lambe and Whitman (1969) and in accordance with current ASTM and American Society of Civil Engineers directives at 0.002 mm (2 microns). In the triangular texture diagrams for sediment types reported in this investigation, the 200 sieve-size (74 microns) separates the silt from sand and the 2 micron size separates silt from clay.

HEAVY MINERAL ANALYSIS

The methods used in determining the heavy mineral concentration and identification of heavy mineral varieties in the sediment has been described in detail in Annex B. The techniques used are standard methods such as described by Folk (1968) and Krumbein and Pettijohn (1938) as well as the use of the Franz Isodynamic Magnetic Separator and x-ray diffraction unit to confirm petrographic techniques. The flow diagram for the magnetic separation used on 12 of the samples is depicted in Annex B as Figure 1B. Results obtained by the combined method add greater confidence to the reported values of this investigation. Actinolite, for example, with its higher iron content than tremolite was easily separated by magnetic techniques and the fractions verified by x-ray diffraction analysis. Bundles of sillimanite needles were also collected by use of the magnetic separator and verified by means of x-ray diffraction.

SAND ANALYSIS
LIGHT FRACTION

The sand was fractioned into a +40, +60, +100 and +200 sieve size and examination of 100 grains made on each sieve size with the binocular microscope. The fine sand sizes on the 100 and 200 sieves were also examined with the petrographic microscope using index oil immersion techniques.

X-RAY DIFFRACTION ANALYSIS OF BOTTOM SEDIMENT

The silt and clay size materials (finer than 74 micron) comprises the bulk of the bottom sediment in the study area except for locations in the lower bay and continental shelf area. This material was air dried and passed through a 200 sieve and representative powder press samples were x-rayed with Ni filtered Cu K2 radiation. Glycolated sedimented slides were also x-rayed to determine the presence of montmorillonite. Material between the 74 and 44 micron size was identified by both x-ray diffraction and petrographic microscope techniques.

Quantitative mineralogical analysis of the fines is difficult because a given clay mineral may have a range of composition, crystallinity, grain size, or combinations of these. The effect of these variables based on intensity parameters could result in errors of 100 percent or more. A technique to eliminate most of the errors is to effect identification by standard methods as outlined by Brown (1961) and Grim (1968) and consider the results a first estimate. When the minerals in the samples are identified, at least two synthetic mixtures are made using reference minerals to bracket the background x-ray intensity and composition of the sample being studied. The synthetic mixtures are proportioned to contain the constituents identified in the first approximation in amounts that differ by about 5 to 20 percent for each mineral. This data allows a second estimate for establishing a more exacting figure for the various components. For mixtures tested, it is estimated, based on this investigation and other studies that errors are reduced to less than 10 percent for each mineral in the mixture.

X-RAY DIFFRACTION ANALYSIS OF SUSPENDED SEDIMENT

A semiquantitative technique of considerably less accuracy than that described for the bottom sediment was necessary because of the limited size of the material collected on the 0.45 micron millipore filter from the suspended samples. The millipore filter sample previously used to determine suspended load or particulate matter was trimmed to fit a conventional glass microscope slide and fixed flat. X-ray diffractograms thus obtained from the millipore-mounted slides were analyzed by an approximate intensity method as follows:

a. Feldspar was computed as one times the 3.21 A peak intensity.

b. Quartz was computed as three times the 4.26 A peak intensity.

c. Illite was computed as two times the 10 A peak intensity.

d. Chlorite was computed as one times the 3.54 A peak intensity. The 14.5 A peak intensity after glycol treatment was also used to verify the chlorite.

e. Kaolinite was computed as one times the 3.58 A peak intensity. The 7.15 A peak intensity was also used as a check after chlorite had been evaluated.

f. Montmorillonite was computed as one times the 17A peak intensity of the glycolated sample. Values seldom exceeded more than 5% of the clay fraction.

g. Vermiculite was computed as one times the 14.5 A peak if glycol did not move the material to 17 A and HCl treatment did not remove the peak.

The approximation of crystalline constituents determined by peak intensity values while less quantitative than that used on bottom sediments provided basic information of value in consideration of composition and grain size. Where sufficient suspended sample was available, the material was scraped from the millipore filter and a powder press sample prepared for analysis; an approximation of organic content was also accomplished on some of these samples by the hydrogen peroxide leaching method after being subjected to x-ray analysis.

The grain size of the suspended samples is also approximated since any grain less than 74 micron size is considered silt or clay. Since investigation has disclosed that quartz, feldspar, and minor mica constitute silt size and the clay minerals constitute clay-size, these fractions are also an expression of the texture. Organic matter seldom exceeds 16 percent of the suspended samples in the area studied and differential thermal analysis of fractionated Marcus Hook shoal sediments has disclosed predominant occurrence in less than 5 micron size.

X-RAY DIFFRACTION TECHNIQUE FOR DIATOMS

The x-ray diffraction method described by Goldberg (1958) employs an internal standard and was used to determine the diatom concentration in the bottom sediments. This method converts the opaline silica to cristobalite by heating and using x-ray diffraction to measure the cristobalite peak heights. The samples were first treated with 10 percent H_2O_2 and warmed to destroy organic material. The dry sample was then mixed with alumina powder in precisely 1 to 1 ratio and heated in a porcelain crucible at 1000°C for 4 hours for the conversion of opal to cristobalite. After cooling, the sample was reground and a powder press sample in an aluminum planchet prepared for x-ray diffraction analysis. A standard calibration curve for the determination of diatoms was prepared with the same diatom source used for the differential caustic leach method for this curve, the peak height of the cristobalite peak at 4.04 A was divided by the alumina peak height of 3.47 A to give the ratio for the plot versus weight percent of opal.

ELECTRON MICROSCOPE ANALYSIS OF FINES

Scanning electron micrographs and carbon replica micrographs were obtained on sediment samples with the Cambridge Stereoscan II scanning electron microscope at the Analytical Instrumentation Laboratories of Georgia Tech's Engineering Experiment Station. Specimen of air dried fines were magnified from 10,000 to 45,000 times for identification of diatom genera and other discrete sediment particles. Point counts of diatoms in the sediment was also used to supplement the quantitative chemical techniques for this amorphous material.

ELECTRON DIFFRACTION AND MICRO-PROBE ANALYSIS

Electron diffraction patterns were also obtained of thin films on silt-size quartz particles for identification of these amorphous coatings. The identification of these thin films on the particle surface was not possible by x-ray diffraction because the thickness of the layer was not sufficient. The low penetrating power of the electron beam, however, enables a graphic presentation of the atom arrangement on the immediate surface and thus enable identification of the film. Amorphous iron coatings were thus identified which were known from microprobe investigation. The microprobe had revealed both high silicon and iron content in similar areas of quartz-rich samples and provided the preliminary information concerning the thin film.

ORGANIC MATTER ANALYSIS—COMBINED METHOD

The bottom samples were analyzed by a combined DTA, TGA, and mass spectrograph technique described by Neiheisel (1972) to separate the low temperature organic matter from anthracite coal. The use of this method requires prior knowledge of all mineral and amorphous hydrous materials such as opaline diatom tests which contain water as well as other ma-

terials which are combustible at temperature less than 950°C. The generalized equations used in this method are as follows:

a. Organic matter = TGA weight loss (110°-550°C) —Water loss from minerals (including amorphous iron minerals) and diatoms (110°-550°C).

The calculated weight loss due to dehydration of minerals for the 110°-550°C temperature ranges approximates the sum of the weight percent for each of the following compounds: 7% kaolinite; 2.2% illite; 3% chlorite; 10% montmorillonite; 2% glauconite; 6% hydrous iron compounds; 4% diatoms.

b. Anthracite coal = TGA weight loss (550°-950°C) -Water loss from minerals and diatoms.

The calculated weight loss due to dehydration of minerals for temperatures greater than 550°C approximates the sum of the weight percent for each of the following minerals: 2% diatoms; 7% kaolinite; 2.2% illite; 6% glauconite; 44% calcite.

Quantitative evaluation of anthracite coal for comparison with earlier investigations employed a chemical method outlined in House Document 529 (1946) and consists of the following steps:

a. A sufficient portion of the sample as received was dried at 105°C ± 1°C., for 2 hours and mixed well; this prepared the sample for analysis on a dry basis.

b. A 1-gram portion was ignited in a platinum crucible to constant weight.

This determination gave the total loss on ignition consisting of volatile matter (organic) and coal.

c. A second 1-gram portion of the dried material was treated with chemically pure nitric and hydrochloric acids. evaporated to dryness, and then taken up with dilute hydrochloric acid. filtered through a prepared Gooch crucible, dried at 105° C.. ± 1° C.. for 1 hour, and the weight of crucible and contents was recorded. The crucible and contents were then ignited to constant weight, and the loss in weight recorded as coal.

d. The value obtained in paragraph B minus that obtained in paragraph C equals volatile matter (organic). The value obtained by subtracting the result of paragraph B from the original weight (dry basis) is the natural earthy materials. The result of the determination in paragraph C is a value for coal. In this procedure. the weight of the ash of the coal appeared as natural earthy material. Application of a percentage representing ash content of coal. corrects the values obtained for coal and natural earthy materials.

The coal was divided by 0.783. a factor obtained from studies of prototype coal material. to report the results as percent of mine waste in the sample. This method was used to supplement the combined DTA. TGA. and Mass Spectrometer method previously described.

CHROMATOGRAPH—ORGANIC METHODS

Nineteen bottom sediments and four suspended samples from the water column were

analyzed by chromatographic techniques to determine the nature of the organic pollutants in the sediment. The samples were analyzed by J. H. Reuter (1970) for prototeinaceous matter, (amino acids) carbohydrates, hydrocarbons, and oxygen-containing substances (fatty acids). Analysis of amino acids consisted of subjecting 0.5 g of freeze-dried sediment to acid hydrolysis (6N HCl) for 22 hours at 110° C under nitrogen atmosphere; the sample was then centrifuged and HCl removed by evaporation under reduced pressure. The sample was desalted on a cation-exchange resin and an aliquot analyzed on the automatic amino acid analyzer. Carbohydrate analysis consisted of digesting a 3 g. freeze-dried sample in cold concentrated (72%) sulfuric acid for 3 hours and diluting the solution to 0.5 N prior to hydrolyzation of the sample at 110° C for 10 hours; the hydrolyzate was centrifuged and neutralized with $BaCO_3$, then desalted on a sequence of cation-anion-cation exchange resin. After concentration to dryness, samples are dissolved in 1 ml ethanol (60%). Aliquots of 5 microliters were then potted on thin-layer chromatoplates (silica gel) and chromatographed with a variety of solvent systems. Semi quantitative estimates of the carbonates were made by comparing the spots obtained from spraying sulfuric acid-ethanol mixture on the sample with a standard. The hydrocarbons and fatty acids analysis consisted of extracting 150 g. of freeze-dried sample by sonication with three 150 ml portions of a benzene-methanol (90:10) mixture. The residue was determined gravimetrically; the n-hexane fraction was also determined gravimetrically. An aliquot of the n-hexane soluble fraction was used for silica gel chromatography. Sample placed on a silica gel column were collected using n-hexane, carbon tetrachloride, benzene and finally methanol (in this order) as eluants. Each fraction was taken to dryness by evaporation under a stream of filtered nitrogen, and then measured gravimetrically The silica gel chromatography of the n-hexane soluble

fraction of the solvent extractable organic matter yields some interesting results. The fraction eluted by n-hexane contains normal and branched alkanes; the carbon tetrachloride fraction contains mostly cyclic alkanes; the benzene fraction is mostly composed of aromatic hydrocarbons; the methanol fraction contains mostly oxygen-containing compounds, probably predominantly fatty acids.

OIL AND GREASE AND C.O.D. METHODS

Oil and grease was determined at South Atlantic Division Laboratory for total sample by the hexane extraction method. The acidified sediment was dried by mixing with magnesium sulfate monohydrate prior to extraction by hexane in the Soxhlet extraction apparatus.

The chemical oxygen demand (C.O.D.) was performed on shoal sediment and spoil samples at South Atlantic Division Laboratory to reflect upon the reducing power of the organic materials. The method used is as outlined by APHA (1965) and consists of adding $K_2Cr_2O_7$ solution to a sample size sufficient to consume one half of the $K_2Cr_2O_7$: $HgSO_4$ and Ag_2SO_4 solutions are then added to the sample which is further diluted with distilled water prior to addition of concentrated sulfuric acid followed by boiling and reflux for 2 hours. After cooling the sample was titrated, using ferrion indicator, to end point with $Fe(NH_4)_2(SO_4)_2$.

NITROGEN ANALYSIS OF BOTTOM SEDIMENTS

Nitrogen in the bottom sediments was limited to the total Kjeldahl nitrogen method. The total Kjeldahl nitrogen includes ammonia and organic nitrogen, but does not include nitrite and nitrate nitrogen. This method, using mercuric sulfate as a catalyst, converts organically bound nitrogen in the tri-negative state

to ammonium bisulfate by digestion with sulfuric acid to which potassium sulfate has been added to raise the boiling point to 345°—370° C. The temperature should not exceed 382°C or loss of nitrogen will result. After dilution, the solution is made alkaline with sodium hydroxide and the ammonia is distilled into 2 percent boric acid · solution. The distillate containing the nitrogen is determined by titration with 0.02N H_2SO_4, using a mixed indicator. In the presence of large quantities of nitrogen-free organic matter, it is necessary to add an additional 50 ml of sulfuric acid-mercuric sulfate-potassium sulfate solution for each gram of solid material in the sample. Because organic nitrogen in unsterilized sewage and sludges is continually ammonified, the determination must be made on a freshly collected sample. All samples should be well iced and no preservative added and sample containers filled only three-fourths full to prevent breaking when frozen.

AMORPHOUS HYDROUS IRON OXIDE METHOD

The amorphous and low temperature iron compounds were extracted from the sample by the sodium dithionite method as described by Jackson (1968). This iron method excludes high temperature iron such as occurs in clay minerals, magnetite, and other ferromagnesian silicates. In this method, removal of iron oxides from sediment employs sodium dithionite ($Na_2S_2O_6$) for the reduction, sodium bicarbonate as a buffer, and sodium citrate as a chelating or complexing agent for ferrous and ferric iron. The determination of the iron extracted by the dithionite was accomplished by the color-metric method employing thiocyanate. The color determination was obtained from a Beckman spectrophotometer and iron determination made by comparison with standards.

HEAVY METAL ANALYSIS

Heavy metal analysis was made on 75 bottom sediment and spoil samples by Law and Company of Atlanta, Georgia using atomic absorption techniques. Analysis was made on air dried sediment and results reported in milligrams per 1000 grams of sediment. Heavy metal analysis was also performed on leachates from the dithionite iron analysis to determine the concentration of these metals with low temperature iron.

In the atomic absorption technique, metal complexes are freed by digestion of bottom sediment samples with concentrated HNO_3 acid H_2O_2 (30%). A wide range of elements can be determined by atomic absorption with the selection of the proper source (hollow cathode lamp). The principle of atomic absorption and its application to the analysis of metals is based upon the element of interest being dissociated from its chemical bonds and placed into an unexcited, un-ionized "ground" state. It is then capable of absorbing, at discrete lines of narrow band width, radiation provided by a hollow cathode lamp with a cathode made of the element being sought. The absorption of the light by the metal in the ground state is related to the concentration of the metal being sought.

ARSENIC ANALYSIS

Arsenic was determined by the silver diethyldithiocarbamate method. In this method organic arsenic compounds are reduced to arsine by zinc in an acid medium. The resulting mixture of gases is passed through a scrubber containing pyrex wool impregnated with lead acetate solution and into an absorbing tube containing silver diethyldithiocarbamate dissolved in pyridine. Arsine reacts with silver diethyldithiocarbamate to form a soluble red substance having maximum absorbance at about

535 mu. The absorbance of the solution is measured spectrophotometrically and arsenic is determined by reference to an analytical curve prepared from standards.

PHOSPHATE ANALYSIS

Phosphate analysis was performed on bottom sediment utilizing the ammonium molybdate and hydrazine sulfate method for total phosphorus. This technique does not suffer interference from arsenic, iron, tungsten, silica, titanium, zirconium, and vanadium. The ammonium molybdate and hydrazone sulfate react in an acid medium with dilute solutions of orthophosphate to form a heteropoly acid (phosphomolybdic acid) which is reduced to an intensely colored molybdenum blue by sodium sulfite. The intensity of blue color was determined on a Beckman spectrophotometer with an infrared phototube operated at 800 mu.

ELECTROPHRETIC MOBILITY MEASUREMENTS

Electrophoretic mobility measurements were made on shoal sediments of less than 74 micron size in a Micromeritics Model 1202 Electrophoretic Transport Analyzer in a pH range of 4 to 8: solutions of NaOH and HCl were used to control the pH of the cell samples.

Beneficiated and artificially prepared minerals were also subjected to the range of measurements performed on the prototype sample.

DIATOM ANALYSIS

Scanning electron micrographs were made of the shoal sediments and several locations from the tributary streams and bay area for qualitative estimates of diatom tests and morphological features of the diatoms for identification of genera. In oder to obtain quantatitive data of more than 75 bottom sediment samples, the differential caustic leach methods described by Hashimoto and Jackson (1960) and Follet, et al (1966) for soil analyses was adapted to this investigation as well as correlating tests involving x-ray diffraction techniques (Goldberg, 1958) previously described. A standard curve was constructed using prototype sediment previously analyzed microscopically to assure the presence of but negligible amounts of diatoms or other biogenous silica and adding to this sediment known amounts of diatoms. The resulting silica dissolved by 0.5 N sodium hydroxide during a 2½ minute boil was determined by chemical analysis and this weight percent of silica divided by the total available silica (obtained by chemical analysis of the total sample) was used to obtain the approximation of diatoms from the standard curve.