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**U.S. DEPARTMENT OF COMMERCE**
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

# Assessment of Offshore Dumping in the New York Bight, Technical Background: Physical Oceanography Geological Oceanography Chemical Oceanography

ROBERT L. CHARNELL, Editor

BOULDER, COLO.
APRIL 1975

U.S. DEPARTMENT OF COMMERCE
Rogers C. B. Morton, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

ENVIRONMENTAL RESEARCH LABORATORIES
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Atlantic Oceanographic and Meteorogical Laboratories
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## PREFACE

In late 1973 and early 1974, attention in the scientific community was focused on consequences of sewage sludge dumping in the apex of the New York Bight. Newly acquired data seemed to indicate a change was occurring in the movement and distribution of sludge material in bottom sediments. To some university scientists, it appeared that increases in the rate of disposal had produced a quantity of sludge that could no longer be assimilated by the environment; the alarm was sounded that if the dumping continued at the same rate, irreversible contamination would occur to the beaches of Long Island within a few years. A call for immediate relocation of the present dumpsites was made.

Early in August 1974, United States Senator James L. Buckley convened the Subcommittee on Environmental Pollution of the Senate Public Works Committee for a public hearing on the sewage sludge dumping issue. The subcommittee was eliciting facts in the matter, in order to make an informed recommendation regarding dumpsite relocation.

The National Oceanic and Atmospheric Administration (NOAA) was asked to provide testimony at this hearing. Since 1973, NOAA had been conducting a large scale examination of the New York Bight marine ecosystem and had been collecting relevant data in the apex that could shed light on the suggested irreversible degradation of the environment. NOAA's Atlantic Oceanographic and Meteorological Laboratories (AOML) had been collecting data for the Marine Ecoystems Analysis (MESA) Program in the apex since July 1973; with these and historic data, a picture of the present conditions and reasons for and rates of change were beginning to emerge.

This report is a summary of AOML analyses of the apex ecosystem as we understood it at the end of July 1974. The three parts represent three different single-discipline views of a complex ecosystem. Because our research has not been completed, conclusions of this report must be considered tentative; they are nevertheless immediately useful in preliminary assessments of the environmental significance of sewage sludge dumping in the New York Bight apex.

Robert L. Charnell
November 1974

Technical Report ERL 332-MESA 3 supersedes
Technical Memorandum ERL MESA-1.

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ABSTRACT

Physical Oceanography: Analysis of historic and MESA data shows two distinct circulation regimes. 1) Near the harbor mouth and along the New Jersey coast, New York Harbor discharge flows southward parallel to the New Jersey coast; at depth, there is a return flow of external water into the estuary. In spite of its importance in the oceanographic and ecological systems of the region, this superposed flow system is recognized in measurements as only a slight imbalance of much stronger ebb and flood tidal currents. 2) Outside the region of strongest influence from river discharge, a persistent clockwise circulation or eddy appears to exist. In the eddy's most inshore portion, flow is toward the north and east, counter to the general flow over the continental shelf adjacent to this part of the coast. Details of its horizontal extent, its vertical structure, and its persistence are imperfectly known at present.

Geological Oceanography: Fine-grained waste dumped in New York Bight is entrained in a clockwise circulation pattern and is dispersed to the north. A significant portion is deposited in the low area (Christiaensen Basin) immediately northwest of the dumpsites. The fraction of finer dredge spoils and the bulk of sewage sludge is widely dispersed through the Bight apex in highly dilute form. There are no "pure" sludge beds; there has been no detectable aggradation of the sewage sludge site since 1936. However, the Christiaensen Basin, a natural zone of mud deposition, appears to be significantly contaminated with sewage sludge. Near Long Island beaches, there are scattered, thin, small patches of mud, physically indistinguishable from natural mud patches on similar, less populous coasts. Microscopic examination of samples indicates that less than 3 percent of the resolvable particles in these patches are of artificial origin, the lowest contamination level detected by microscopic technique in the Bight apex. No evidence for a front of sewage sludge approaching the Long Island shore was observed.

Chemical Oceanography: Data from water sampling show that nutrient (nitrates, nitrites, silicates, and phosphates) distributions are dominated by the lower New York Bay outflow, with dumped sewage sludge contributing very small amounts. Bottom grab samples were analyzed for total organic carbon and total carbohydrates. The carbohydrate/TOC ratio indicates that the whole Bight contains some sewage-derived materials with the greatest concentration in the Hudson Shelf Valley, in the Christiaensen Basin, and north of the geographical sewage sludge dumpsite. This is consistent with the distribution expected if sewage sludge were disseminated throughout the apex by the hypothesized current pattern (gyre). Although carbohydrate/TOC ratios in sediments throughout the area close to Long Island suggest the presence of sewage-derived material, low TOC values found in all but isolated pockets demonstrate that contaminant material comprises only a small fraction of the sediments.

# 1. PHYSICAL OCEANOGRAPHY; WATER MOVEMENT WITHIN THE APEX OF THE NEW YORK BIGHT

Robert L. Charnell, Dennis A. Mayer, Donald V. Hansen

## 1.1 INTRODUCTION

The Marine Ecosystems Analysis (MESA) New York Bight Project is in the field phase of a program to evaluate changes in the water quality of the region. The physical oceanographic part of the effort is oriented to supplying information that will lead to understanding the mechanisms of water movement and material dispersion and eventually result in predictive models for coastal zone planners and managers.

MESA measurements in the apex were begun in mid 1973 and at the time of this writing only preliminary analyses of these data have been completed. Heretofore only scattered direct measurements of currents had been made and these dominantly were in the apex. Data from these measurements were inadequate to describe temporal and spatial structure of flow, but were useful in designing the MESA measurement program.

Present interest in the structure of water movement around the apex dumpsites southeast of Ambrose Light Station required an evaluation of what is known about flow in this area. At present the picture can only be general, with a quantitative description to be supplied as analysis of MESA data progresses. This summary report is based on two data sources: the historic data from a seabed and surface drifter program conducted by the National Marine Fisheries Service Sandy Hook Laboratory in 1969 and from the two measurement efforts conducted for the MESA program in the last half of 1973.

The general movement of water over the continental shelf off southern New England and the Middle Atlantic States is to the west and south, parallel to the continental margin. The net current is, however, masked by high spatial and temporal variability. Structure of the spatial variability in currents of the Bight apex has been a prime focus of the MESA project; temporal variability is the principal impediment to its rapid elucidation. The major features of the spatial structure of circulation that relate to disposal of waste materials in shelf waters of the New York Bight are as follows:

a. In the immediate vicinity of the entrance to the Hudson and Raritan Rivers estuary, the oceanographic regime is dominated by influence of discharges from these rivers. As in all such estuaries, there is a seaward flow of brackish water in surficial layers. At sea, this discharge turns to flow southward, paralleling the New Jersey shoreline. Lower in the water column, there is return flow of Bight water into the estuaries.

This two-layer flow appears in measurements only as a slight imbalance of the much stronger ebb and flood tidal currents in the respective layers.

b. There is strong evidence from recent MESA results that outside the region of strongest influence from river discharges, there is a persistent clockwise circulation or eddy. In the eddy's most inshore portion, off New Jersey and Long Island, flow runs counter to the general flow over the continental shelf adjacent to this part of the coast. Details of the seaward extent and vertical structure of the eddy are imprefectly known.

The evidence on which these statements are based is developed in sequel.

## 1.2 LAGRANGIAN MEASUREMENTS USING SURFACE AND SEABED DRIFTERS-1969

Data from the Sandy Hook Laboratory's 1969 study most relevant to movement of materials by currents in the New York Bight resulted from deployment of Lagrangian drifters which measure water movement at the surface and bottom of the water column. Reaction of these drifters to water movement approximates that of other small movable objects at the surface and near the seabed. Their behavior thus provides a direct estimate of the effect of water movement on the transport and dispersal of sewage sludge and dredging spoils. The seabed drifter is a positively buoyant plastic saucer (18 cm diameter) fastened to a small diameter stem 54 cm long. The free end of this stem is weighted so that the whole drifter has slight negative buoyancy. Surface drifters used for the study were small bottles, ballasted to float vertically and to present a low above-surface profile to minimize wind effects. Drifter movement in the marine environment is effected by advective and dispersive processes, each with many time and space scales. Recovery data represent a time and space integral of these processes, about which little structural information is available.

### 1.2.1 Temporal Variations

During 1969, drifters were deposited along a grid of 23 stations on approximately a monthly basis. Of the 1886 surface drifters released, 497 or about 26% were recovered by the public and returned to the project office. Of the 2190 seabed drifters released, 710 or about 32% were returned. This represents the total release and recovery for all stations during 1969 without regard to temporal variations. These rates of return are very high for this type of sampling. Data on the rate of return for all stations as a function of time are presented in figure 1.1.

The central portion of the figure shows rate of return for surface drifters released at times indicated by dots while the bottom portion shows rate of return for seabed drifters released at times also indicated by dots. The uppermost part of the figure shows the weekly mean wind vectors at Ambrose Light Station during 1969. Winds showed a dramatic shift in mean direction from northerly to southerly during March and April. Winds continued to be from the south and weaker until near the end of September when another shift to northerlies occurred. During spring and summer the winds exhibited a diurnal periodicity in the north component.

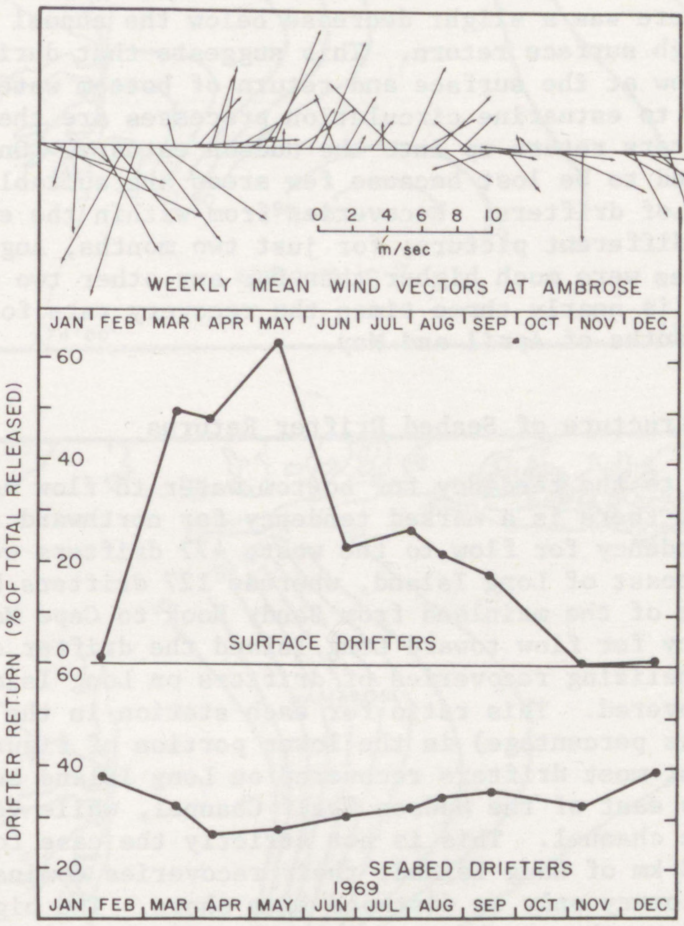



*Figure 1.1 Time history of drifter returns compared with wind at Ambrose Light Station.*

It is apparent from the surface drifter returns that wind-induced effects tended to dominate surface circulation. In the early part of the year when winds were from the north-northwest, virtually no surface drifters were recovered; they undoubtedly were swept out to sea. Conversely, during spring and summer, winds pushed surface water, and hence drifters, in toward the Long Island beaches. Then during late summer and fall, recoveries decreased as the winds became variable and ultimately switched toward the southeast. It is not likely that decreased beach traffic in winter months accounted for the decline of surface drifter returns since returns of bottom drifters had a slight maximum for this period.

In general, however, return of seabed drifters showed only slight seasonality. There was a slight decrease below the annual average during the period of high surface return. This suggests that during the spring when river outflow at the surface and return of bottom water into the harbor mouth due to estuarine circulation processes are the strongest, more seabed drifters return up into the Hudson estuary. Once inside the estuary, they tend to be lost because few areas are suitable for beaching and recovery of drifters. Recoveries from within the estuary tend to show a slightly different picture; for just two months, August and September, recoveries were much higher than for any other two month segment. This higher rate is nearly three times the recovery rate for the more nearly average months of April and May.

### 1.2.2 Spatial Structure of Seabed Drifter Returns

In addition to the tendency for bottom water to flow northwest into the Hudson mouth, there is a marked tendency for northward flow with only a slight tendency for flow to the west; 477 drifters were recovered along the south coast of Long Island, whereas 127 drifters beached along the eastern coast of the mainland from Sandy Hook to Cape May. To examine the tendency for flow toward Long Island the drifter data have been organized by normalizing recoveries of drifters on Long Island to the total number recovered. This ratio for each station in the apex grid has been presented (as percentage) in the lower portion of figure 1.2. The data indicate that most drifters recovered on Long Island beaches originated at stations east of the Hudson Shelf Channel, while very few originated west of the channel. This is not strictly the case for drifters released within 8 km of Long Island; their recoveries dominantly show a dependence of recovery only on distance from shore. The high rate of relative return from the south central portion of the apex suggests that dominant long period flow is toward the north. The general impression conveyed by this year of bottom drifter data leads to the hypothesis of general clockwise circulation in the Bight.

This picture is consistent with the rates of return of seabed drifters released near the existing sewage sludge dumpsite. Return rate for those drifters was slightly lower (24%) than the overall return rate of seabed drifters (30-40%), but still relatively high. Two-thirds of recoveries for drifters released near the dumpsite were on Long Island. The drifters did not move rapidly across the 19 km to the beach.

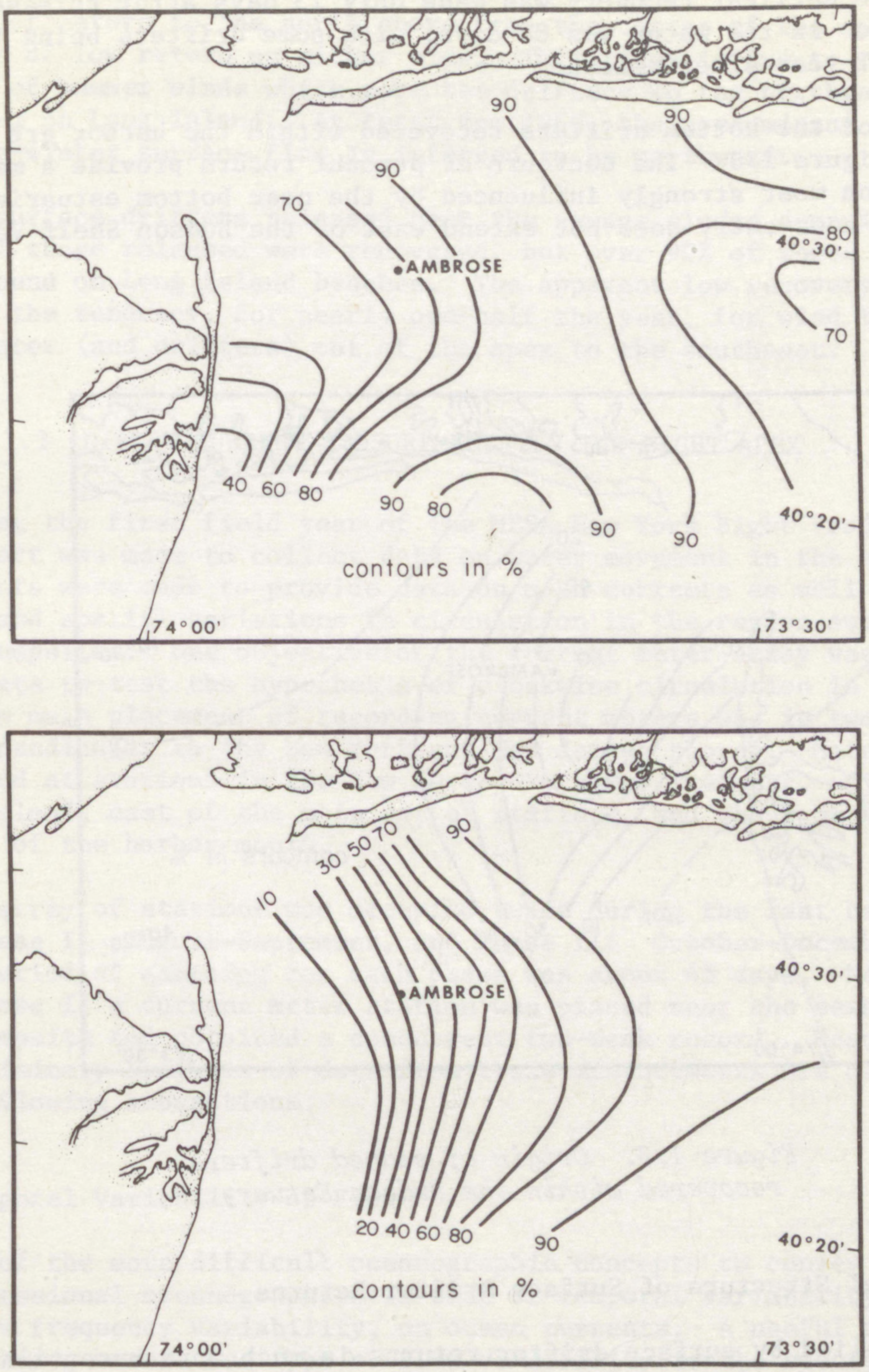



*Figure 1.2 Origin of drifters recovered on Long Island. Contours are of total recovered on Long Island as percent of all returns from individual stations. Upper panel: Surface drifters. Lower panel: Seabed drifters.*

Although the earliest recovery was made only 13 days after release, the average time in the water was 88 days, with some drifters being found as much as 1 year after release.

Data for the bottom drifters recovered within the harbor are presented in figure 1.3. The contours of percent return provide a measure of the region most strongly influenced by the near bottom estuarine flow. This effect apparently does not extend east of the Hudson Shelf Valley.

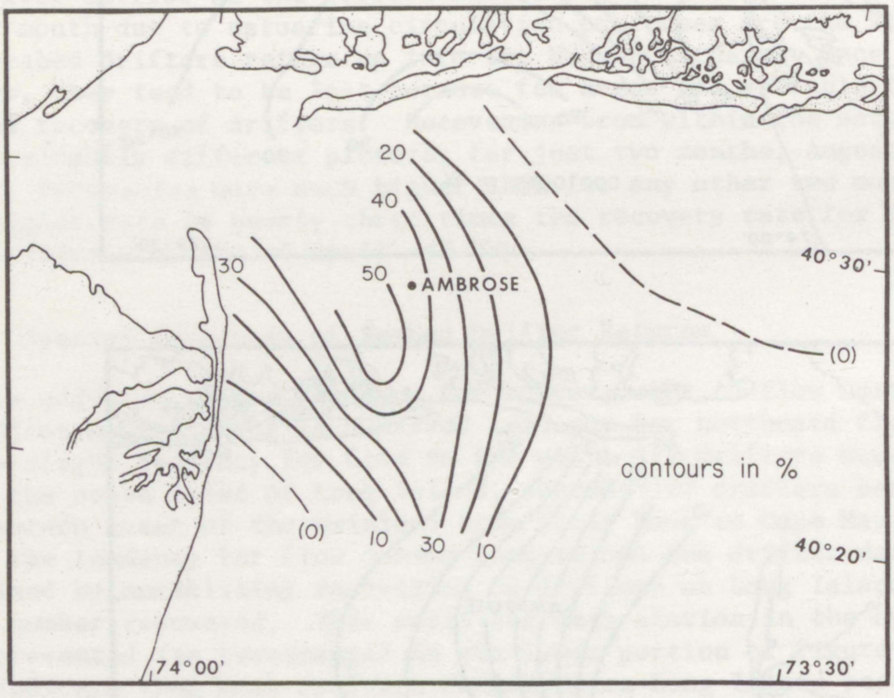



*Figure 1.3. Origin of seabed drifters recovered within the Hudson Estuary.*

### 1.2.3 Spatial Structure of Surface Drifter Returns

Flow implied by surface drifter returns is much more uncertain due to a higher degree of variability induced by the winds. However, it is clear from the data that drifters released closest to Long Island's south shore had the greatest incidence of shore recovery. In a manner similar to that used to show the seabed drifter recoveries, the origin of release for the 406 drifters collected on the south shore of Long Island is shown in the upper segment of figure 1.2. There is a ridge of high rate of return to the north shore from the center of the apex with areas of low return on either side. This ridge is due to the incidence of summer winds which move the drifters to the northward and ground them on Long Island. At least for 1969, the predominant character of non-winter surface flow is inferred to be northward.

For surface drifters released near the sewage sludge dumpsite, only 17% of all those released were recovered, but over 90% of those recovered were found on Long Island beaches. The apparent low recovery rate is due to the tendency, for nearly one-half the year, for wind to blow surface water (and drifters) out of the apex to the southeast.

## 1.3 DIRECT CURRENT MEASUREMENTS IN THE BIGHT APEX

During the first field year of the MESA New York Bight Project, a major effort was made to collect data on water movement in the apex. Measurements were made to provide data on mean currents as well as temporal and spatial variations in circulation in the region surrounding the dumpsites. One objective of the current meter array was to provide data to test the hypothesis of clockwise circulation in the apex. The main placement of recording current meters was in two transects perpendicular to the New York and New Jersey shores. Meters were also placed at stations in the New Jersey-Rockaway transect, adjacent to Long Island, east of the main set of stations, and about 56 km southeast of the harbor mouth.

The array of stations was occupied twice during the last half of 1973: Phase I: August-September, and Phase II: October-December. Maximum period of sampling for each phase was about 45 days. Near the end of Phase I, a current meter station was placed near the sewage sludge dumpsite and obtained a concurrent two-week record. Results from preliminary analysis of data from these measurements are discussed in the following subsections.

### 1.3.1 Temporal Variability of Flow

One of the more difficult oceanographic concepts to convey to other than professional oceanographers is that of temporal variability, especially low frequency variability, on ocean currents. A useful technique for displaying amount and type of flow variability is the spectrum function for energy of the flow. Two such spectrum functions are shown in figure 1.4. The curves, denoting energy in the east component of flow at station F for Phase I and II, are typical of nearshore current measurements in the Bight. The major features of these functions are the peaks that occur near periods of 12 hours, 19 to 25 hours, and at the left-hand limit. Respectively, these peaks are associated with the

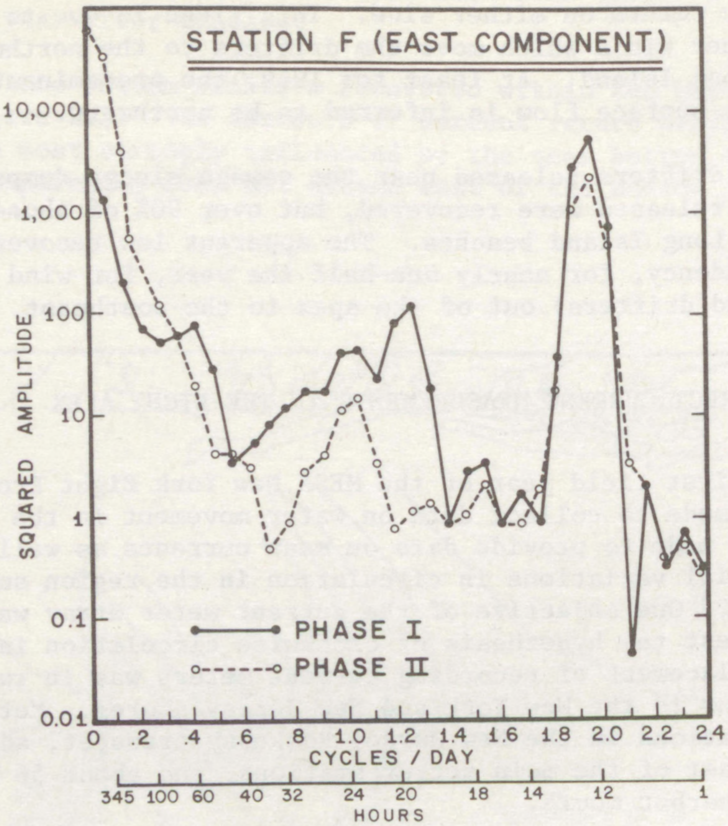



*Figure 1.4 Energy spectra for east component of current meter data from Station F during Phases I and II.*

semidaily tides, a mixture of inertial currents and daily tides, and irregular variations of time scales amounting to several days. Each time scale plays a particular role in the movement of water-borne materials. In general terms, the effect of energetic currents of high frequency is to create turbulence and to maintain materials in suspension, but not necessarily to transport or disperse them over long distances. Advective transport is effected by low frequency processes. A period of 40 hours is commonly used to distinguish between high and low frequency processes in the ocean. For the Station F spectra shown in figure 1.4, about 75% of the current variance occurred at periods less than 40 hours during Phase I. However, during Phase II these higher frequencies accounted for only 36% of the current variance. During Phase II a similar frequency distribution of current energy was found at the nearshore Station K.

However at Station A, further offshore, the high frequency portion of current energy is only 28% for Phase I, then drops to about 10% for Phase II. By comparative measure, the ratio of variance energy to energy of the mean flow, a ratio that is the prime interest in discussions of pollutant advection, shows a value at Station F of about 13 for Phase I which drops to 3 for Phase II.

### 1.3.2 Phase I Average Flow

Phase I measurements were made during the period of the year when strong stratification exists in apex. Accompanying salinity-temperature-depth (STD) data show that during most of the period a strong pycnocline existed about midway in the water column, although the structure changed from one of a multilayer to one of marked two layers during the period of measurement. The bulk of current meter data was obtained from the lower portion of the water column.

Figure 1.5 shows the mean current vectors for Phase I. The vectors represent the net movement in the lower portion of the water column over the 50 days the current meters were in operation. Locations in the water column of meters used in this compilation and that of figure 1.6 are shown in table 1.1.

*Table 1.1 Level of Current Meter Observations*

| Station | Water Depth (m) | Distance of Meter above Bottom (m) | Percent of Water Column |
|---|---|---|---|
| A | 45 | 15 | 33 |
| D | 10 | 1 | 10 |
| E | 16 | 8 | 46 |
| F | 24 | 9 | 38 |
| G | 38 | 15 | 41 |
| K | 20 | 9 | 44 |
| ST-4 | 28 | 11 | 39 |

Station ST-4 is the dumpsite station whose period of observation was 14 days. Data from all stations show estuarine circulation into the Raritan Bay and support the hypothesis of clockwise gyral circulation in the apex.

Data from station D are dominated by strong tidal motions. There is a net bottom water flow into the harbor of about 3 cm $sec^{-1}$. This flow is consistent with estuarine circulation concepts.

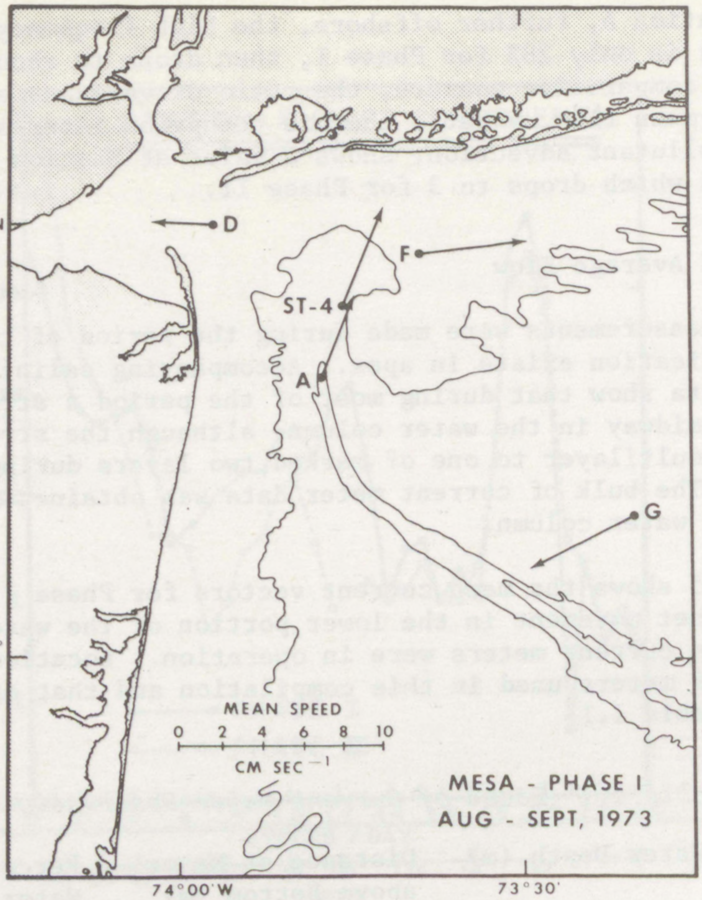



*Figure 1.5 Mean current vectors for selected stations during Phase I.*

Mean speed at all other stations is a reasonably consistent 4-6 cm $sec^{-1}$. This speed is substantially below the instantaneous speeds characteristic for this period. The data records exhibit a high degree of variability due primarily to tides, but with winds dominating flow for significant portions of the records. Characteristically, at Station F maximum speeds are about 50 cm $sec^{-1}$, nearly ten times the long term mean.

Data from a station (H, not shown) to the east, adjacent to Long Island, show a weak mean speed (3 cm $sec^{-1}$) and a direction of flow toward the southwest. This direction is consistent with shelf flow reflected by Station G but represents a reversal of the inshore counterflow at Station F. During Phase I this Long Island station appears to occupy a position outside of the apex gyre. Station G data may not indicate the position of the southeast limb of the gyre but they do indicate that general long term movement on the shelf is toward the southwest.

### 1.3.3 Phase II Flow Character

The second phase of current measurement was begun in late October and completed in early December 1973. Several stations were added to the original array to increase measurement density in the sections perpendicular to New York and New Jersey and in the Sandy Hook to Rockaway transect.

During Phase II the water had become nearly homogeneous in temperature and salinity. Historical data suggest this transition occurs sometime in October and continues through January. Data from STD casts made while the current meters were operating show a homogeneous water column that was gradually cooling for the entire operation period.

A preliminary examination of records from several levels at selected stations suggests that the effect of stratification on currents is significant. When a layered density structure exists (Phase I), flow in various layers generally has different speeds and directions; during nonstratified conditions, measurements at various levels on a single station generally show flow to be more uniform top to bottom. The effect of stratification may be significant in relation to the competence of the flow to erode or suspend particulate material in Bight waters.

Direction of long term mean flow during Phase II is not significantly different from that observed during Phase I. Speeds are generally higher owing to the higher level of wind energy input to the water column. Figure 1.6 shows a summary of the direction data for each station at the level approximately 30-40% of the way up the water column. The data were subjected to a low pass filter to remove variations with periods less than 2 hours. The polar histograms of figure 1.6 show the frequency distribution of currents partitioned into 10-degree increments, where the length of each line represents the percentage of the total record occupying that direction segment. As in Phase I, data taken from the transect denoted by Station A and K show that flow is generally northward; for the Long Island transect (Stations E, F) flow is predominantly eastward.

Comparison of data from Stations E and F indicates that at stations further offshore, low frequency flow has a greater frequency of cross-contour flow than at the inner stations. The strong directionality of the data from Station A is due to the major depth change associated with the Hudson Shelf Channel where Station A is located.

Although the station at the sewage sludge dumpsite was not reoccupied during Phase II, these data have been included for comparison. Favored flow directions here are to the northeast, in conformance to the counterflow, and to the northwest, perhaps associated with the estuarine bottom flow into the mouth of the Hudson estuary. Estuarine return flow is still indicated at Station D, but it is evident that there is great variability in this confined region.

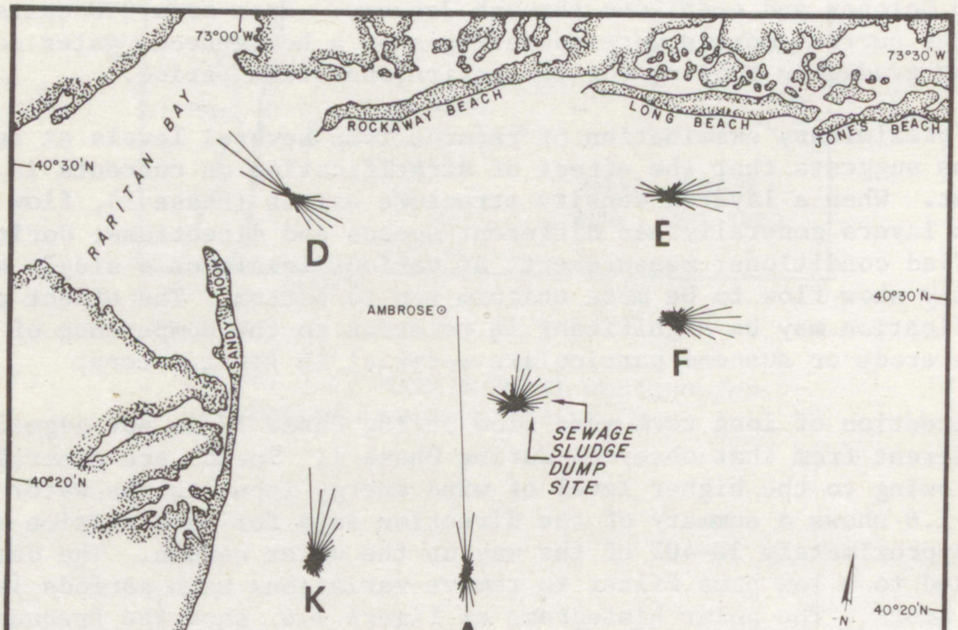



*Figure 1.6 Polar histograms of direction frequency for stations of Phase II.*

### 1.3.4 Speed of Flow Near Long Island

The direction roses of figure 1.6 show only the tendency for the direction of flow. A speed rose, constructed in a similar manner but using average speed in each direction component shows little directionality in speed. This suggests that figure 1.6 can be used to indicate general magnitude of transport during Phase II.

A more direct manner to exhibit current speed data is to present the current vectors as a sequence in time. Such a presentation of vector time series for Station E is shown in figure 1.7. Here the data

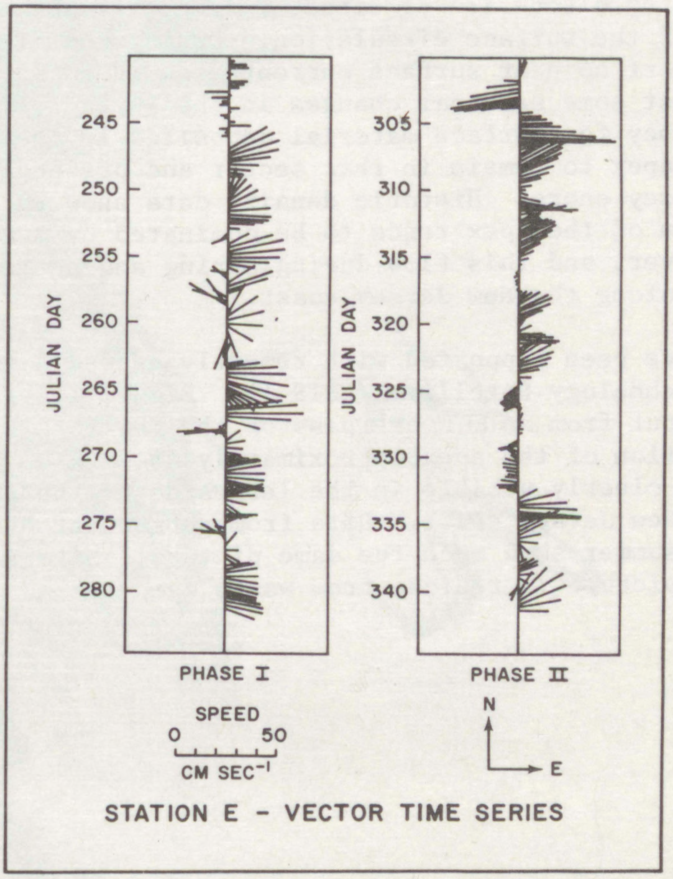



*Figure 1.7 Vector time series of data from Station E during Phases I and II.*

were subjected to a 40-hour low-pass filter to remove the high frequency (tidal) component and then resampled every 6 hours. The data for both Phase I and II are presented with time increasing toward the bottom of the page. In general, direction is more consistent in Phase II, but both data sets show a dominance of eastward flow. Speed of flow is comparable for each phase with speeds of 20-30 cm $sec^{-1}$ characteristic. A speed of 50 cm $sec^{-1}$ occurred abruptly during Phase II near day 305 following a reversal in flow. This reversal and high speed were observed in conjunction with passage of a major storm front through the area.

## 1.4 INFERENCE OF SURFACE FLOW FROM ERTS DATA

In the foregoing discussion of direct current measurements no mention was made of the surface circulation. During the first year of the MESA field effort no near surface current measurements were made. Drifter data suggest some seasonal changes in the surface flow and also indicate the tendency for surface material deposited in the western portion of the Bight apex to remain in that sector and preferentially move toward the New Jersey shore. Historic density data show that flow in the western portion of the apex tends to be dominated by the outflow from the Hudson River, and this flow during spring and summer is generally to the south along the New Jersey coast.

These data have been supported with remotely sensed data from the Earth Resources Technology Satellite (ERTS-1). Figure 1.8 is an example of the output from an ERTS overpass of the New York Bight. The figure shows a portion of the apex approximately 48 km x 48 km. Outflow from the Hudson is clearly visible in the left side of the frame and appears to hug the New Jersey coast. Data from subsequent overflights during spring and summer show much the same picture. Material visible in the center of the picture is residue from waste dumps.

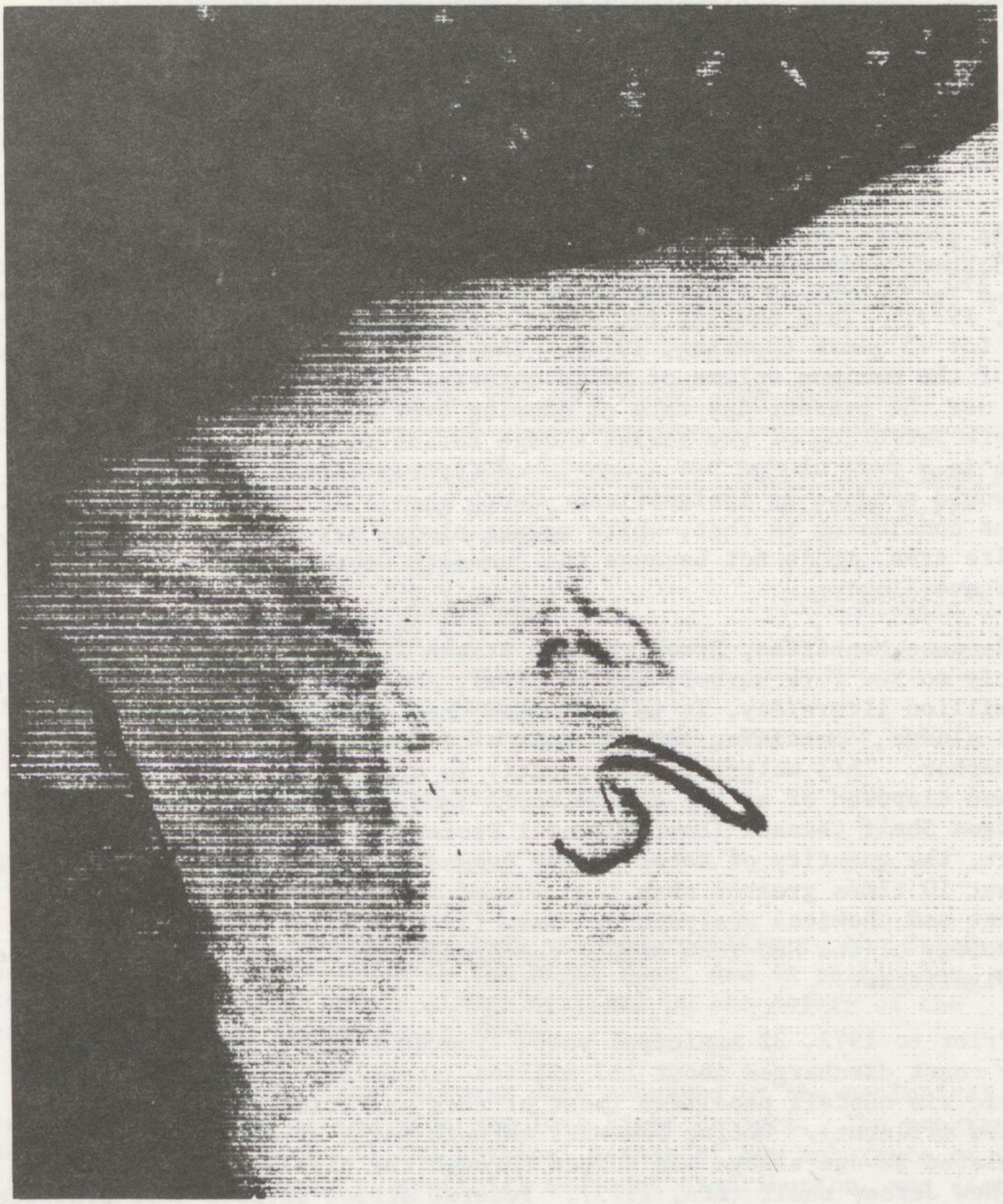


*Figure 1.8 ERTS-1 data (0.6-0.7μm) for overflight of New York Bight apex on 16 August 1972.*

# 2. GEOLOGICAL OCEANOGRAPHY; SEDIMENTATION IN THE NEW YORK BIGHT APEX AND APPLICATION TO PROBLEMS OF WASTE DISPOSAL.

Donald Swift, Anthony Cok (Adelphi University), David Drake
George Freeland, William Lavelle, Thomas McKinney (Vassar College)
Terry Nelsen, Richard Permenter, William Stubblefield

## 2.1. INTRODUCTION

The New York Bight apex is a major depository for the disposal of waste, including waste acid, dredge spoil, cellar dirt, and sewage sludge. Waste disposal at the sewage sludge dumpsite presently occurs at a rate of approximately 4.5 million $m^3$/yr. Of this volume approximately 6% or 270,000 tons is solid material (based on percent solid estimates by Gross, 1972). This dumping (at ever increasing rates) has been taking place for 45 years (Dewling, 1974). The following calculation gives some idea of the maximum volume of solid material dumped during the 45 years: If we use the present-day rate of dumping over the 45-year periods, then complete retention of the sewage sludge solids in a 5 x 5 km area would result in a pure sludge bed about 50 cm (approximately 1.5 ft) thick. This would produce an insignificant depth change at the dumpsite. The obvious conclusion is that, while sewage sludge may be dispersed from the dumpsite area, it is not because the dumpsite depression has filled and is now overflowing.

Because Manhattan, Brooklyn, and Staten Island discharge raw sewage directly to New York Harbor, Hudson River, and East River at the rates of 1840 million liters/day, it is estimated that about 1.7 million $m^3$/yr of sewage sludge (containing 100,000 tons of solids) are deposited in New York Harbor. This material subsequently is dredged (along with natural mud) and disposed of at the dredge spoil (mud) dumpsite on the west side of Hudson Shelf Channel (Environmental Protection Agency (EPA), 1973). In fact, the quantity of total solids dumped at the mud site each year is at least 10 times greater than that dumped at the sewage sludge site. Sediment and chemical analyses by Gross (1972) suggest that, in terms of the ecology of the New York Bight, the dredge spoil (mud) dumpsite may be more significant.

Prior to 1972, 32 municipal waste treatment plants along the New Jersey coast discharged about 157 million liters/day of effluent to the Atlantic via outfall pipelines (most of this was primary treated, disinfected effluent). During November through March of each year the accumulated sewage sludge was pumped through the pipelines to the nearshore New Jersey shelf (EPA, 1973). Federal action stopped this practice in 1972 and the sludge is now barged to the offshore dumpsite.

Gross (1972), using data from 1964-1968, pointed out that total ocean dumping off New York including dredge spoil, sewage sludge, waste acid, and cellar dirt amounted to approximately 4.6 million tons/yr of solids (see table 2.1). This amount of sediment is roughly equivalent to the natural sediment load of all rivers between Connecticut and Cape Hatteras, North Carolina.

Recent advances in our understanding of ocean currents over continental shelves have shown that landward residual transport near the bottom commonly occurs within 10 to 50 km of the shore (Bumpus, 1965; Gross et al., 1969). Onshore bottom water flow is especially evident off major coastal estuaries. This type of circulation tends to trap both coarse and fine-grained sediments in the estuaries, coastal wetlands, and inner shelf areas (Meade, 1972).

This potential feedback of some of the wastes dumped offshore and the demonstrated environmental deterioration in the immediate dumpsite areas are among the important reasons for a thorough assessment of man's effects on New York Bight ecology.

*Table 2.1. Waste Disposal New York Bight Apex Dumpsites*

| | Volume ($10^6$ $m^3$/yr) | Solids ($10^6$ tons/yr) |
|---|---|---|
| Sewage Sludge | 3.8 to 4.5 | 0.23 to 0.27* |
| Dredge Spoils | 5.6 to 5.8 | 3.5† |
| Cellar Dirt | 0.54 | 0.59†† |
| Acid Wastes | 2.3 to 3.5 | 0.23 to 0.35** |
| Average totals: | 13.3 | 4.6 |

* Average solid content of 6% (Gross, 1972).
† Based on bulk densities of 1.3 tons/$m^3$ (Gross, 1972; EPA, 1973).
†† From Gross (1972).
** From Gross (1972) and EPA (1973).

Recently public concern has been aroused relative to the deleterious effects of waste disposal in the Bight apex, and in particular, relative to the effects of sewage sludge disposal on the safety of the beaches of the Long Island South Shore.

This report summarizes relevant data acquired by the geological oceanography program of the MESA New York Bight Project. The program has been concerned with (1) the physical nature of the substrate of the Bight apex; its topography, surficial sediment distribution, and distribution of sediment with depth, and (2) the dynamic system of sediment erosion, transport, and deposition within the Bight apex. Data collection and analysis for this program are far from complete. Even when complete the data must be carefully integrated with data from the biological, chemical, and physical oceanography programs, before they can be applied to problems of ocean dumping. However, because of the urgency of the public problem, available data are set forth in this report.

## 2.2 PHYSICAL NATURE OF THE SEA FLOOR

### 2.2.1 Topography, Shallow Structure, and Geologic History

The main topography elements of the floor of the Bight apex (fig. 2.1) are the Hudson Shelf Valley, the Christiaensen Basin (Veatch and Smith, 1939), Cholera Bank, and the New Jersey Platform. The origin of these features must be sought in the geologic history of the Bight apex during the past 15,000 years.

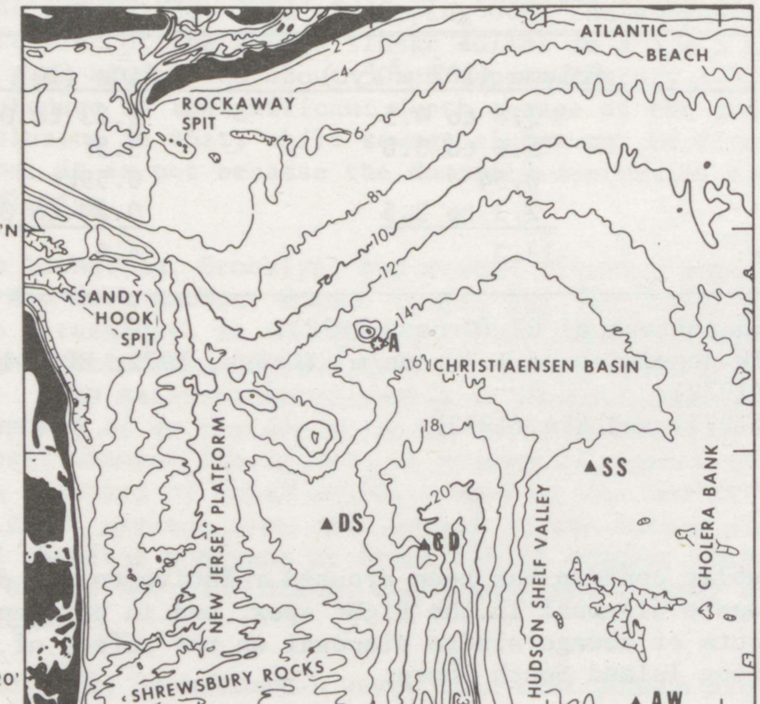



*Figure 2.1. Bathymetry of the New York Bight apex from ESSA bathymetric map 0808N55, and names used in the text. "A" is Ambrose Light; "SS", sewage sludge dumpsite; "DS", dredge spoil dump site; "CD", cellar dirt dumpsite; "AW", acid waste dumpsite.*

Approximately 15,000 years ago, during the period of the last major ice advance of the Pleistocene Ice Age, so much sea water was locked up in the continental ice sheets that sea level was lowered more than 125 m (Milliman and Emery, 1968). The New York--New Jersey shoreline withdrew to the edge of the continental shelf, over 200 km to the east. The Hudson Shelf Valley was incised at this time by the Hudson River flowing east over the extended coastal plain to the distant shoreline.

As the ice sheets melted, the shoreline advanced to its present position. Low coasts of sand and clay, such as the coast of the New York Bight, tend to have a characteristic submarine profile, maintained by wave and wind-driven currents. The profile consists of a relatively steep shoreface (gradient 1:10 to 1:200) which descends to a depth of 15 to 20 m, 2 to 5 km from shore, and which is followed in a seaward direction by a more gently sloping (gradient greater than 1:200) inner shelf floor. During the post-glacial rise in sea level, this profile retreated landwards by a process of erosional shoreface retreat due to scour of the shoreface by wind and wave driven currents (Swift et al., 1972). The sediment eroded from the retreating shoreface was deposited as a blanket of relatively clean sand over the shelf floor. As the Long Island shoreline retreated, sand moving southward in the breaker-driven littoral current tended to pile up on the north side of the ancestral Hudson Estuary mouth in the form of tide-molded shoals. The landward movement of the shoal zone as the estuary mouth retreated has resulted in a raised north rim of the shelf valley (Cholera Bank). South moving littoral drift from the retreating shoreline and sediment swept south after the passage of the shoreline by storm currents have resulted in appreciable filling in the east side of the shelf valley and in the Christiaensen Basin (figs. 2.2 and 2.3).

Approximately 4,000 to 7,000 years ago, the rate of sea level rise decreased. Since this decrease, the coastline of the Bight apex has assumed its present form. Within this relatively recent period Sandy Hook spit has grown into the harbor mouth, and within the historical period, Rockaway spit has done so (Shepard and Wanless, 1972, p. 73-74; Taney, 1961).

Comparison of a recent NOAA bathymetry survey (August, 1973, unpublished) with the 1936 bathymetry (fig. 2.1) indicates a change of less than 2 m throughout the area, except in the vicinity of the dredge spoil dumpsite, where shoaling up to 12 m has occurred.

### 2.2.2 Distribution and Micro-topography of Surficial Sediments

Figure 2.4 presents the net of stations at which samples of surficial sediments were collected by means of a Shipek grab sampler. During this sampling operation, accomplished between June 1972 and July 1974, navigation was provided by Loran A and radar in some sectors, and by Raydist in others.

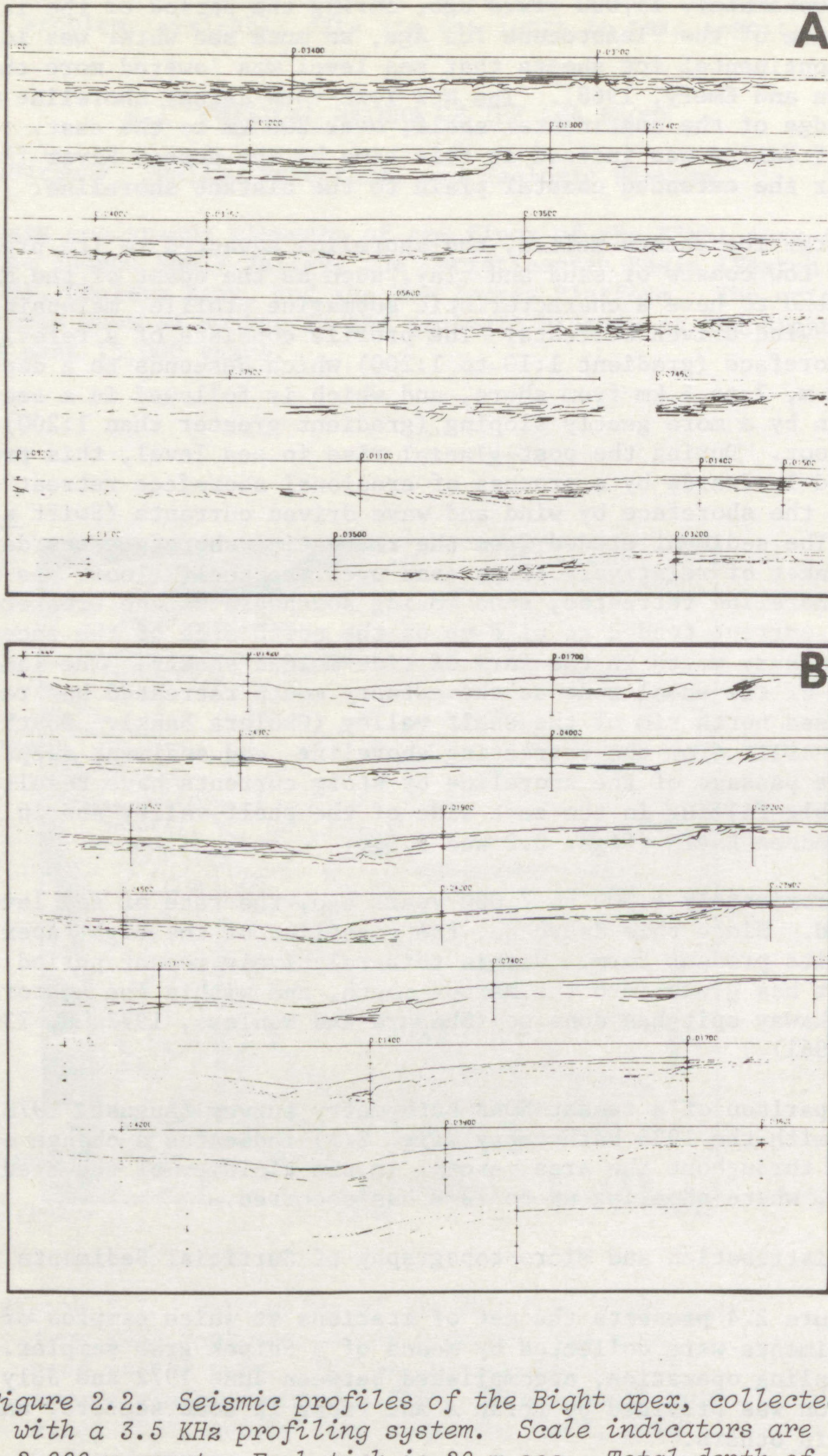



*Figure 2.2. Seismic profiles of the Bight apex, collected with a 3.5 KHz profiling system. Scale indicators are 2,000 m apart. Each tick is 20 m sec. Total depth of penetration is about 50 m.*

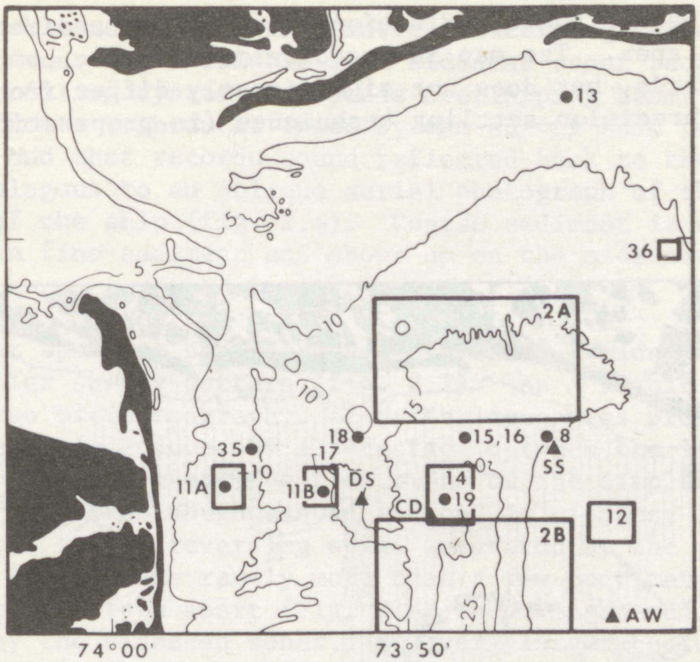



*Figure 2.3. Index map for illustrations in this report.*

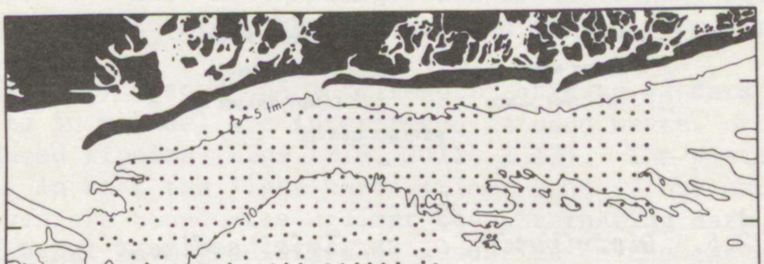



*Figure 2.4. Net of Shipek grab samples in the Bight apex. Sample interval is approximately 0.9 km.*

Figure 2.5 presents the distribution of surficial sediment on the floor of the Bight apex. The map is based on macroscopic comparison of samples with standards, but does not significantly differ from a grain size map based on precision settling techniques (in preparation).

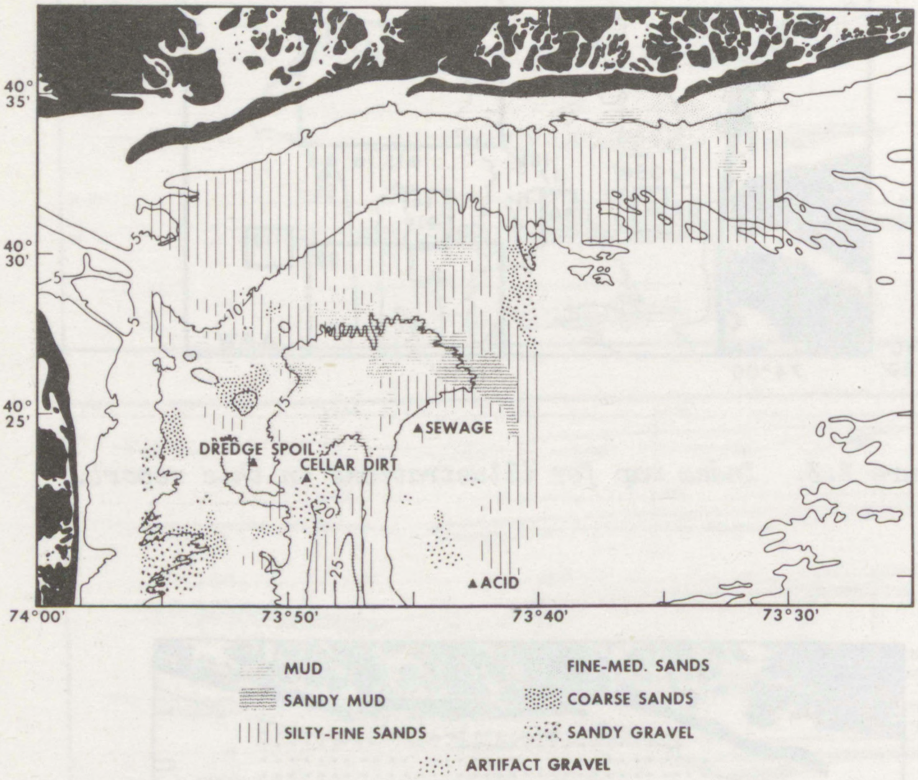



*Figure 2.5. Distribution of surficial sediment types in the Bight apex, based on visual examination of samples.*

Distribution of surficial sediments in the Bight apex is quite systematic. Grain size is primarily a function of depth. Mud occurs in low areas, namely in the axis of the shelf valley, in the Christiaensen Basin, and in the extension of the Hudson Shelf Valley toward the mouth of outer New York Harbor. Small patches of mud also occur in shallower water, near the Long Island shore. The New Jersey Platform and Cholera Bank are floored with sand. The coarsest sand and sandy gravel occur in the shallower northern Cholera Bank and Shrewsbury Rock areas. However, artifact gravel (brick, cement, plaster, stone, wood, metal) occurs on sea floor highs of artificial origin, and on Cholera Bank.

Considerable additional information concerning the distribution of surficial sediments is available from sidescan sonar records. Sidescan sonar is a profiling system that sends overlapping beams of sound obliquely outwards from a transducer towed by the survey ship to the sea floor on either side, and that records sound reflected back to the transducer. The result is analogous to an oblique aerial photograph of the sea floor on either side of the ship (fig. 2.6). Coarse sediment is a better acoustic reflector than fine sediment and shows up on the sidescan record as a dark zone.

The Bight apex has been surveyed by means of sidescan sonar, according to a regular survey pattern (fig. 2.7). As a result, it has been possible to map microtopography, or bottom roughness provinces. Such bottom roughness is induced by interaction between the loose sediment of the sea floor and the overlying flow. One of the simplest and most widespread forms of bottom roughness so induced is ripples, a response of the sandy sea floor to the reversing surge generated by the passage of surface waves. Ripples are rarely more than a few centimeters high and a few tens of centimeters apart (fig. 2.8) and are generally too small to be detected by the sidescan sonar. However, larger bedforms induced by fluid flow occur. Six bedform patterns were recorded.

On the shoreward end of Cholera Bank, and again along the New Jersey shore, sand ribbons were observed (figs. 2.9-2.11). These are straight to sinuous, irregular, or branching strips of medium sand overlying a coarser sand or sandy gravel of subequal width. The sand ribbons are responses to peak flow events when the bottom boundary layer of the flow field is organized into alternating zones of convergent and divergent flow. Sand is swept into ribbons elongated in the flow direction.

More narrowly spaced and more regular streaks of dark on sidescan records (5 to 50 m wide) are interpreted as sand waves, or large-scale current-induced ripples (figs. 2.9, 2.12, 2.13). The pattern is locally asymmetrical in that the light bands (finer sand of the sand wave crests) have sharp western boundaries against the alternating dark bands on the western sides but have gradiational boundaries on the eastern sides. This asymmetry and the fact that some of the features occur very near the Long Island shore in a shore-normal position, suggest that they are sand waves (current-transverse bedforms) rather than sand ribbons (current parallel bedforms). The asymmetry is most commonly weak to absent, however, and the features, unlike true sand waves, rarely have appreciable relief. Hence, it is believed that they were formed as sand waves during peak flow events associated with winter storms, and by the period of observation had been degraded by bottom wave surge and by the activity of burrowing organisms. The sand-wave-like features occur on the north margin of the Christiaensen Basin, and on the seaward portion of Cholera Bank. Their probability of formation is increased over that of sand ribbons where the substrate consists of deep medium-to-fine grained sand, rather than a thin layer of medium sand over a coarser substrate.

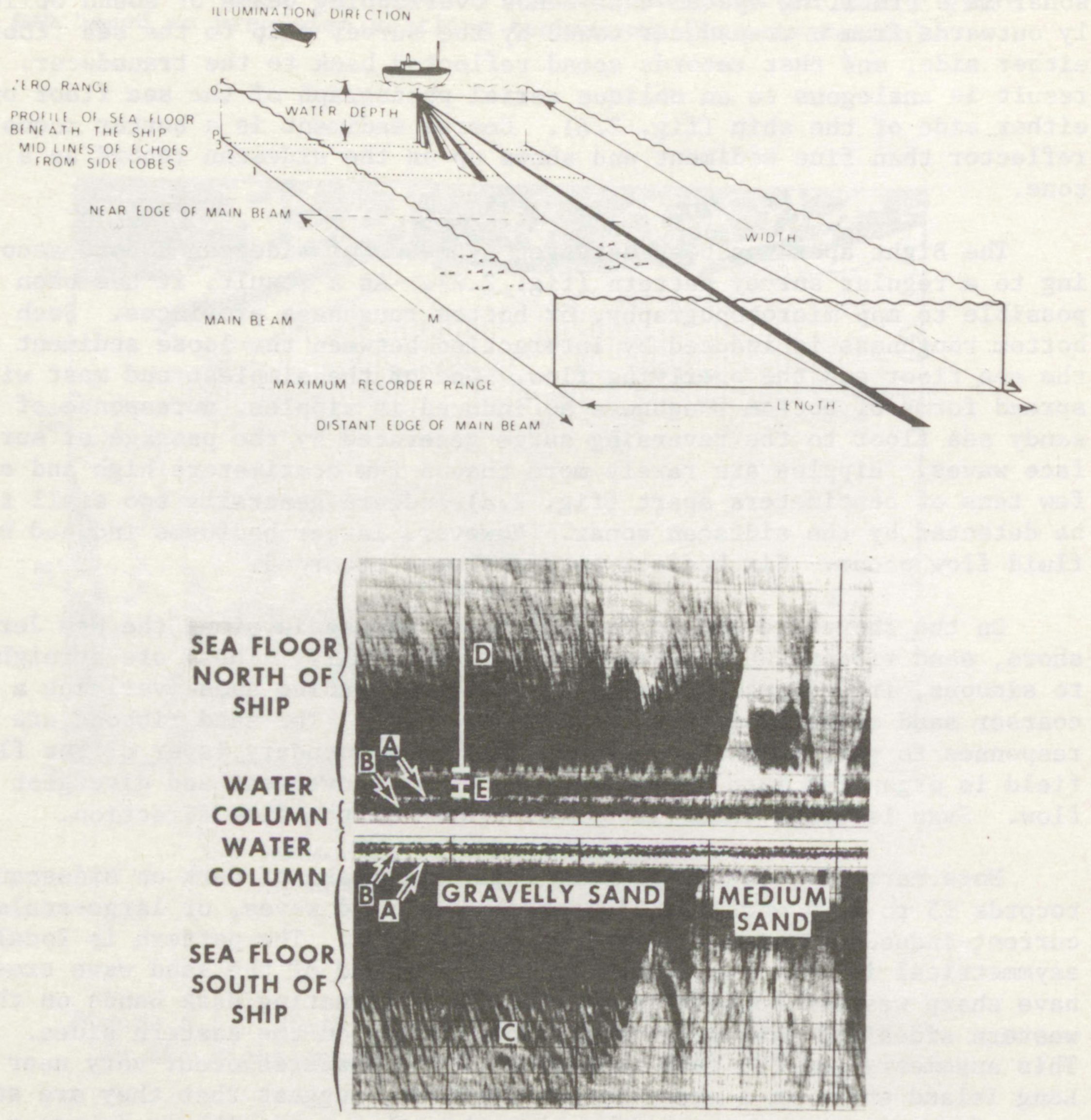



*Figure 2.6. Above: Diagrammatic representation of sidescan sonar system. (The transducer used for the work described by this report was towed behind the ship, rather than fixed beneath it.) A similar beam of sound extends from the far side of the transducer. [From Belderson et al., 1972.] Below: Anatomy of a sidescan record. A. Bottom of sea floor. B. Turbulence in water column due to ship's wake. C. Zig-zag pattern due to refraction of sound in density-stratified water. D. Portion of record due to reflection of side lobe (see above). E. Portion of record due to reflection of main beam.*

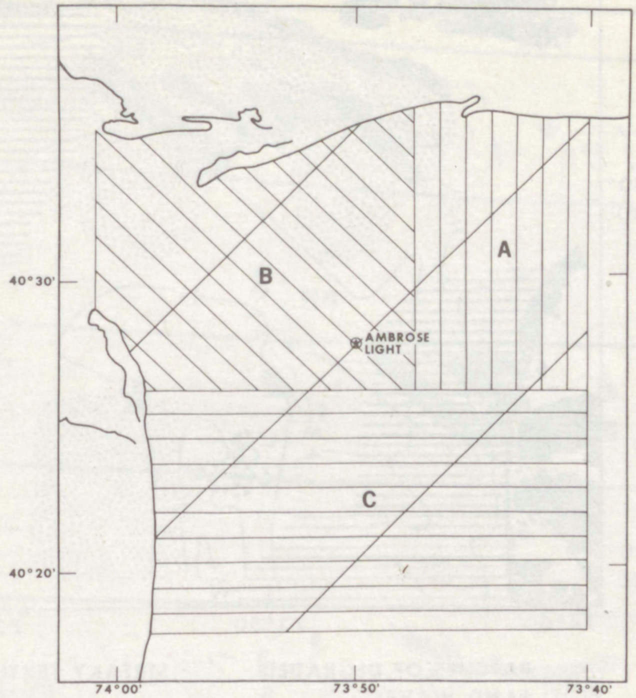



*Figure 2.7. Pattern of tracklines for electronic survey of New York Bight apex. Every fifth line is shown. Sidescan sonar records were obtained from every second line. Selected transects are reoccupied on a quarterly basis.*

*Figure 2.8. Sea floor photograph of fine rippled sand from the Bight apex. See figure 2.3 for location.*

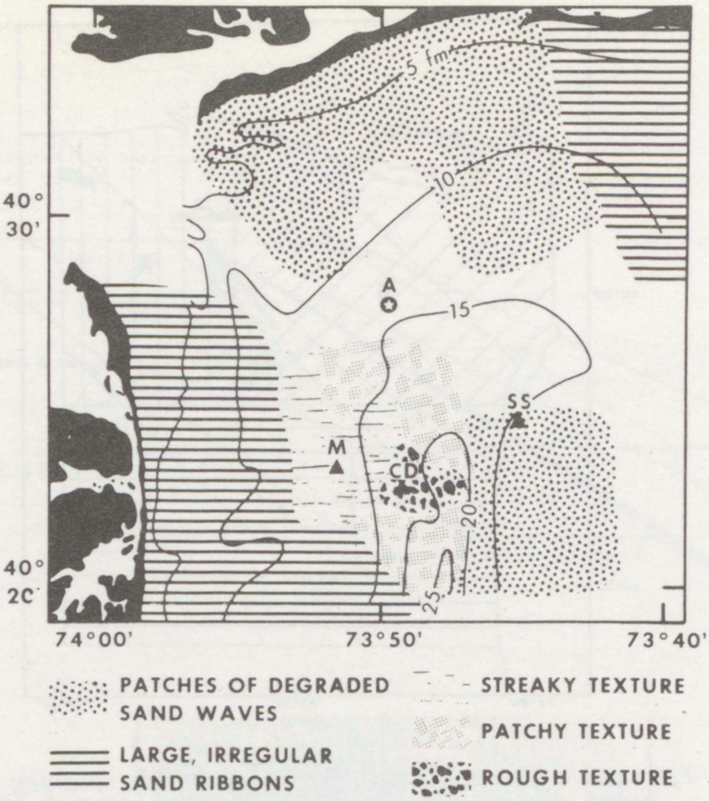



*Figure 2.9. Distribution of bottom roughness patterns in the New York Bight apex.*

Two other patterns are associated with fine-grained bottoms (fine silty sand to mud). A patchy texture (figs. 2.9, 2.14, 2.15, 2.16) appears to be the result of the deposition of a thin discontinuous blanket of mud or silt (light pattern) over a slightly coarser substrate (dark pattern). The patches are up to 20 m in diameter, and tend to be elongated in the predominant flow direction. The few cores collected to date suggest that the patchy layers are a few cm or less thick, and that in areas whose surface is characterized by this pattern the underlying sediment consists of stacked sequences of sand and mud layers. On the margin of the cellar dirt dumpsite, however, the light pattern appears to fill lows on a surface of dumped rubble.

On the New Jersey Platform a more streaky pattern is seen on the surface of the pocket of mud that fills the extension of the Hudson Shelf Valley towards the New York Harbor mouth, perhaps because of the more intense semidiurnal tidal flow experienced by the sea floor in this area (figs. 2.9, 2.11, 2.17).

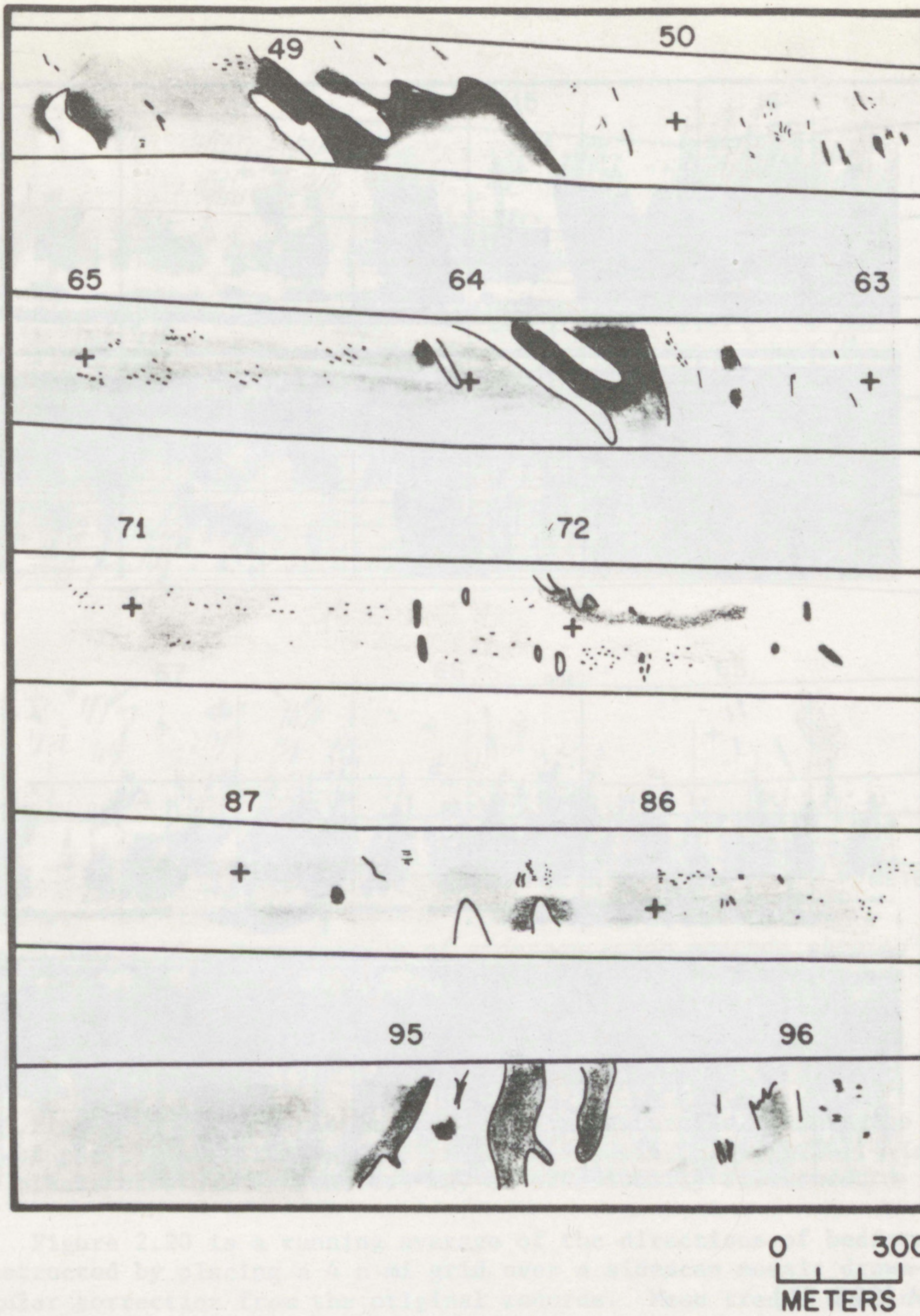



*Figure 2.10. Reproduction of sidescan sonar records showing large, irregular sand ribbon pattern. Recorded strips are 366 m wide. See figure 2.3 for location.*

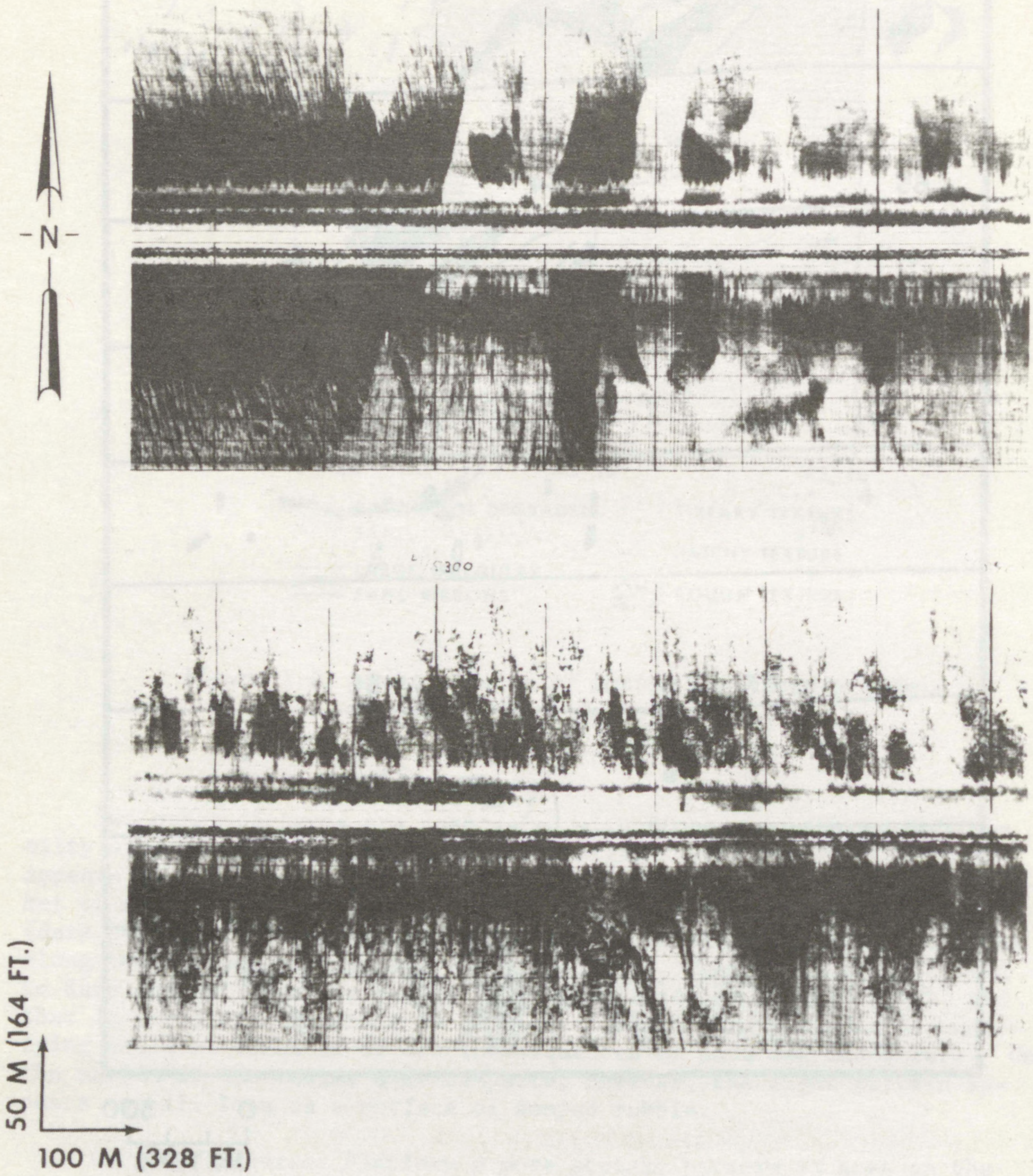



*Figure 2.11. Above: Sidescan sonar record of large, irregular sand ribbons. Below: Sidescan sonar record of small scale ribbon-like features (streaky texture). Blocky objects with dark sides towards sound source are boulders protruding through sediment cover.*

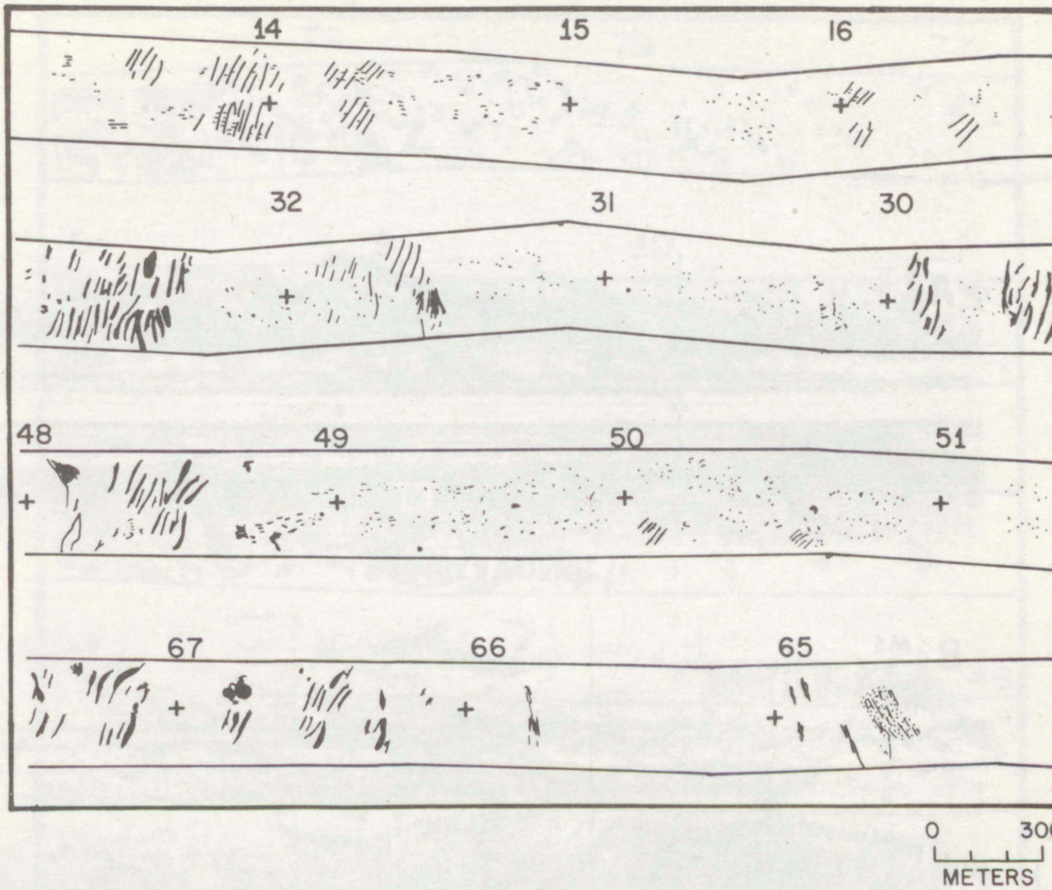



*Figure 2.12. Reproduction of sidescan sonar records showing sand-wave-like features on Cholera Bank. Recorded strips are 366 m wide. See figure 2.3 for location.*

Finally a characteristic dark, rubbly texture is seen in the vicinity of the cellar dirt dumpsite (figs. 2.9, 2.14, 2.18, 2.19). Individual blocks of stone or concrete may be occasionally discerned.

Figure 2.20 is a running average of the directions of bedform trends, constructed by placing a 4 n mi grid over a sidescan mosaic drawn with angular correction from the original records. Mean trends within grid squares were estimated. The dashed line encircles the zone where the bedforms are believed to be dominantly current-parallel, rather than current-transverse. Except in zones of patchy texture (fig. 2.9), grain size distribution within the Bight apex appears stable with time (fig. 2.21).

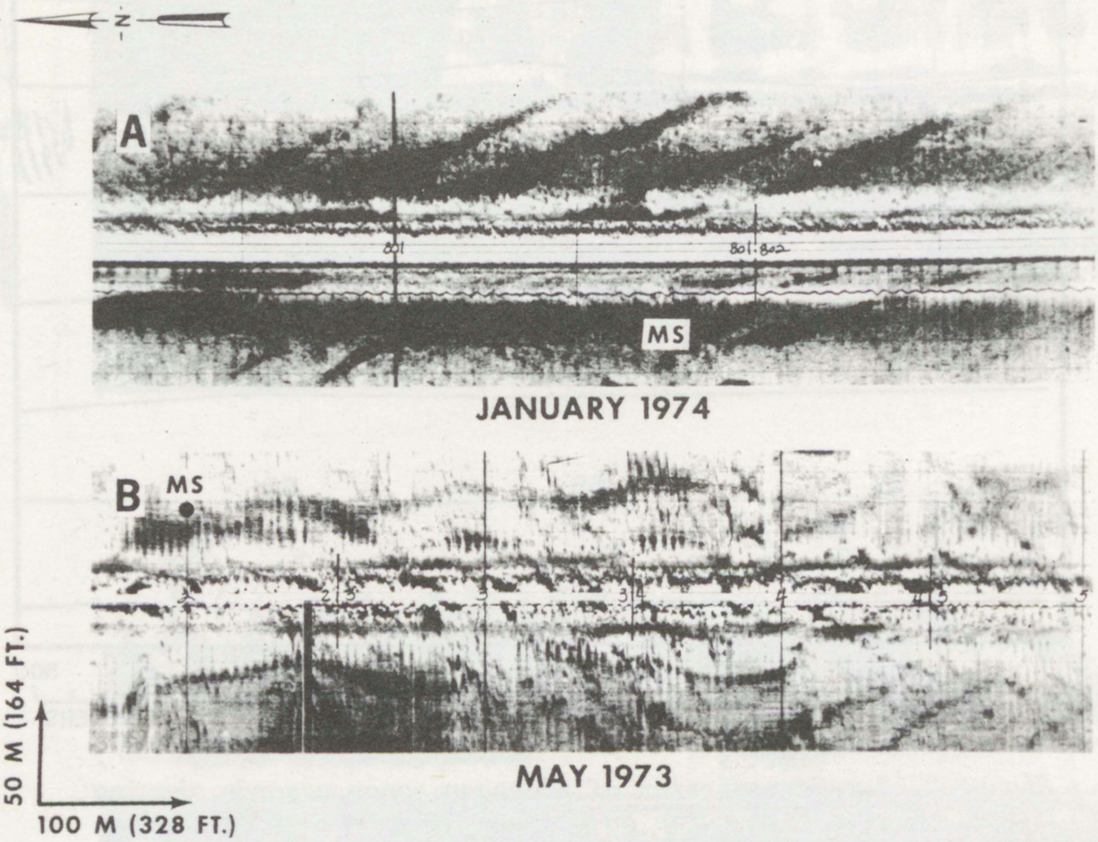



*Figure 2.13. Two sidescan sonar records taken in the same small area off the Long Island south shore. Apparent degraded sand waves visible in January as light (medium sand) streaks between dark (coarse gravelly sand) streaks have been largely obliterated by a poorly defined sinuous pattern by May 1974. Dots labelled MS are the locations of medium sand samples. Positioning error on the sample is ± 15 m. See figure 2.3 for location.*

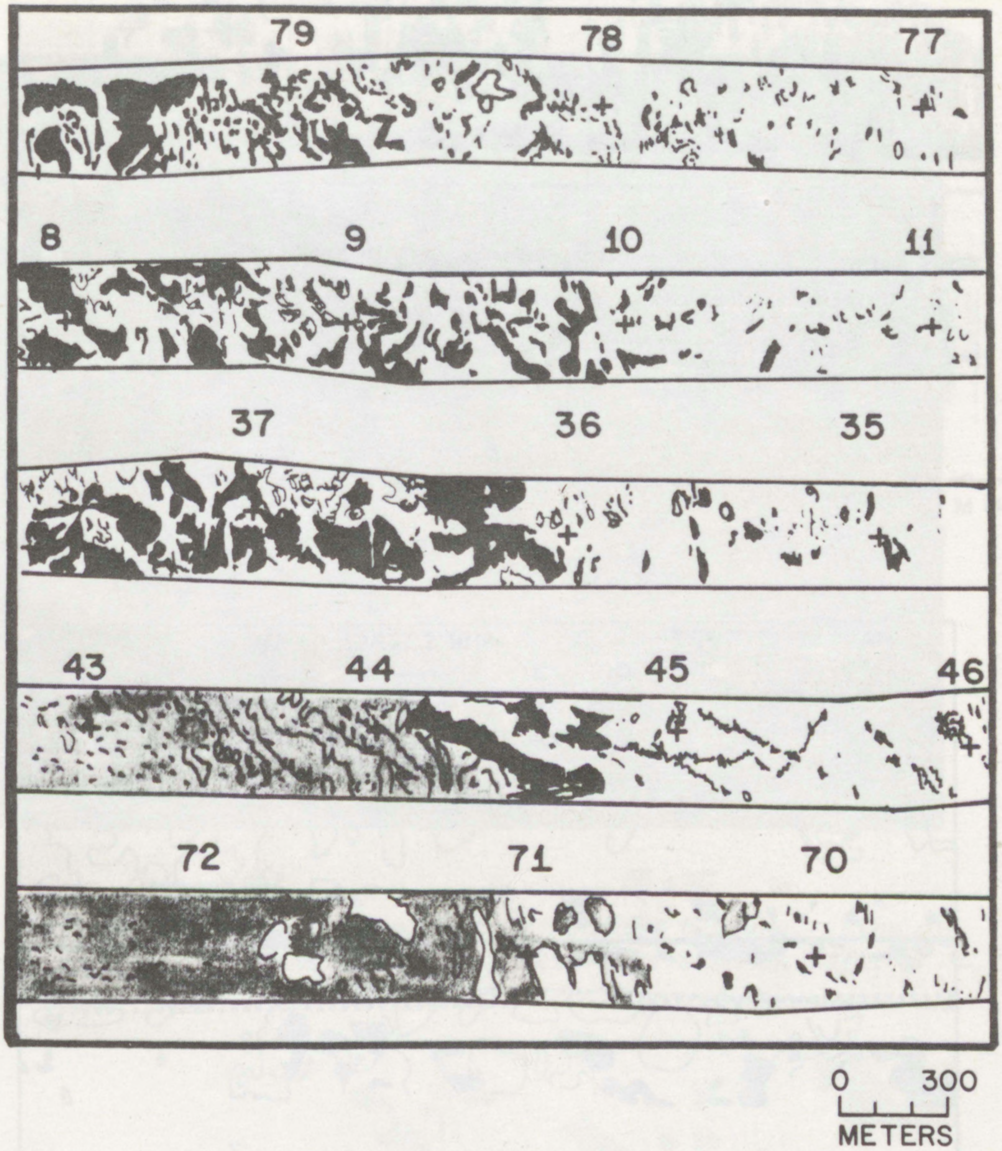



*Figure 2.14. Reproduction of sidescan sonar records showing smooth bottom in northeast, grading into patchy texture in center, and into rubbly texture in southwest corner (cellar dirt dumpsite). Recorded strips are 366 m wide. See figure 2.3 for location.*

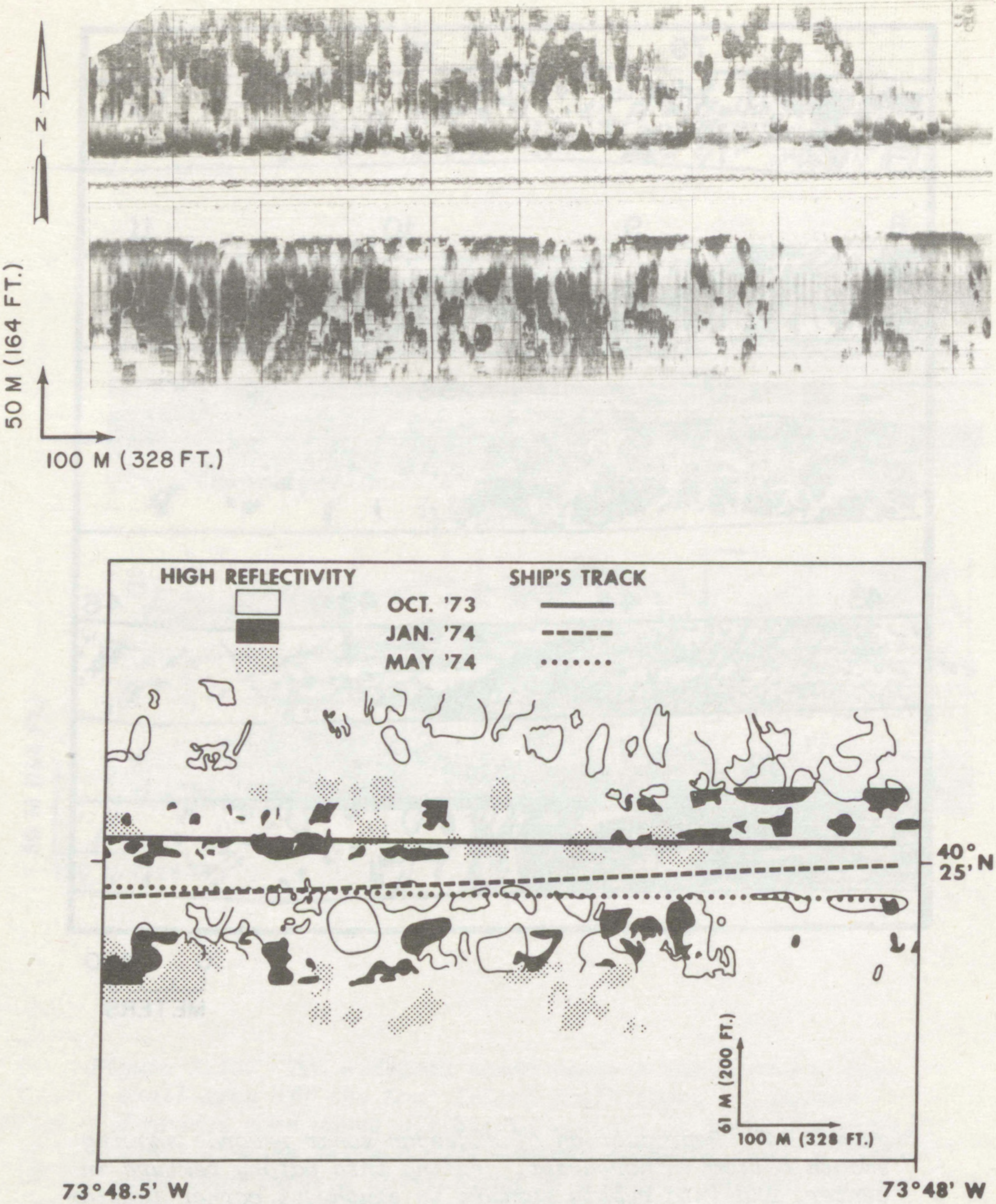



*Figure 2.15. Above: Patchy texture from near cellar dirt dumpsite. Below: Schematic of three sidescan sonar records of the same area on three successive occasions, illustrating patchy texture, and the temporal variation of the pattern. Probable error of Raydist positioning system: ± 15 m.*

*Figure 2.16. Sea floor photo of patchy texture. Fine sand on right; muddy, silty, very fine sand on left.*

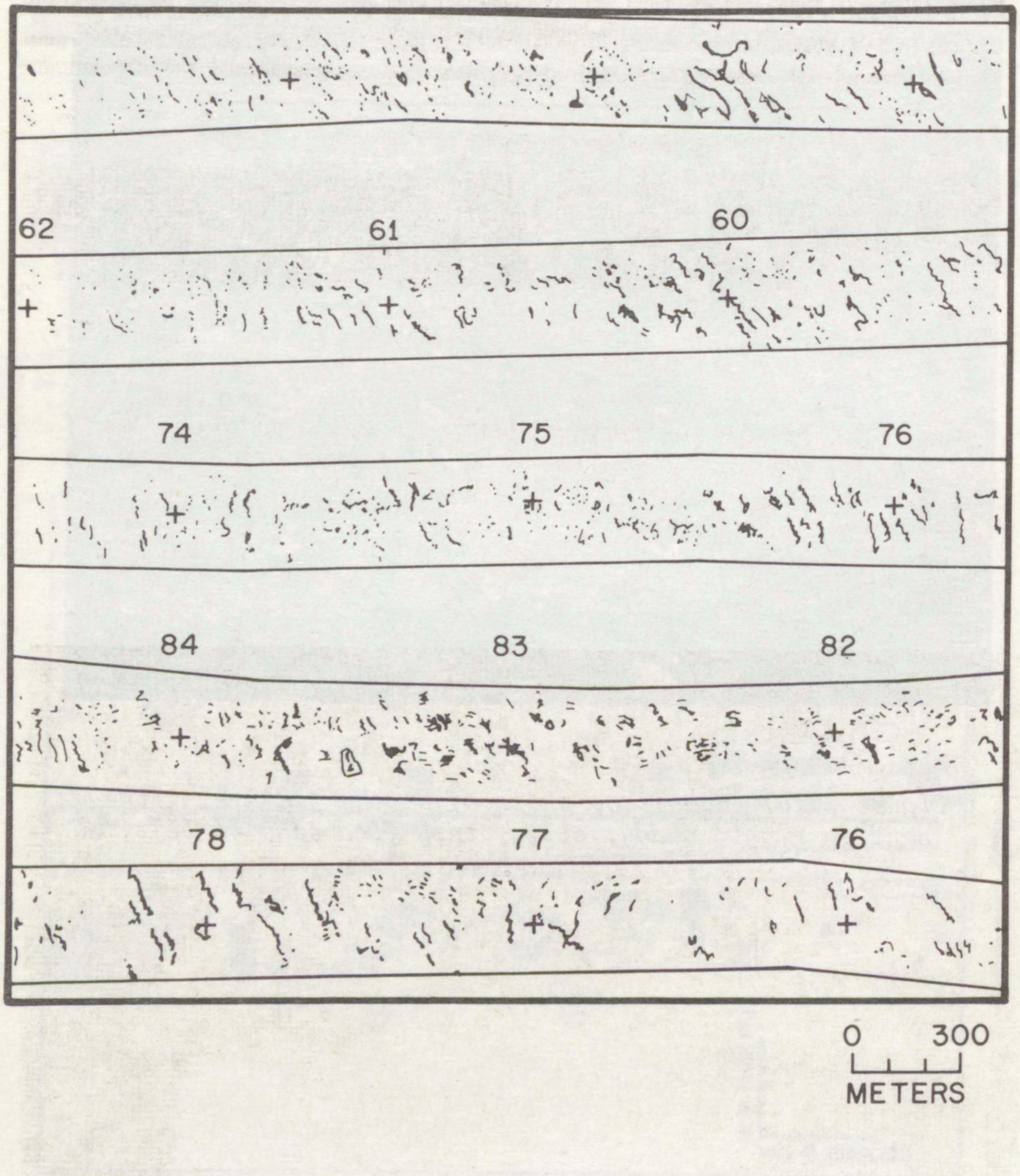



*Figure 2.17. Reproduction of sidescan sonar records showing streaky texture. Recorded strips are 366 m wide. See figure 2.3 for location.*

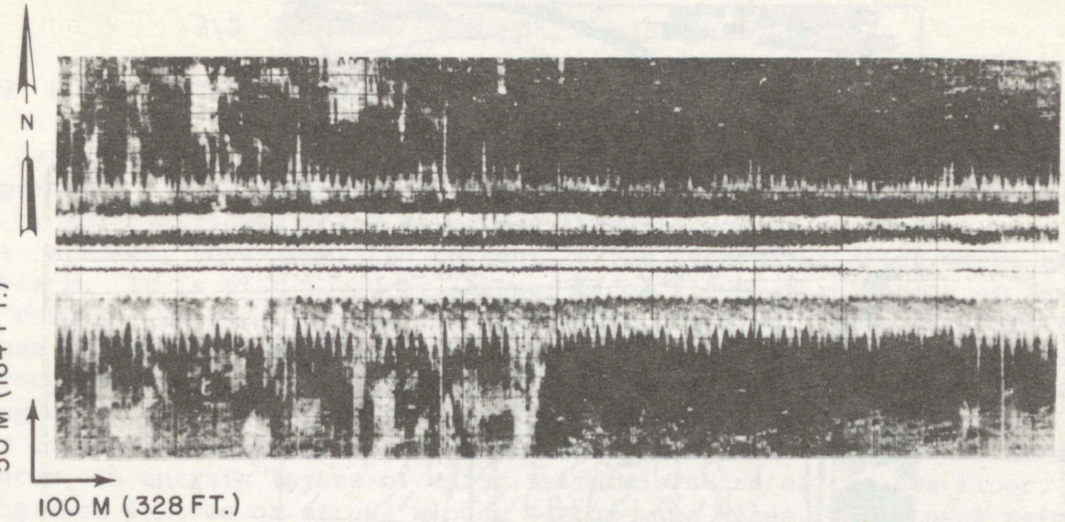



*Figure 2.18. Sidescan sonar record showing rubbly texture. Vertical streaking is an artifact due to rolling of transducer in heavy sea. See figure 2.3 for location.*

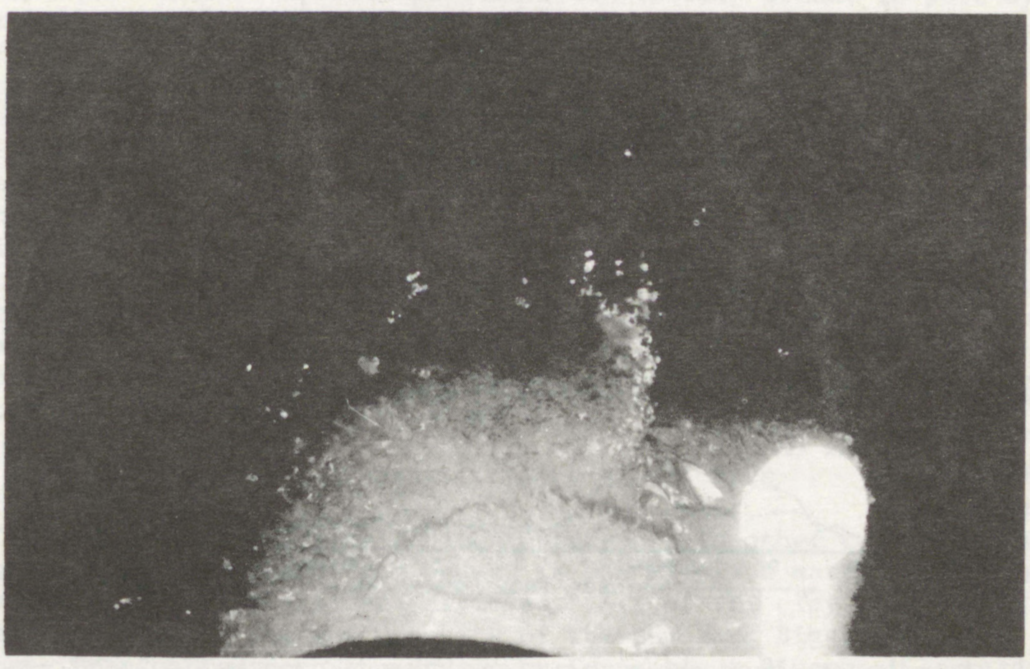


*Figure 2.19. Sea floor photo from zone of rubbly texture. See figure 2.3 for location.*

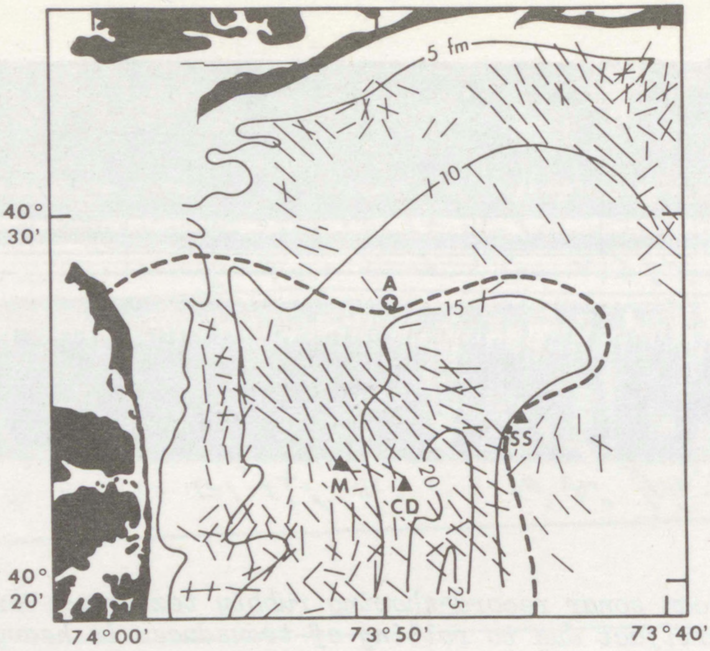



*Figure 2.20. Trends of linear bedforms as revealed by sidescan sonar records. Bedforms are inferred to be primarily current-parallel within the dashed area, current-transverse elsewhere.*

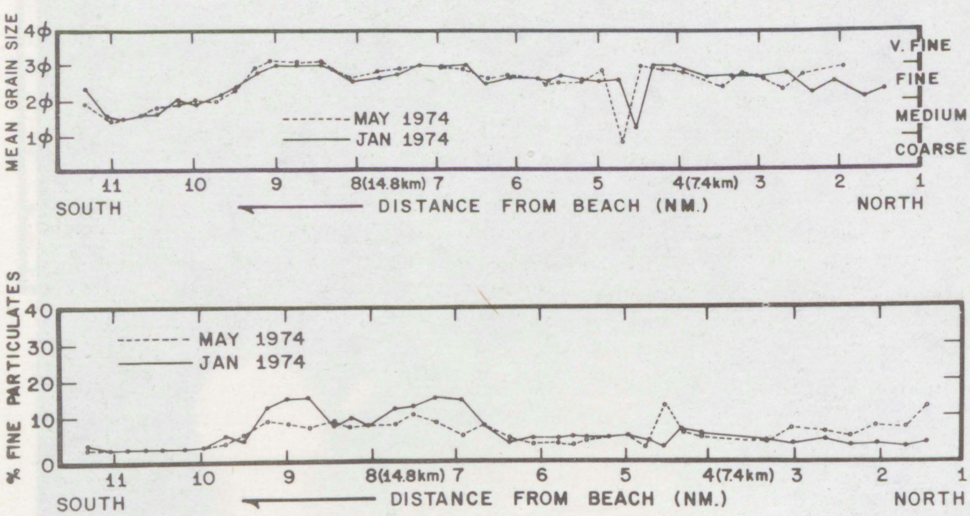



*Figure 2.21. Above: Mean grain diameters from two surveys of north-south transect from sewage sludge dumpsite to Long Island shore. Below: Percent fine particulate matter for same surveys.*

## 2.3 SEDIMENT TRANSPORT IN THE BIGHT APEX

### 2.3.1 Modes of Sediment Transport

Sedimentary processes in the New York Bight apex fall into two basic categories. Coarse sediment (mainly sand) is entrained and transported only by intense flows. Sand moves nearly continuously in the intense, coast-parallel, wave-generated current in the zone of breaking waves near the beach. It is also moved by intense tidal flows at the mouth of New York Harbor. On the floor of the Bight apex, however, flows sufficiently intense to entrain sand (approximately 30 to 40 cm $sec^{-1}$ at 100 cm above the bottom) occur only intermittently, mainly during winter storms, when strong winds can generate strong surface flows of water, and when the water column is unstratified, so that the downward turbulent transfer of momentum can entrain layers of water as far downward as the sea floor. During such periods of strong winds, bottom wave surge, whose peak velocities may be several times as intense as mean flow velocity, increases the discharge of sand, by an unknown but probably great amount, by suspending sand grains in the mean flow.

Suspended fine sediment (mud) is also entrained by the action of bottom wave surge during periods of strong winds, and is transported by peak flow events. However, the minute clay mineral particles when resuspended from the ocean floor tend to form low density, high surface-area agglomerates. These composite particles are loosely bound, in part by electrostatic charges, but probably mainly by the binding action of such organic materials as algal mucus and bacterial slime. Such particles may consist largely of degraded organic matter and diatom frustules, with only minor quantities of embedded clay mineral grains. Pelletization by mud-feeding invertebrates results in denser aggregates. During periods of plankton blooms, the bulk of the suspended material may be living, consisting of diatoms, foraminifera, algae, and other plankton. Settling velocities of these composite particles are low and they may remain in suspension for days or weeks after entrainment, during which periods they may be transported for distances of many tens of kilometers by the slow, tide-modulated fair-weather circulation pattern. Thus the pattern of mud transport and also the coastal mud budget is markedly different than the transport pattern and budget of sand.

### 2.3.2 Suspended Sediment Transport: General Concepts

Detailed studies of fine sediment transport in other coastal areas have shown that the coastal mud budget is not simply a matter of the seaward movement of river derived particles. All of the clay mineral particles that comprise the mud deposits of the New York Bight apex must have been transported down the Hudson or Connecticut Rivers at some time, but in many cases, this must have happened in the distant geologic past. Suspended fine sediment is presently being introduced into the Bight apex from the mouth of the Hudson River, but the volume of throughput is probably small relative to the traffic on the numerous feedback loops of the transport system (fig. 2.22).

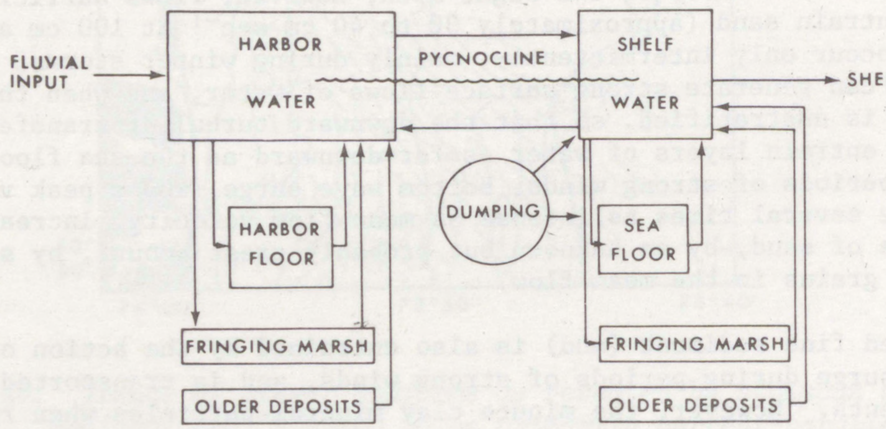



*Figure 2.22. Schematic representation of suspended fine sediment transport system of New York Bight apex. Pycnocline is zone of rapid vertical change in water density between lighter (warmer, fresher) upper water and denser (cooler, saltier) lower water.*

The basic feedback loop is driven by the two-layered (estuarine) circulation, whereby the less saline upper water, flowing seaward over more saline bottom water, entrains bottom water. More bottom water must therefore slowly flow into the river mouth to replace the water thus consumed. Suspended sediment agglomerates may enter the zone of maximum thermohaline stratification either from the up-river side, with the turbid, brackish surface water, or from the sea, with the turbid, saline bottom water. In either case, the agglomerates tend to become caught in a closed loop, whereby they rain out of the seaward-flowing upper water, into the landward-flowing bottom water, only to be re-entrained again in the surface water. Other feedback loops are formed by exchange of mud between the water column on one hand, and sea floor and coastal (lagoonal, salt marsh) mud deposits on the other. The net result of this multicycle, fine-sediment transport system is to maintain relatively high concentrations of suspended fine sediment in the Hudson River estuary and in the coastal waters of the Bight apex. These concentrations are markedly higher than those in the river landward of the salt water intrusion, or on the shelf seaward of the zone of two-layer (thermohaline) circulation.

This picture of coastal suspended sediment circulation has these significant implications for the problems of pollution in the New York Bight apex. First, coastal waters adjacent to such estuarine systems tend to be turbid and brown whether there is human activity in the area or not. Bight apex waters may conceivably have been as brown when visited by Henry Hudson as they are now. Second, the transport system is very nearly an "ergodic" one. In probabilistic terminology this means that it doesn't matter greatly where in the system the fine waste materials are dumped; they will cycle through the system until they reach naturally determined reservoirs of long-term storage, or sinks of permanent storage (estuary floor or shelf floor mud deposits; lagoon floor deposits; fringing marsh deposits). Third, the distinction between natural fine sediment and dumped sediment tends to become blurred subsequent to the introduction of the waste, as it cycles through the feedback loops. Unstable organic compounds break down into more stable ones, which are similar to the stable residues derived from the decay of planktonic life forms, with which they mingle. Inorganic particles are sorted for size, and are mixed with organic particles of similar size. In the more distant parts of the system, increasingly obscure chemical and biologic "signatures" must be sought in order to identify the degree of contamination, including those which are signatures of materials that are significant in terms of environmental quality such as toxic trace metals and pathogenic micro-organisms.

The preceeding analysis suggests that dredge spoil or sewage sludge dumped in the New York Bight apex may ultimately be deposited, albeit in highly dilute form and with altered composition, in areas as far apart as the upper meter of marsh muds in the Hackensack Marshes, or in the upper meter of lagoon floor muds in Great South Bay. Some degree of quantification of the coastal mud budget of the Bight apex may be a final product of the MESA project. The data collected to date, while extensive, do not begin to permit quantification. The most salient elements of the data are presented below. For details, the reader is referred to Drake (1974).

### 2.3.3 Suspended Sediment Transport in the Bight Apex

Figure 2.23 presents the average suspended particulate matter concentration in the Bight apex during the fall of 1973, as determined by Niskin bottle sampling and filtration (see Drake, 1974, for methods). The pattern clearly reflects the mean circulation pattern as deduced by the physical oceanography program (see sec. 1).

Surface water flowing out of the Hudson Estuary turns to the south and forms an easily distinguishable turbid current flowing along the New

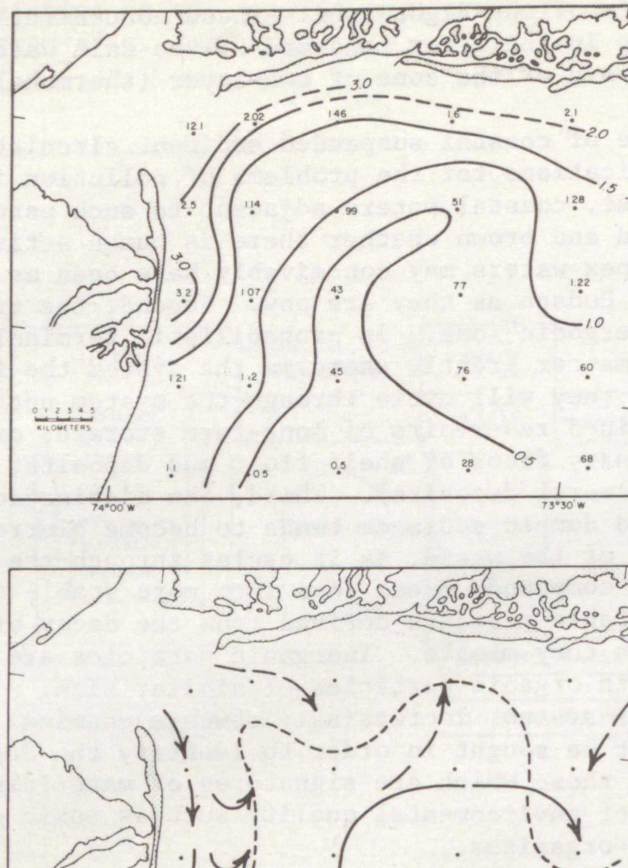



*Figure 2.23. Above: Total suspended load in mg/liter, at 10 meters depth, November 1973. Below: Generalized circulation pattern of the New York Bight apex as inferred from the distribution of suspended sediments during fall, 1973. Dashed line is mean position of boundary between more turbid coastal water and less turbid offshore water. Turbid, brackish surface effluent of harbor flows down New Jersey shore. Clockwise gyre is driven by southwesterly drift of offshore shelf water and, on bottom, by the influx of saline water into the harbor. Solid arrows are currents that appear to be persistent.*

Jersey coast. If a suspended particulate matter concentration of > 1.0 mg/l is used to arbitrarily mark the seaward width of this current the average width is 4 to 6 km.

A sharp decline in suspended particulate matter and a marked compositional change are observed to the east of the Hudson Plume; in fact, the lowest suspended particulate concentrations in the area are observed over the north-south trending Hudson Shelf Valley. Samples above the valley contain the abundant diatom population which is characteristic of central shelf water, and chemical analysis indicates that these samples are rich in high protein phytoplankton. In addition, water in the channel is often colder than water at the same depth elsewhere in the area. These data demonstrate a northward (upslope) flow of water from offshore along the Hudson Shelf Valley that is in part channelized by the valley. When meteorological conditions are appropriate (strong westerly or northwesterly winds) this current reaches the sea surface and may extend to within at least 5 km of Long Island.

Figure 2.23 shows that the Hudson Shelf Valley current turns to the northeast as it approaches the Long Island shore, and that it becomes coupled with, or entrained by a turbid plume extending south along the eastern margin of Cholera Bank. The plume is easily recognizable in ERTS-1 images, and resembles an enormous rip current.

Iron oxide particles generated at the acid waste dumpsite provide an excellent tracer of the circulation pattern (fig. 2.24). The particles range in size from colloidal, yellow filter coatings to sand sizes (> 62 microns) as orange and red aggregates having the appearance of floccules. X-ray defractograms show no evidence of crystal structure, and there is reason to believe that the grains are a mixture of hydrated iron oxide and iron stained plankton debris.

Characteristic vertical distributions of suspended sediment are presented in figures 2.25, 2.26, and 2.27. Figures 2.26 and 2.27 present representative examples of the vertical distribution of suspended particulate material through the fall of 1973. The vertical profiles reflect the seasonal breakdown of temperature and salinity stratification. In early September, both temperature and salinity contribute to a stable stratification with a distinct, steep, gradient pycnocline between 15 and 25 m (fig. 2.25). The pycnocline during this period tends to shoal toward shore, suggesting a slow upwelling of deeper shelf water. In nearshore areas (within 5 to 7 km of the coastline) flow of relatively low salinity water from the Hudson estuary and Long Island inlets produces a 5 to 10 m thick, low density, high turbidity surface layer (fig. 2.26).

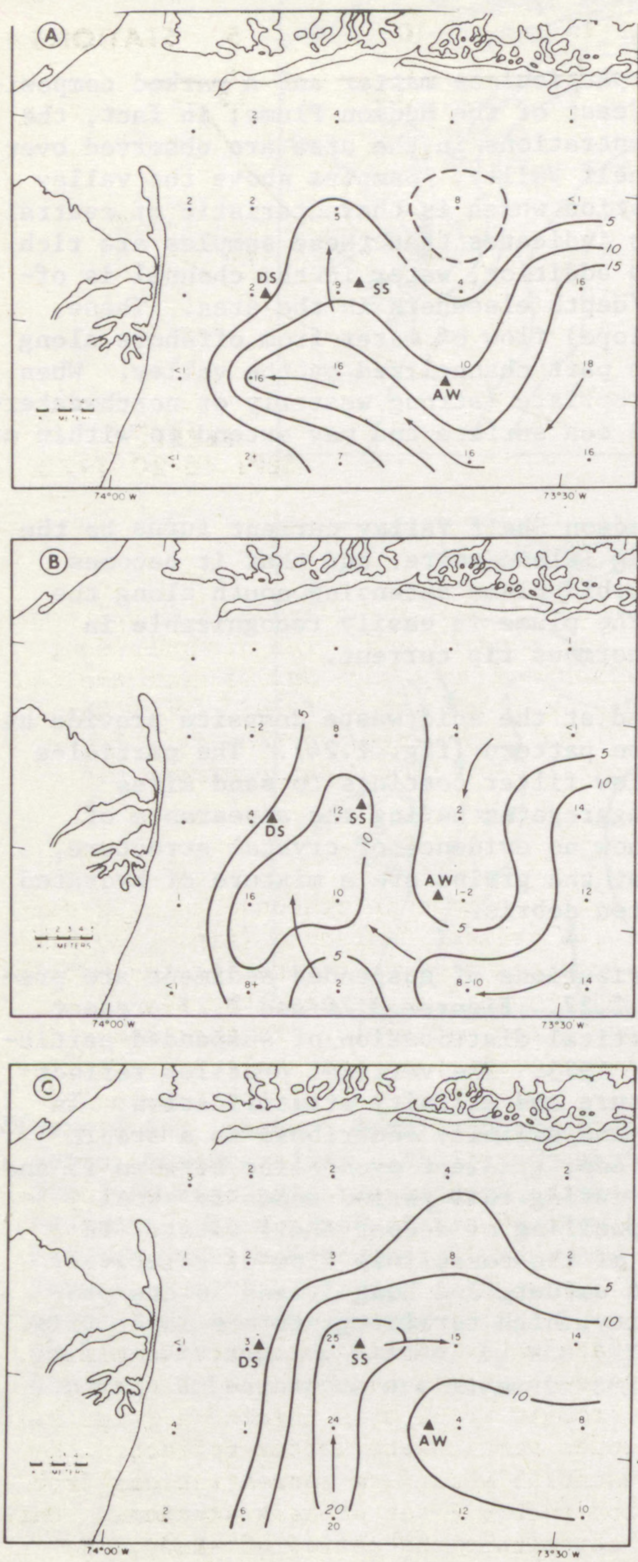



*Figure 2.24. Distribution of iron oxide particles in late November 1973, in terms of number of grains (x $10^3$) per liter of water. At the surface the distribution reflects (A) the surface gyre, but with increasing depth it reflects (B) the influence of the shelf valley, and (C) the acceleration of flow due to the saline bottom water indraught of the harbor.*

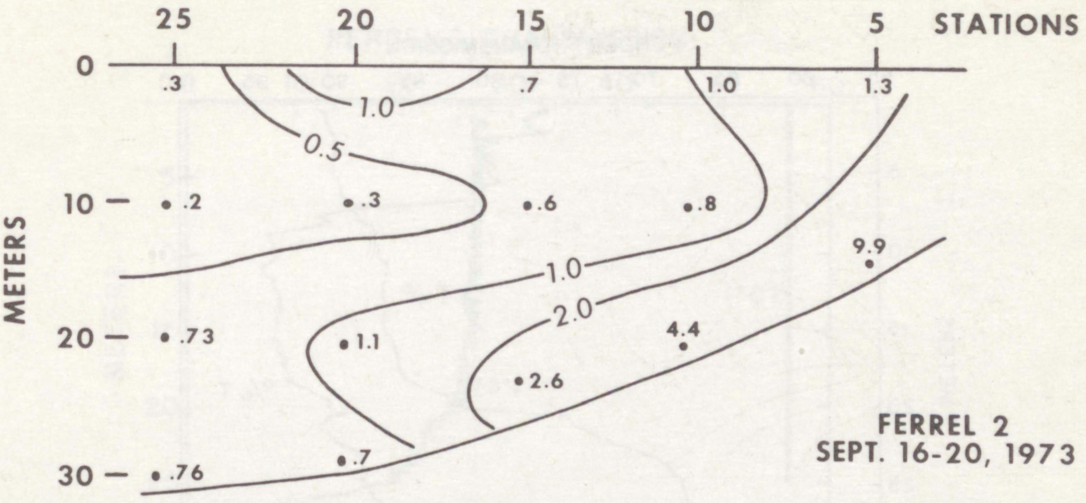



*Figure 2.25. Vertical distribution of total suspended load in mg/liter. The cross section extends south from Long Island. The distribution, showing high values near the surface and very high values near the sea floor, is typical of shelf areas. The near bottom turbid layer has been termed the "nepheloid layer" and it is expected that this layer will contain and transport much of the New York Bight contaminants.*

Suspended particulate matter is stratified in response to this density layering. Three layers typically present nearshore (fig. 2.25) are a turbid surface layer, a relatively clear mid-water zone located within or below the shallow pycnocline, and a turbid layer near the sea floor, resulting from wave resuspension of bottom materials. Further seaward the surface turbid layer becomes less distinct as the shallow pycnocline breaks down. The small maxima at the surface in the offshore parts of the area can be attributed to plankton production. However, the significant near-bottom increase in suspended particulate matter appears to be a permanent feature of all portions of the Bight apex. The near bottom ash content of this material ranges between 40 and 84 percent of the total weight, and most of this material is probably resuspended inorganic clay and silt.

By late November of 1973, surface water cooling, convective mixing, and the effects of increasingly frequent storms had produced a nearly homogeneous surface layer ranging from 10 to 30 m in thickness (fig. 2.27). The vertical distribution of suspended particulate matter reflected the weak or no stratification, with essentially uniform concentrations from the surface to the top of the bottom turbid layer at many stations. During the period of stratification, throughout the period of study, the

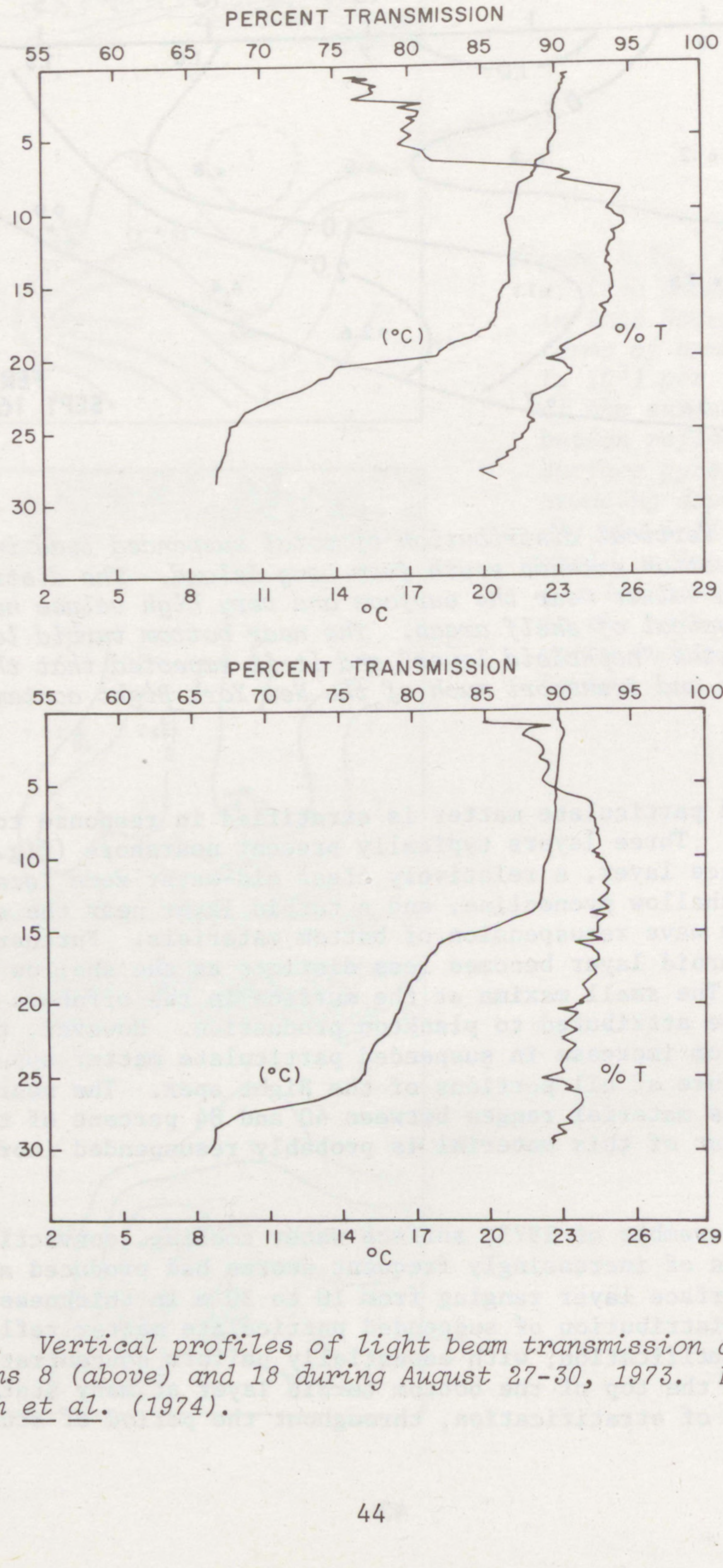
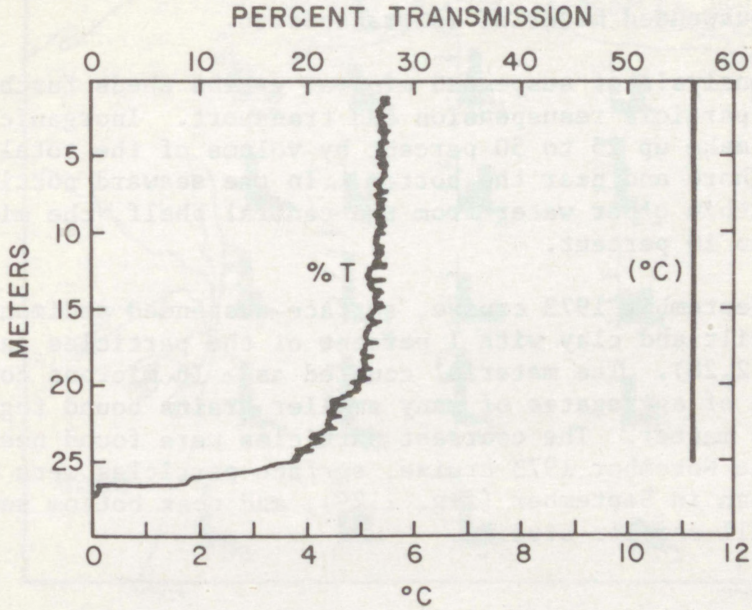



*Figure 2.26. Vertical profiles of light beam transmission and temperature at stations 8 (above) and 18 during August 27-30, 1973. Data from Hazelworth et al. (1974).*



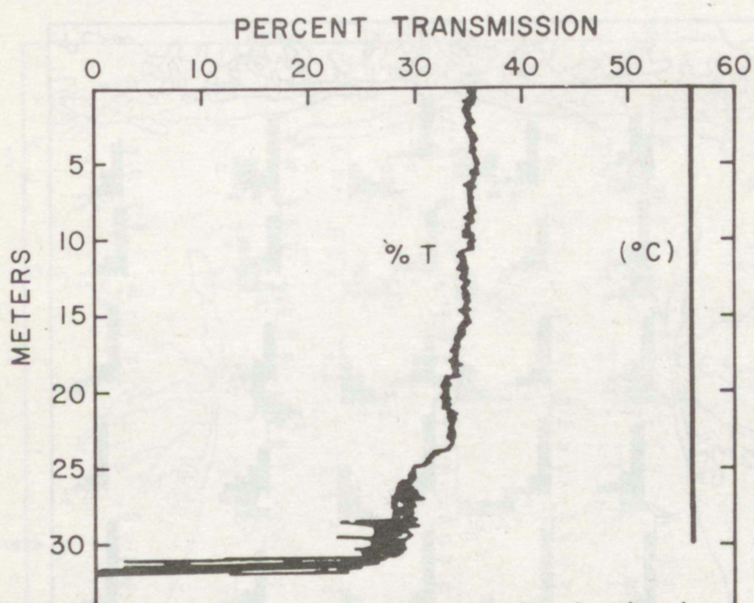




*Figure 2.27. Vertical profiles of light beam transmission and temperature at stations 8 (above) and 18 during November 26-29, 1973.*

highest concentrations of suspended particulate material were observed in the wave-surge generated bottom turbid layer, and it is in this layer that the bulk of the suspended material is transported.

Grain size analysis of suspended mineral grains sheds further light on the nature of particle resuspension and transport. Inorganic mineral grains typically make up 25 to 50 percent by volume of the total suspended matter close to shore and near the bottom. In the seaward portions of the Bight apex and within clear water from the central shelf, the mineral content is below 5 to 10 percent.

During the September 1973 cruise, surface suspended sediment was predominantly fine silt and clay with 1 percent of the particles larger than 16 microns (fig. 2.28). The material counted as > 16 microns consisted, in nearly all cases, of aggregates of many smaller grains bound together by amorphous organic matter. The coarsest particles were found nearest to shore. During the November 1973 cruise, surface particles were significantly coarser than in September (fig. 2.29), and near bottom samples were the coarsest of all samples studied.

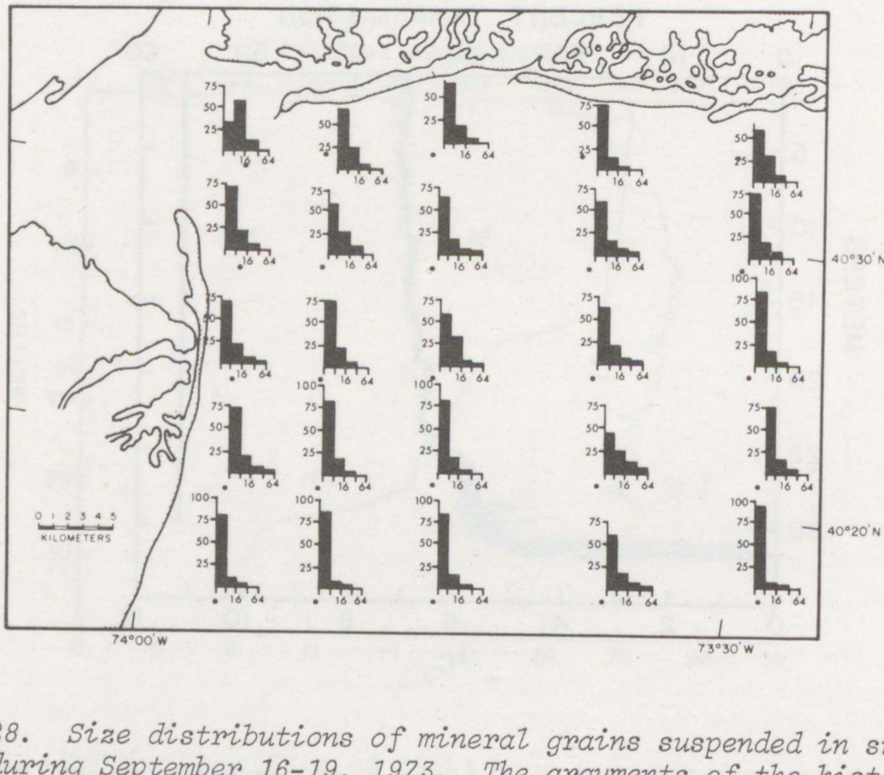



*Figure 2.28. Size distributions of mineral grains suspended in surface waters during September 16-19, 1973. The arguments of the histograms are volume percent (vertical axis) and mean diameter in microns (horizontal axis).*

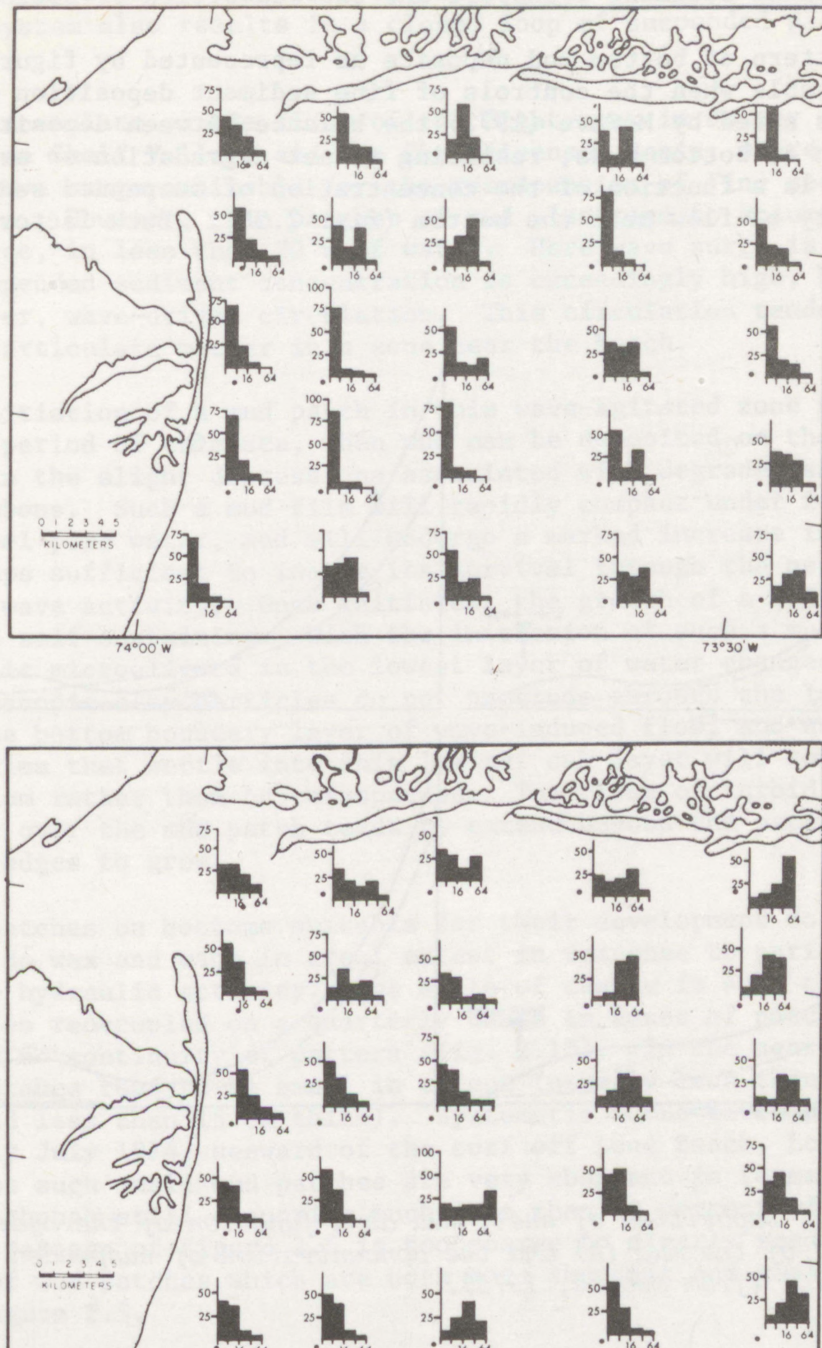



*Figure 2.29. Size distributions of mineral grains suspended in surface waters (above) and 2 m off the bottom (below) during November 26-29, 1973. Axes of histograms as in Fig. 2.28.*

2.3.4 Suspended Sediment Transport and the Deposition of Bottom Muds

The pattern of bottom mud deposits as represented by figure 2.5 becomes explicable when the controls of fine sediment deposition are considered. As noted by McCave (1972) the balance between deposition and resuspension of bottom muds, resulting in net aggradation or erosion of the bottom, is a function of the concentration of suspended sediment and the intensity of flow near the bottom (fig. 2.30). Both factors tend to

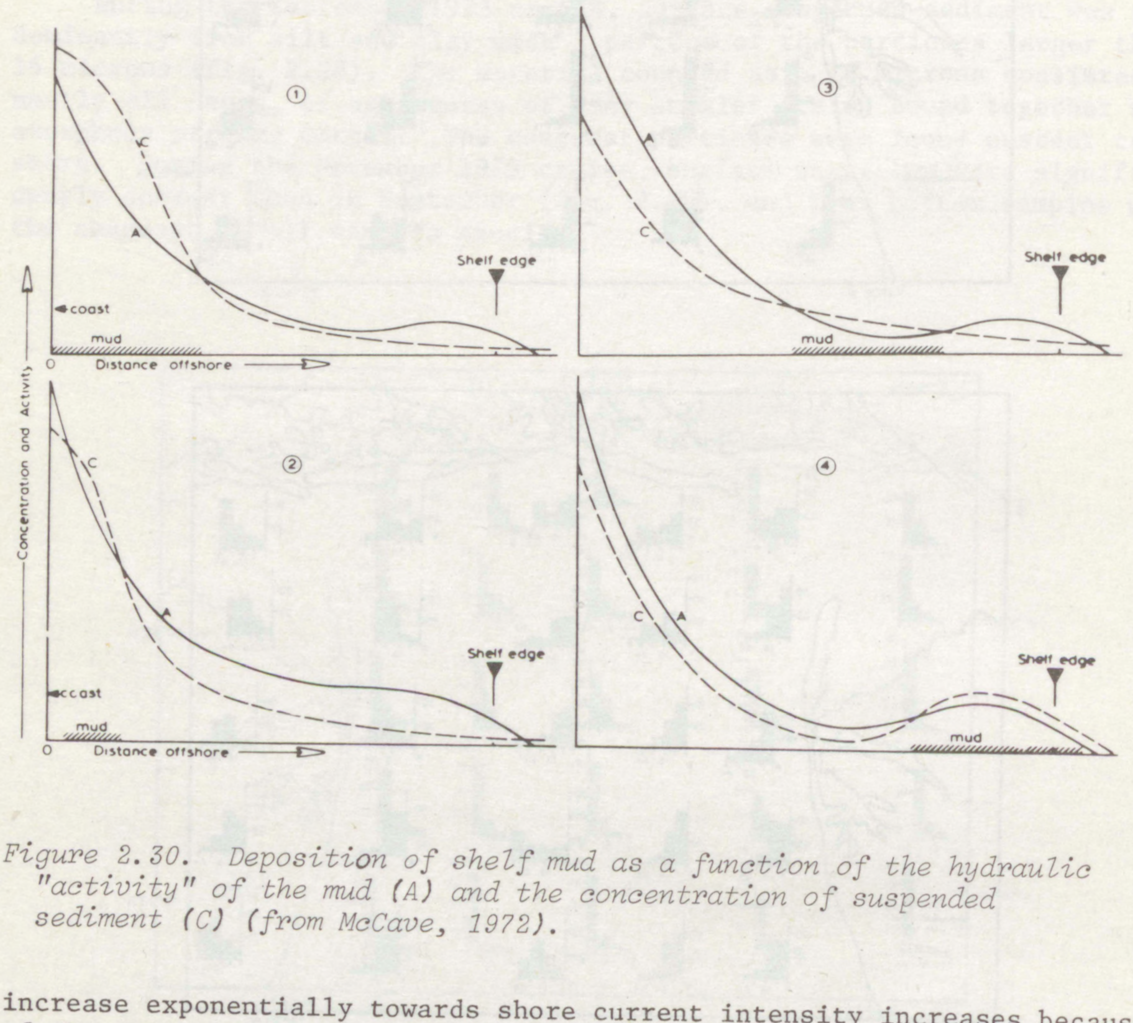



*Figure 2.30. Deposition of shelf mud as a function of the hydraulic "activity" of the mud (A) and the concentration of suspended sediment (C) (from McCave, 1972).*

increase exponentially towards shore current intensity increases because of the increasing release of wave surge energy as the sea floor shoals. Suspended sediment concentration increases because of the two-layer estuarine circulation mechanism which tends to concentrate suspended sediment near the shore (see sec. 2.3.2). Very near the beach a further circulation mechanism transpires, whereby the landward asymmetry of bottom wave surge causes bottom water to move towards the beach, while surface rip currents flow seaward to relieve the pressure head. This hydraulic system also results in a closed loop of suspended particulate transport.

Muds accumulate on the floor of the Bight apex in deeper areas such as the Hudson Shelf Valley, and the Christiaensen Basin, where the energy of bottom wave surge available for the resuspension of fine sediment is less intense. However, thin patches of mud also tend to accumulate on the shoreface, in less than 20 m of water. Here wave surge is intense, but the suspended sediment concentration is exceedingly high, because of the two-layer, wave-driven circulation. This circulation tends to recycle suspended particulate matter in a zone near the beach.

The initiation of a mud patch in this wave-agitated zone probably requires a period of calm sea, when mud can be deposited on the turn of the tide, in the slight depressions associated with degraded sand waves or sand ribbons. Such a mud film will rapidly compact under its own weight, expel pore water, and will undergo a marked increase in cohesiveness, perhaps sufficient to insure its survival through the next period of intense wave activity. Once initiated, the growth of a mud patch tends to be self sustaining. With the initiation of such a mud layer, the hydraulic microclimate in the lowest layer of water changes. The flat, microscopic clay particles do not protrude through the laminar sub-layer of the bottom boundary layer of wave-induced flow, and additional clay particles that settle into this laminar sub-layer will tend to adhere to the bottom rather than be resuspended. The cloud of turbid water immediately over the mud patch tends to extend beyond the patch, and causes its edges to grow.

Clay patches on bottoms suitable for their development do not migrate, but do wax and wane in areal extent in response to periods of mild and intense hydraulic activity. The scale of change is such that side-scan profiles reoccupied on a quarterly basis in zones of patchy bottom show almost no continuity of pattern (fig. 2.15). In the nearshore zone, such mud patches tend to be small in extent (usually less than 10 m in diameter and less than 15 cm thick). Systematic SCUBA dives performed during early July 1974, seaward of the surf off Long Beach, Long Island, suggest that such small mud patches are very abundant in terms of absolute numbers, although still occupying much less than 10 percent of the bottom. The sample pattern of figure 2.5 is too coarse to clearly resolve the distribution of mud patches which are both more abundant and smaller than shown in figure 2.5.

A parenthetic note concerning the color of shelf floor muds is in order here. Shelf floor muds are invariably enriched in organic matter, as a consequence of hydraulic sorting processes, which tend to group finely divided clay particles with comminuted organic matter. Clays also characteristically contain about 5 percent by weight of iron oxide. These two components are responsible for the color of shelf mud. Characteristically a shelf mud is veneered by a thin, oxidized "brown layer" pigmented by $Fe_2O_3$. Depletion of oxygen by decaying organic matter several millimeters below the water-sediment interface results in a black color which is due to carbonaceous organic material. This color pattern is characteristic of muds on totally unpopulated coasts as well as highly populated ones.

Mud patches on the Long Island coast may or may not be highly contaminated with sewage sludge, but gross color and texture are no guides. Terms such as "sludge", "black greasy stuff", "like black mayonnaise" do not indicate whether the organic admixture consists of degraded planktonic material of natural origin, or of human waste.

It is possible to make some order-of-magnitude calculations with respect to the vexing problem alluded to earlier, namely the relative roles of natural materials and introduced materials in the fine sediment dispersal system of the Bight apex (Drake, 1974), based on the data collected in the fall of 1973. The calculations attempt to determine the amount of fine sediment entrained during the storm of November 26 to 27. They assume that the concentrations of suspended material observed from the beginning of September through November 9 were characteristic of the fair weather regime. It is further assumed that contribution of "new" material from land and plankton production were constants. This is unlikely. However, microscope analysis of filters indicates that the plankton standing crops in September-October were higher than in November; hence the "excess" turbidity measured in late November is underestimated rather than overestimated. The late November storm involved high velocity winds (20 to 30 knots) but no coastal precipitation; hence a constant discharge from the Hudson estuary may be assumed.

Using all data for the fall surveys (Drake, 1974), the mean difference in suspended particulate matter for the apex water volume between the first four surveys and the survey of November 26 to 30 is approximately 0.5 mg/l. This omits the poorly known concentrations in the near bottom zone (0 to 5 m above the bottom), and therefore is a conservative estimate. The volume of the Bight apex included within our station grid is roughly 20 $km^3$, which yields a suspended solids "excess" of the post-storm period over the pre-storm period of about 10,000 metric tons, assuming a particle density of 2.0 $g/cm^3$. This figure may be compared with the estimated average daily input of sewage solids of 750 metric tons. In other words, the late November period of heightened hydraulic activity increased the suspended particulate concentration from an apparent steady state condition to a more intense concentration level equivalent to the addition of 12 days worth of barge dumping.

2.3.5 Coarse Sediment Transport: General Concepts

In the previous section it was pointed out that the fine sediment transport pattern of the Bight apex is not simply a matter of turbid river water flowing out to sea, but instead a much more complex system in which the traffic on numerous feedback loops may be much more voluminous than the throughput volume.

The fluvial throughput model of sediment transport is yet less applicable to the sand budget of the Bight apex. Most estuaries serve as sand sinks rather than sand sources for the coastal sand budget, and the morphology of the Hudson estuary mouth suggests that it is no exception. The littoral drift discharge of both the northern New Jersey and Long Island coastal compartments converges on the estuary mouth (figs. 2.31, 2.32). Here the sand accumulates in a massive sand shoal filling the estuary mouth. Such estuary mouth shoals tend to be stabilized by the interdigitation of ebb-dominated and flood-dominated paths of tidal flow.

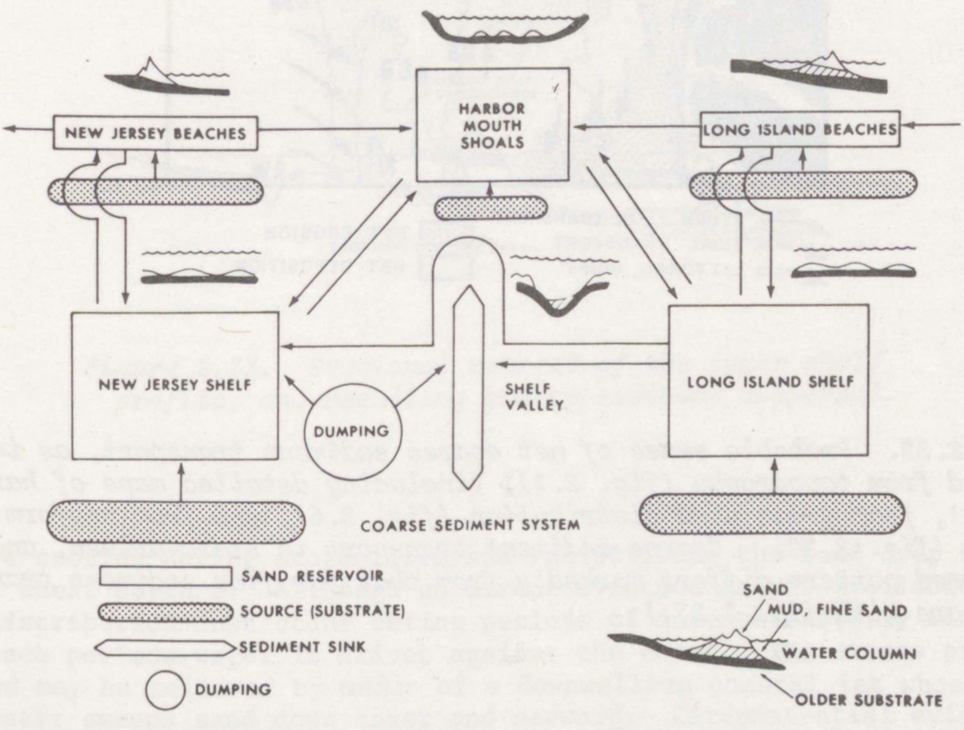



*Figure 2.31. Schematic representation of probable pattern of coarse sediment exchange in New York Bight apex. Compare with figure 2.22.*

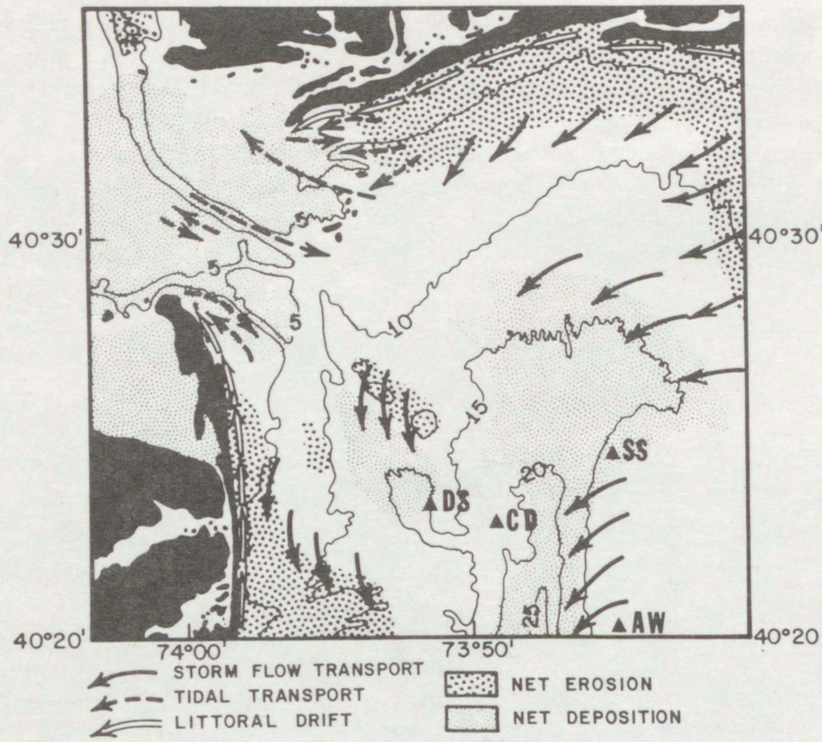



*Figure 2.32. Probable sense of net coarse sediment transport, as inferred from topography (fig. 2.1), (including detailed maps of harbor mouth), from grain size distribution (fig. 2.5), and from bedform patterns (fig. 2.20). Coarse sediment transport is storm-driven, and the inferred pattern differs markedly from that for fine sediment transport. (Compare with fig. 2.23.)*

The main source of sand for the coastal sand budget is instead the eroding shoreface and inner shelf surface. This surface is presumably attempting to develop the ideal, concave up, exponentially curved surface in response to the present hydraulic regime. However, the ideal surface toward which the actual shelf surface is trending is not a stationary one, but one which is slowly translating upwards and landwards in response to the slow post-glacial rise in sea level (fig. 2.33). The actual surface, in attempting to follow this ideal surface, must release sand by

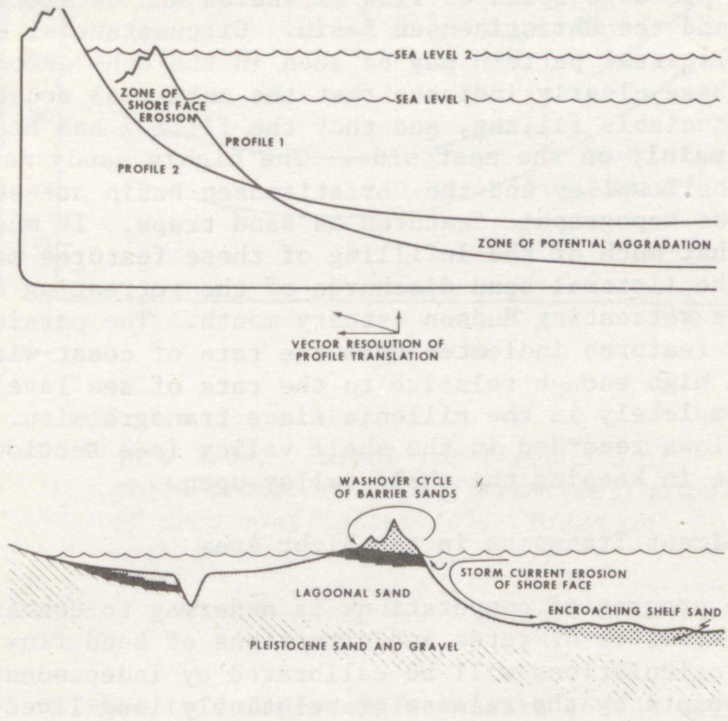



*Figure 2.33. Erosional retreat of the inner shelf profile, and resulting coarse sediment dispersal.*

shoreface erosion during storm flows and redistribute the sand over the adjacent shelf surface. Although no direct evidence is yet available, such redistribution must occur during periods of intense easterly winds. During such periods water is driven against the coast. The excess pressure head may be relieved by means of a downwelling coastal jet whose bottom water sweeps sand down coast and seaward. Circumstantial evidence for such flows occurs in the form of patches of sand-waves (figs. 2.9, 2.13), oriented oblique to the coast, which are most clearly defined in early spring, and which tend to be obliterated by the end of summer.

During such peak flow events the Bight apex gyre probably does not function, and the flow trends instead west and south through the apex. This spasmodic, high intensity flow field rather than the fair weather flow field is probably responsible for the bedform patterns of figure 2.9, which may constitute a time-averaged response to such flows. It is probably also responsible for the distribution of sand grain sizes of figure 2.5. The coarse, gravelly sands of inner Cholera Bank and the New Jersey Platform may be lag concentrates beneath zones of flow constriction and acceleration during storms, where finer sands may be swept away to be deposited in such probable zones of flow expansion and deceleration as the shelf valley and the Christiaensen Basin. Circumstantial evidence for such a sand dispersal pattern may be seen in the sub-bottom profiles of figure 2.2. These clearly indicate that the ancestral subaerial valley has undergone appreciable filling, and that the filling has been asymmetrical, occurring mainly on the east side. The highly sandy nature of the muds of the shelf valley and the Christiaensen Basin attest to the efficiency of these topographic features as sand traps. It must be recognized, however, that much of the infilling of these features may have been accomplished by the littoral sand discharge of the retreating Long Island coastline into the retreating Hudson estuary mouth. The persistence of these topographic features indicates that the rate of coast-wise sand flux has not been high enough relative to the rate of sea level rise to fill the lows completely in the millenia since transgression. The intense northward flows recorded in the shelf valley (see section 1) may have played a role in keeping the shelf valley open.

### 2.3.6 Coarse Sediment Transport in the Bight Apex

An intensive program of computations is underway to convert current meter data into estimates of rates and directions of sand flux in the Bight apex. The calculations will be calibrated by independent estimates attained at key points by the release of relatively long-lived (3-month working period) radioisotope tracers. The following is a preliminary statement of approach, together with some preliminary data.

The initiation of coarse sediment movement has been extensively studied in the last three decades, and the flow velocity requisite for varying grain densities, bed configurations, and water viscosities is generally understood. Figure 2.34, shows threshold velocities for a smooth bed of quartz sand, from information developed by Shields and published by Graf (1971) and subsequent workers. A band rather than a single line is presented because of uncertainties in resolving the velocity profile of the boundary layer that are beyond the scope of this report. A representative threshold curve is close to but slightly below the upper margin of the band. For a rippled bed whose corrugated surface has developed resistance to flow, the curve should be near or slightly above the upper margin of the band. In general, the minimum velocity threshold for grain motion is approximately 30 cm $sec^{-1}$ for fine sand, and slightly higher for coarser grades.

In order to appreciate the significance of this number, the reader should review the velocity records described in section 1. During the fall of 1973, peak flows regularly attained velocities of 50 cm $sec^{-1}$ at mid-depth.

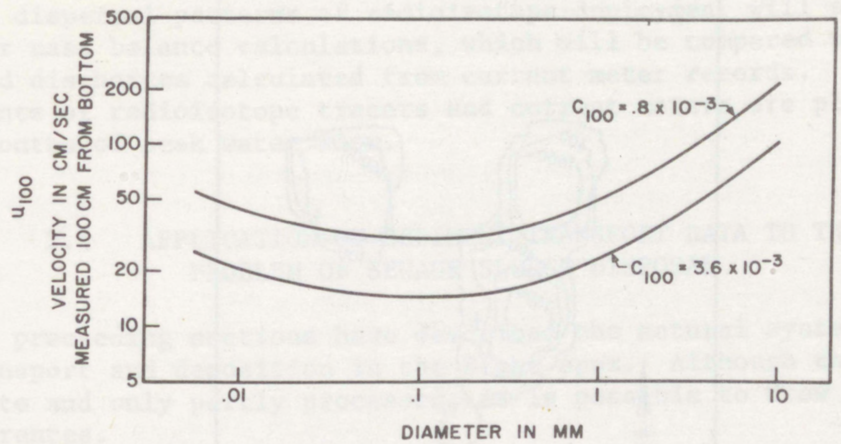



*Figure 2.34. Curves for threshold of grain transport at different estimates of drag coefficient (C). Based on work of Shields (Graf, 1971).*

The first attempt to independently measure coarse sediment flux by means of radioisotope tracers was undertaken in November 1973, using the radioisotope sand tracer (RIST) system developed by Oak Ridge National Laboratory and the Coastal Engineering Research Center (Duane, 1970). Sand from the Bight apex was impregnated with a radioisotope of gold, with an 8-day effective working period (approximately 3 half-lives). The experiment, undertaken 4 km off the New Jersey coast in 30 m of water, corroborated our estimate of threshold velocities and supported the hypothesis that sand transport occurs mainly under severe storm conditions. Bottom currents measured coincidentally with the experiment show a north-northeast residual current superimposed on a relatively strong tidal flow. Peak current velocities measured at 100 cm from the bottom were on the order of 35 cm $sec^{-1}$, just sufficient to initiate sand transport, and insufficient to move appreciable quantities. Figure 2.35, shows contours of observed radiation on the final survey day. Caution must be used in interpretation of the figure because of the contouring algorithm employed. However, the lower left hand dispersal pattern displays a very limited dispersal to the north-northeast.

In April 1974, sand labeled with an isotope of Ruthenium (120-day effective working period) was released on the crest of Cholera Bank. Figure 2.36 presents the time development of the pattern through two surveys undertaken 3 weeks apart. Sand from the drop sites was transported

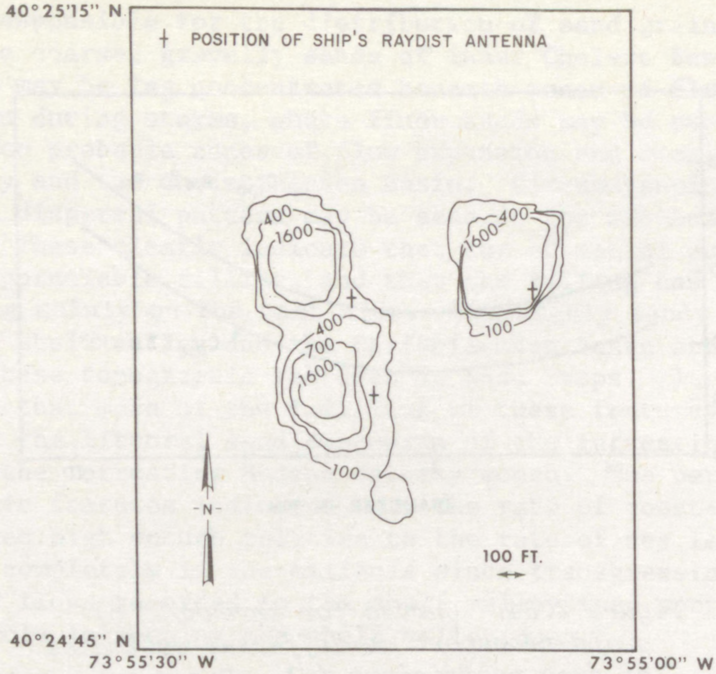



*Figure 2.35. Dispersal pattern of gold-labeled tracer sand at end of November 19, 1974, experiment. See figure 2.3 for location.*


*Figure 2.36. Dispersal patterns for two surveys, Ruthenium labeled sand of spring experiment. See figure 2.3 for location.*

first to the east and then to the west, in response to coast parallel flow, modulated by tidal currents peaking at 30 to 40 cm $sec^{-1}$.

The dispersal patterns of radioisotope deployment will serve as the basis for mass balance calculations, which will be compared with theoretical sand discharges calculated from current meter records. Simultaneous deployments of radioisotope tracers and current meters are planned for the winter months of peak water flow.

## 2.4 APPLICATION OF SEDIMENT TRANSPORT DATA TO THE PROBLEM OF SEWAGE SLUDGE DISPOSAL

The preceeding sections have described the natural system of sediment transport and deposition in the Bight apex. Although the data are incomplete and only partly processed, it is possible to draw the following inferences.

### 2.4.1 Pattern of Waste Dispersal

Suspended solids concentrations in the lower one-third of the water column surrounding the dredge spoil and sewage sludge dumpsites are 30 to 50 percent higher than would be expected if no dumping were occurring. Existing data do not permit distinguishing of dredge spoil from sewage sludge. Quantitative measurement of these components in natural suspended material requires identification of the chemical signature of sewage sludge.

The dispersal of easily identifiable red iron hydroxide particles from the acid waste dumpsite (figure 2.24) indicates entrainment of these particles in the clockwise circulation pattern (figure 2.23). There seems to be no question that material from all of the dumpsites is being transported by this clockwise gyre toward the Long Island shore.

Suspended solids concentrations (biogenic remains and mineral particles) are naturally high and quite variable within 10 km of both the Long Island and New Jersey shores (figure 2.23). This material is composed of both living and non-living plankton and terrigenous minerals that are supplied by the Hudson River estuary, by inner shelf currents moving westward along Long Island, by tidal exchange with the shallow lagoons behind Long Island's barrier islands, and by *in situ* plankton production. Microscopic analysis shows that suspended solids at all water depths within 15 km of Long Island during the fall of 1973 contained only trace amounts (much less than 1 percent by grain count) of processed cellulose (assumed to be disintegrated toilet paper) and the black soot particles that are characteristic of suspended solids samples collected from the near bottom water of the sewage sludge dumpsite. It is clear that the sewage-related materials that move in suspension are tremendously diluted by natural particles during transport northward toward Long Island.

### 2.4.2 Bottom Muds Versus Sewage Sludge Beds

A major conclusion derived from our initial data is that the entry of sewage-related materials into natural bottom deposits is a subtle process indeed. These materials are too fine and mobile to pile up and remain on the bottom at the dumpsite. It is significant that the sea floor at the dumpsite consists predominantly of bare sand. Patches of mud, whether natural or sewage-related are thin, small, and infrequent. The locus of organic-rich muds deposition appears to coincide precisely with the contours of the Christiaensen Basin. This basin lies between the designated dumpsite and the mouth of New York Harbor, and the high concentrations of organic carbon described in section 3 may be the consequence of short dumping. However, our analysis of the fine sediment transport system indicates that the bulk of the sewage sludge will wind up in this zone of natural fine sediment deposition no matter where it is dumped in the Bight apex.

To better define the distribution of sewage-derived particulate materials that are being deposited in the Bight apex, 13 bottom samples were separated into light and coarse fractions, filtered onto membrane filters, and microscopically examined for artificial contaminants. Three samples were from the Christiaensen Basin muds immediately northwest of the sewage sludge dumpsite; four were from mud patches within 5 km of the Long Island shore; four were from brown muds near the New Jersey coast, and two were from muds inside Jones Inlet. The results are presented in Table 2.2.

These data suggest the following conclusions. The muds off Long Island are predominantly natural in origin and contain at most only 2 to 3 percent of sewage-derived particles. Muds from other areas contain more solid material attributable to man than do the black muds from the Long Island shore. The relatively large amounts from the New Jersey Platform, for instance, are probably derived from the Hudson River outflow.

There is no material on the floor of the New York Bight apex that has been clearly identified as sewage sludge (predominantly sewage-derived material), although the muds of the Christiaensen Basin are probably significantly contaminated, and may locally contain more contaminant than natural materials. No front of sewage sludge, or of any other material was observed moving towards the Long Island shore. The dimensions of muddy areas, and the boundaries between sand areas and mud areas probably shift with the passage of the seasons. Nearshore mud patches appear and disappear

Microscopic examination of samples from nearshore mud patches do not reveal indicators of contamination in significant quantities. However, it is not possible to resolve toxic trace metals or pathogenic microorganisms by microscopic methods, and these materials are potentially more mobile and transportable than the observed cellulose fibers and soot particles.

*Table 2.2 Particle Count Analysis of Contamination of Bight Apex Muds*

| | Natural Mineral and Biogenic Grains | Artificial* Grains |
|---|---|---|
| | (% by grain counts per 250 grains) | |
| <u>Near Dumpsite Samples</u> (3 samples) | | |
| Coarse fraction | 89% | 11% |
| Fine fraction | 84% | 16% |
| <u>Long Island Shore</u> (4 samples) | | |
| Coarse fraction | 97.6% | 2.4% |
| Fine fraction | >99.0% | <1.0% |
| <u>New Jersey Platform</u> (4 samples) | | |
| Coarse fraction | 96.8% | 3.2% |
| Fine fraction | 96.7% | 3.3% |
| <u>Jones Inlet Muds</u> (2 samples) | | |
| Coarse fraction | 97.8% | 2.2% |
| Fine fraction | 98.6% | 1.4% |

*Processed cellulose fibers (mainly toilet paper) and soot-like particles. The latter are a significant component of sediments on the northwest side of the dumpsite but may be derived from other waste dumping in the New York area.

## 2.5 REFERENCES

Belderson, R. H., N. H. Kenyon, A. H. Stride, and A. R. Stubbs, 1972. Sonographs of the Sea Floor. Elsevier, New York, 185 pp.

Bumpus, D. F., 1965. Residual drift along the bottom on the continental shelf in the Middle Atlantic Bight area. Limnol. and Oceanogr., 10 (Redfield Vol.): R50-R53.

Dewling, R. T., 1974. Ocean disposal. In Ocean dumping in the New York Bight. Environmental Protection Agency briefing report, p 19-29.

Drake, D. E., 1974. Suspended particulate matter in the New York Bight Apex: September-November 1973. NOAA Tech. Rept. ERL 318-MESA 1, 56 pp.

Duane, D. B., 1970. Synoptic observations of sand movement. Proc. 12th Coastal Eng. Conf., p 799-813.

Environmental Protection Agency 1973. Ocean dumping in the New York Bight: facts and figures. Environmental Protection Agency, Region II.

Graf, W. H., 1971. Hydraulics of sediment transport. McGraw-Hill, New York, 504 pp.

Gross, M. G., 1972. Geologic aspects of waste solids and marine waste deposits New York metropolitan region. Bull. Geol. Soc. Amer., 83: 3163-3176.

Gross, M. G., B. A. Morse, and C. A. Barnes, 1969. Movement of near-bottom waters on the continental shelf off the northwestern United States. J. Geophys. Res., 74: 7044-7047.

Hazelworth, J. B., B. L. Kolitz, R. B. Starr, R. L. Charnell and G. A. Berberian, 1974. New York Bight Project, Water Column Sampling Cruises #1-5 of the NOAA Ship FERREL, August-November, 1973. MESA Report 74-2.

McCave, I. N., 1972. Transport and escape of fine-grained sediment from shelf areas. In D. J. P. Swift, D. B. Duane, and O. H. Pilkey (editors), Shelf Sediment Transport: Process and Pattern. Dowden, Hutchinson and Ross, Stroudsburg, Pa., p 225-248.

Meade, R. H., 1972. Transport and deposition of sediments in estuaries. In B. W. Nelson (ed.), Environmental Framework of Coastal Plain Estuaries. Geol. Soc. Amer. Mem., 133: 91-120.

Milliman, J. D., and K. O. Emery, 1968. Sea levels during the past 35,000 years. Science, 162: 1121-1123.

Shepard, F. P., and H. R. Wanless, 1972. Our Changing Coastlines. McGraw Hill, New York, 557 pp.

Swift, D. J. P., 1972. Holocene evolution of the shelf surface, central and southern shelf of North America. In D. J. P. Swift, D. B. Duane, and O. H. Pilkey (editors), Shelf Sediment Transport: Process and Pattern. Dowden, Hutchinson and Ross, Stroudsburg, Pa., pp 499-574.

Taney, N. B., 1961. Geomorphology of the south shore of Long Island, New York. Beach Erosion Board Tech. Memo. 128, 50 pp.

Veatch, A. C., and P. A. Smith, 1939. Atlantic submarine valleys of the United States and the Congo Submarine Valley. Geol. Soc. Amer. Special Paper 7,101 pp.

# 3. CHEMICAL AND GEOCHEMICAL OCEANOGRAPHY OF THE NEW YORK BIGHT APEX REGION AS IT PERTAINS TO THE PROBLEM OF SEWAGE SLUDGE DISPOSAL

Douglas A. Segar, Patrick Hatcher, George A. Berberian
Larry E. Keister, Maxine Weiselberg

## 3.1 INTRODUCTION

The following is a summary of the New York Bight ecosystem chemistry as it relates to understanding the disposition of sewage sludge barged and dumped into the ocean about 16 km south of Long Island and 13 km east of New Jersey. Three basic questions are of concern: Is sewage-derived material approaching the Long Island beaches? Is the material reportedly found near the beaches derived from the barge-dumped sewage sludge? Does any such material exist at high concentrations so as to be a significant contaminant in the marine environment? Unequivocal answers are not possible at this time. However, the available evidence is reviewed in the context of these questions.

## 3.2 WASTE DISPOSAL

### 3.2.1 Contaminants Introduced into the New York Bight

Sewage sludge is not the only contaminant being released into the New York Bight. Other materials such as dredge spoil and acid wastes are dumped at sites close to that of the sewage sludge dumping. Both of these materials can contain large amounts of trace metals. The dredge spoil often contains large quantities of organic matter, much of which is derived from sewage introduced directly into estuaries from which the spoil is removed. In addition, a multiplicity of point sources ranging from the Hudson estuary to the smallest drainage ditch introduce many contaminants into the Bight. Contaminants contained in such outfalls include a spectrum of organic compounds, trace metals, and suspended materials, including treated and untreated sewage.

### 3.2.2 Composition of Sewage Sludge

Raw sewage reaching the treatment facility originates from a variety of sources, principally domestic human and kitchen wastes, industry, and commercial establishments. Primary sewage treatment involves degritting, grease and scum removal, and then clarification by sedimentation. The clarified waste water is then pumped off and the remaining thickened sludge disposed of by dumping. Secondary treatment usually consists of aeration of the clarified waste water from the primary treatment together with the addition of some of the sludge to supply biological activators. The resulting products are then disposed of as with primary treatment. Chlorination is frequently used at one or more stages of these processes. In New York the resulting sludge slurry is barged to the ocean disposal site.

Sewage sludge is an extremely heterogeneous material comprising amorphous organic aggregates but including such identifiable material as tomato and melon seeds, human hair, and fragments of rubber and plastic.

Organic matter in sewage sludge has not yet been, and probably never will be totally characterized; however, some major constituents have been identified (Hunter and Heukelekian, 1965; Gross, 1972; Walter, 1961). Total organic carbon usually accounts for 20% to 40% of the dry weight of solids. Proteins and carbohydrates compose around 20% and 10% of dry weight respectively. One constituent of the sludge is cellulose fibers originating primarily from paper products. Other minor components are amino sugars, soluble acids, fats, anionic detergents, hydrocarbons, and amides, all together composing less than 10% of the dry weight of solids. Recently Kolattukudy and Purdy (1973) identified a biopolymer called cutin as a significant component of sewage sludge. This biodegradation-resistant polymer is derived from the cuticle waxes of most staple vegetables. Also, associated with the solid sludge material are bacterial and fungal populations, and trace metals originating both in domestic and non-domestic wastes. Dissolved trace metals and organic compounds released into the sewage system may be at least partially scavenged from solution by the solid materials during the sewage transportation and treament process.

### 3.2.3 Fate of Sewage Sludge After Dumping into the Ocean

When sewage sludge is released into sea water, the new chemical environment causes rapid chemical alteration of the sludge. The nature and extent of such transformations have not been studied in detail. In addition, sludge material undergoes biological and physical changes. Certain microbial species in sewage experience a hostile environment and eventually die out. These are subsequently replaced by marine microbes. Physical fractionation occurs due to the wide range of densities and sizes of particles introduced to the water column. The range of particle sizes dumped changes as the electrolyte action of sea water permits the aggregation of small particles to form larger clumps. The physical separation of fractions of the sludge is important for determining both the initial sedimentation site and any subsequent resuspension, transport, and redeposition.

Physical transport of material in the New York Bight apex is discussed in more detail in sections 1 and 2. However, it is relevant to point out that different types of material may be deposited and transported in very different patterns. Therefore, it is not possible to delineate the ultimate distribution of sewage sludge per se from the observed distribution of any one of its component parts. For example, distributions of tomato seeds, hair, and cellulose particles may be totally different even though they are all derived from the same barge. This problem is further complicated by the fact that different fractions of the sludge will be subjected to degradation and transformation to materials which may be physically indistinguishable from the naturally occurring sediments or dissolved components. Additionally, the different fractions may experience different rates of decomposition during the time they reside in the marine environment. For example, plastic particles may be transported great distances over long periods of time while more easily degradable materials will be assimilated by the ecosystem within a few days and before they can be transported far from the dumpsite.

The fate of sewage sludge dumped into the oceans is thus not easily understood nor simply described and is a complex function of the physical, geological, and particularly the biological and chemical forces working in different ways on different materials within the sludge. Ultimately all of the materials of the sludge will be converted into chemical forms which may be indistinguishable from those of naturally occurring compounds and solids.

### 3.2.4 Methods for Identification of Sewage Sludge in Marine Sediments

Methods for identification of sewage sludge in the sediments from natural waters are all dependent upon some physical or chemical property of sludge being traced to the site of deposition. However, as pointed out, the distribution of any one component of sewage in bottom sediments may not necessarily reflect the fate of the transported sludge as a whole.

Physical properties of sewage such as its "black, mayonnaisey consistency", and the presence of human hairs, plastic particles, and tomato seeds, have recently been used in attempts to define the boundaries of the so-called sludge bed resulting from ocean dumping in the New York Bight and other areas. Sediments that are black and sloppy in texture usually contain large quantities of organic matter which is fine grained and has a density not very different from that of water. Because of the fine grain and low density, such sediments are found to accumulate in topographic depressions or in areas of low wave and current energy. Also, because of these physical characteristics they are easily resuspended and transported by the overlying water. In coastal locations such sediments are often formed naturally from the detrital organic matter generated at the coastline and by shallow water plant communities. It is likely, therefore, that without any contribution from man, pockets of black mud-like sediments would occur naturally in the New York Bight, particularly close to the shore and to river and channel mouths. Presence of this type of sediment in pockets close to the Long Island shore is, therefore, not necessarily related to the dumping of sewage sludge offshore. This is particularly true when it is considered that a number of inlets along the Long Island shore are themselves probable sources of sewage-derived organic detritus.

Slowly biodegradable constituents of sewage sludge such as tomato seeds and hair are not rendered unidentifiable in the marine environment until long after the other components of the sludge are oxidized and assimilated. They may, therefore, be transported beyond the area reached by the major proportion of the sludge and their distribution will not accurately define the area adversely affected by the sludge.

Several reports concerned with the New York Bight (Gross 1969, 1970 a, 1970 b, 1972; Carmody et al., 1973) have discussed the distribution of trace metal concentrations in the sediments. High trace metal concentrations have been observed at the sewage sludge dumpsite. The concentrations decrease with increasing distance from this area. Although sediments derived from sewage sludge contain high trace metal concentrations, it cannot be inferred that all fine sediments with high trace metal concentrations in the New York Bight contain sewage sludge. High trace metal concentrations (in some instances higher than the highest observed in the New York Bight) are found in many fine-grained sediments throughout the marine environment. Anomalously high local concentrations have been observed in areas where contaminant inputs do not include sewage (Segar & Pellenbarg 1973).

High organic carbon content of sediments would give an indication of the presence of sewage sludge, if the contribution of organic matter from other sources to the sediments were negligible. This in fact is not the case, particularly near the coastline. We have estimated that the total amount of organic matter dumped into the Bight as sewage sludge is less than one-half the organic matter produced in the region by marine plants. Therefore, organic carbon contents alone cannot be used to trace the sewage sludge influence, particularly at sites far from the dumpsite where organic carbon values are comparatively low and natural sources are significant.

Nevertheless, since sewage sludge is composed primarily of organic materials it seems logical to use some of these components as possible tracers. Whatever components are chosen as tracers must ideally be major components of sewage, only slowly biodegradable, and not found naturally in the dumping environment in any significant quantities. We are searching for specific compounds or groups of compounds to act as organic tracers and to enable us to delineate the transport patterns and fate of sewage sludge. Preliminary work has indicated that total carbohydrates normalized to total organic carbon may be used to obtain a crude estimate of the distribution of sewage-derived materials.

Carbohydrates derived from phytoplankton are generally those easily degraded in the marine environment. Glucose, fructose, mannose, and other monosaccharides constitute a substantial fraction of phytoplankton-derived organic matter (Parsons et al., 1961). As the organisms die and settle to the sediments, these carbohydrates are preferentially oxidized or degraded as compared with more resistant cellulolytic carbohydrates which comprise a small fraction of phytoplankton carbohydrates. Carbohydrates are therefore rarely retained in recent sediments comprising mainly phytoplankton remains.

Terrigenous organic matter generally contains a substantial amount of carbohydrates, mainly structural carbohydrates such as cellulose and hemicellulose (Rogers 1965). If we define the carbohydrate/TOC x 100 ratio as R, then the expected R for these terrigenous substances is generally greater than 30. Sewage is considered a terrigenous substance and, therefore, possesses similar properties. The organic matter in soils derived from terrigenous substances undergoes extensive and rapid decomposition soon after it is deposited. The breakdown of cellulolytic carbohydrates is accelerated as compared with the marine environment, and R decreases rapidly to a value of generally less than 10. The major input of terrigenous organic matter to the near-shore areas is derived from the leaching of these low carbohydrate soils in the watershed. Since R of this leached material is generally low, and the contribution of terrigenous matter to the New York Bight is small (Meade 1969). sedimentary contribution of non-sewage terrigenous materials is expected to be low.

In non-polluted near-shore sediments R is generally less than 10, indicating that carbohydrates comprise only a small fraction of the organic matter (Degens _et al_., 1961). Even after substantial decomposition, this ratio remains low due to the fact that, although the labile carbohydrates have long disappeared, the resistant cellulolytic carbohydrates also undergo bacterial degradation. This process is slow but, nevertheless, more rapid than the breakdown of highly resistant non-carbohydrate materials which may account for more than 80% of the organic matter present. Under these circumstances, the C/TOC ratio would be expected to decrease with increasing age.

Sewage sludge contains a substantial amount of carbohydrate material (Walter, 1961), mostly in the form of cellulose and hemicellulose (Hunter and Heukelekian, 1965), both of which are resistant to biological degradation. After sludge is dumped in the ocean, it undergoes substantial microbial degradation, both before and after it reaches the sediments. The amount of organic matter thereby decreases. Cellulolytic carbohydrates, however, do not undergo the equivalent amount of decomposition in such a short time span as other more easily degradable organic constituents of sewage. Therefore the R would be expected to increase upon rapid biological degradation. Extremely high R ratios might therefore be characteristic of sewage-derived material that has been aged somewhat in the environment.

In sediments of the New York Bight, R is commonly greater than 20, indicating a high proportion of carbohydrates relative to organic matter as compared with other similar areas. As sewage sludge contains large amounts of cellulose and other resistant carbohydrates (R=30), it seems likely that these cellulolytic carbohydrates have enriched the sediments of the New York Bight. The non-biodegradable nature of these cellulolytic carbohydrates over a short time span allows them to enrich the surficial sedimentary organic matter and, therefore, reflect a relatively high C/TOC ratio. The ratio may therefore be a crude tracer of sewage derived materials.

## 3.3 PRELIMINARY RESULTS OF THE MESA PROGRAM

### 3.3.1 Water Column Chemistry

In the New York Bight apex, the nutrients, [nitrate ($NO_3$), nitrite ($NO_2$), silicate ($SiO_3$), and phosphate ($PO_4$)], have been measured at periodic intervals in conjunction with a water sampling and hydrographic program. Additionally, analyses of dissolved and suspended trace metals and of suspended organic matter have recently been initiated. Nutrients are released with most urban and industrial contaminants; their concentration distributions may, therefore, be related to the proximity of outfalls or dumpsites. Their concentrations are also intimately related to biological production and degradation in the water. The distribution and cycles of nutrients in an area such as the New York Bight are, therefore, complex and depend upon the water circulation patterns and various physical, chemical, and biological reactions between the diverse components of the outfalls and dumps and the sea water.

Sewage sludge is generally enriched in dissolved nutrients such as nitrates, nitrites, and phosphates (Weinberger, et al., 1966). Approximately $5 \times 10^6$ tons of sludge are being disposed of in the New York Bight annually. This equals $1.5 \times 10^4$ tons daily, a locally large volume of liquid in the dump area. As this sludge is dumped, mixing occurs rapidly thereby diluting the concentrations of nutrients. In the immediate vicinity of a dump, the nutrient concentrations are expected to be high. However, as the sewage sludge liquids mix into an area comparable to the MESA water chemistry grid, the calculated concentrations of nutrients derived from sewage sludge decrease significantly to values which are below detectable levels. It is therefore not too surprising to find that nutrient concentrations in the Bight are not indicative of sewage sludge disposal.

Preliminary analyses of data from MESA Cruises 2 and 5 (September 16-20 and November 25-29, 1973), are presented here. These cruises were during periods of highly stratified, and well mixed conditions, respectively. Surface and bottom nitrate and silicate distributions are presented in figures 3.1 - 3.8.

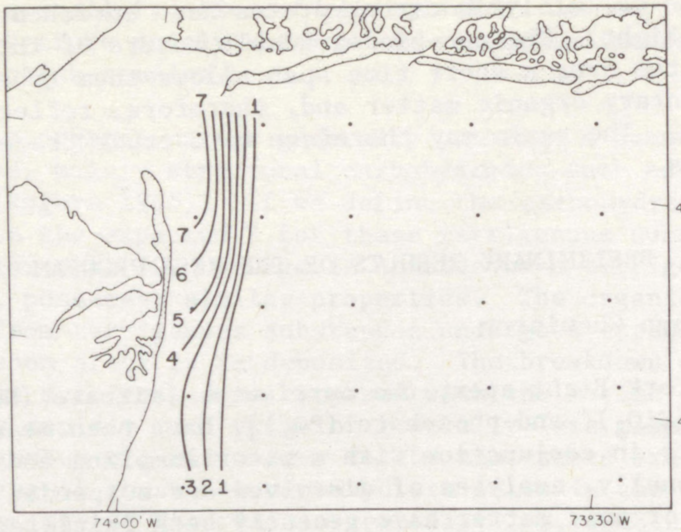



*Figure 3.1 Distribution of surface nitrate (μg-at/ℓ) measured during MESA Cruise 2, September 16-20, 1973.*

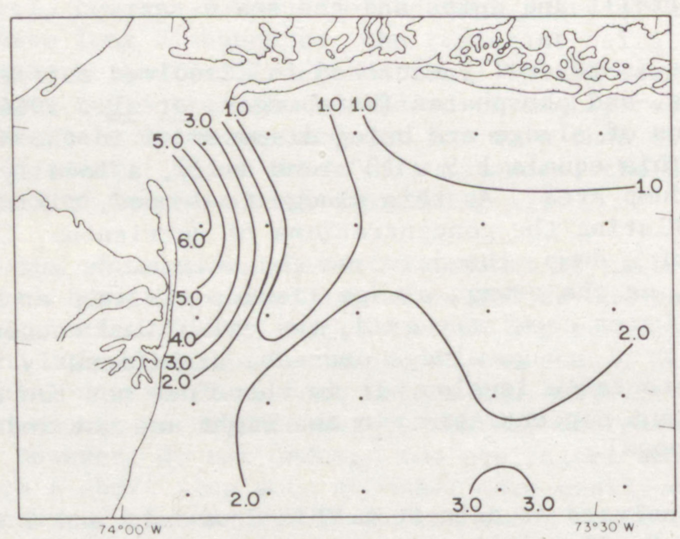



*Figure 3.2 Distribution of bottom nitrate (μg-at/ℓ) measured during MESA Cruise 2, September 16-20, 1973.*

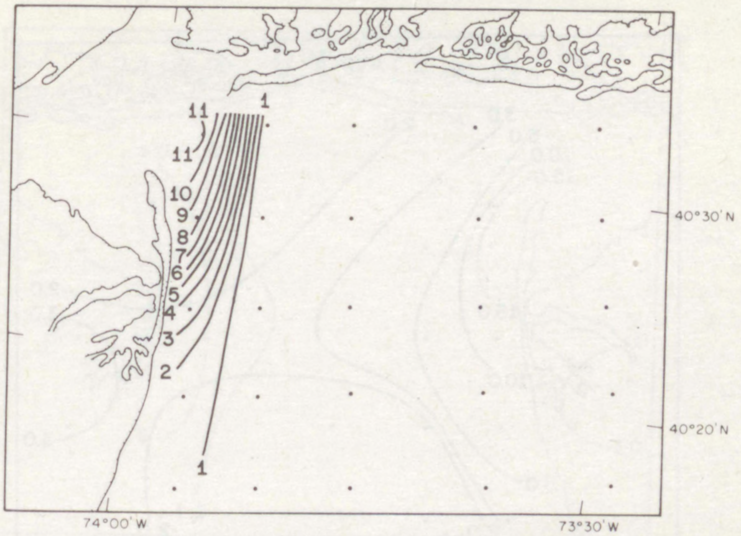



*Figure 3.3 Distribution of surface silicate (μg-at/ℓ) measured during MESA Cruise 2, September 16-20, 1973.*

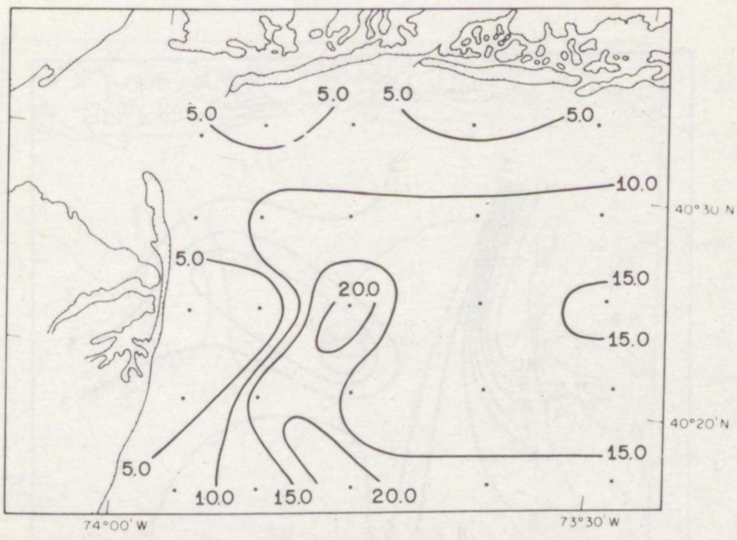



*Figure 3.4 Distribution of bottom silicate (μg-at/ℓ) measured during MESA Cruise 2, September 16-20, 1973.*

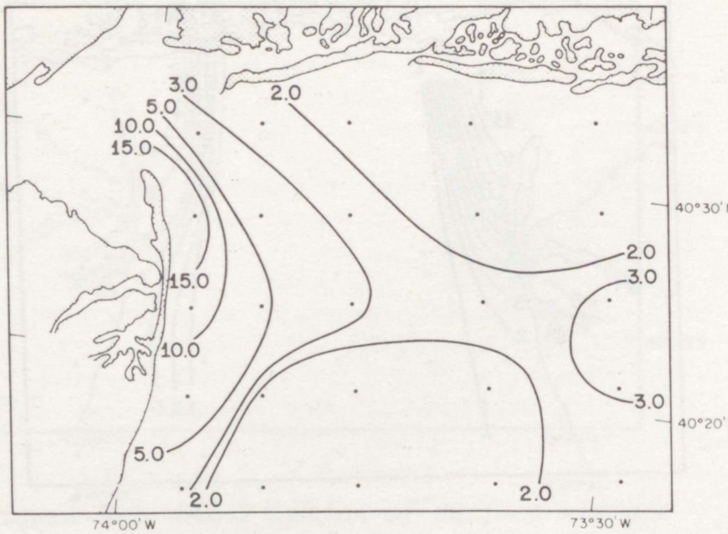



*Figure 3.5 Distribution of surface nitrate (μg-at/ℓ) measured during MESA Cruise 5, November 25-29, 1973.*

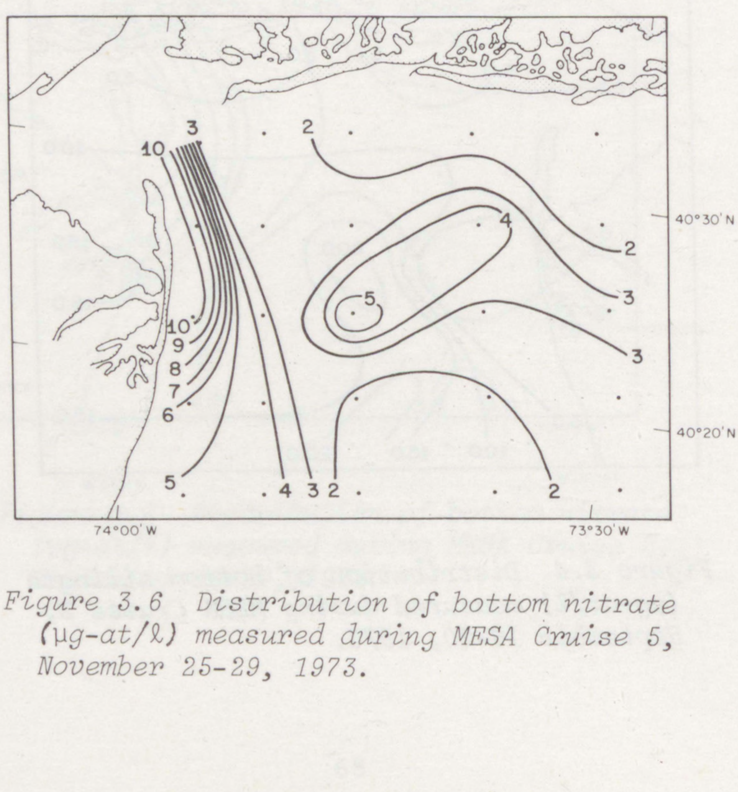



*Figure 3.6 Distribution of bottom nitrate (μg-at/ℓ) measured during MESA Cruise 5, November 25-29, 1973.*

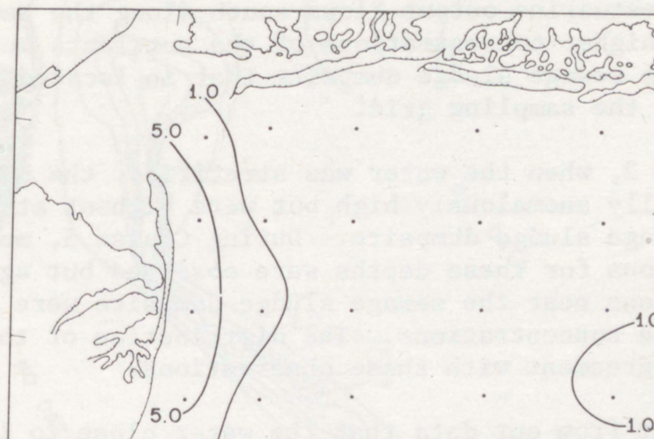



*Figure 3.7 Distribution of surface silicate (µg-at/ℓ) measured during MESA Cruise 5, November 25-29. 1973.*

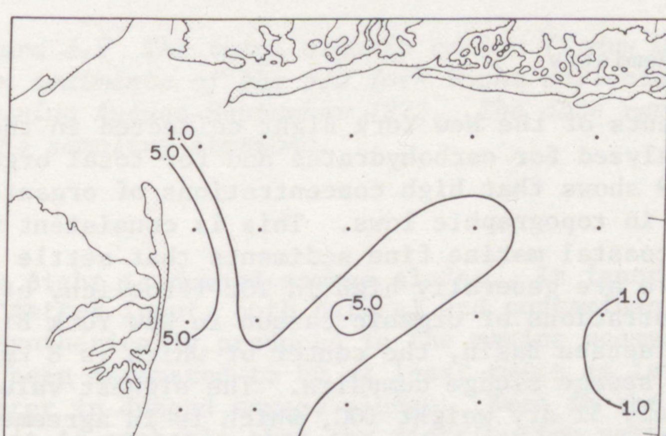



*Figure 3.8 Distribution of bottom silicate (µg-at/ℓ) measured during MESA Cruise 5, November 25-29, 1973.*

A prominent feature of all the distributions is the high concentrations along the New Jersey coast. This is probably nutrient-rich lower New York Bay water flowing into the Bight, consistent with other observations that this estuarine output flows south along the New Jersey shore. Generally higher concentrations of the nutrients were found in the vicinity of the sewage sludge dumpsite that is located close to the central station of the sampling grid.

During Cruise 2, when the water was stratified, the bottom silica values were generally anomalously high but were highest at the station closest to the sewage sludge dumpsite. During Cruise 5, more normal low silica concentrations for these depths were observed but again the bottom concentrations near the sewage sludge dumpsite were somewhat high as were the nitrate concentrations. The distribution of the other nutrients was in agreement with these observations.

It is apparent from our data that the water close to Long Island normally has much lower concentrations of all the nutrients, both at the surface and the bottom, than water along the New Jersey shore. It appears that the nutrient distribution in the water column is influenced more by the outflow of water from lower New York Bay than by contamination from the dumpsite except perhaps for silica during highly stratified conditions.

The release of nutrients from the dumped sewage sludge does not appear to be a major additive to the normal nutrient level occurring in the area.

### 3.3.2 Sediment Chemistry

Bottom sediments of the New York Bight collected in the fall of 1973 have been analyzed for carbohydrates and for total organic carbon (TOC). Figure 3.9 shows that high concentrations of organic carbon are located primarily in topographic lows. This is consistent with the observation that coastal marine fine sediments that settle in topographic lows elsewhere are generally high in TOC (Froelich, et al., 1971). The highest concentrations of organic carbon in New York Bight sediments are in the Christiaensen Basin, the center of which is 8 km to the west of the designated sewage sludge dumpsite. The highest values encountered are approximately 5% dry weight TOC, which is in agreement with Gross (1970 b). This value is almost an order of magnitude less than that for sewage sludge taken directly from the municipal sewage treatment facility.

Previous workers have attempted to define the sludge bed extent using organic matter concentration distributions. This definition assumes that the only significant source of organic sedimentary material

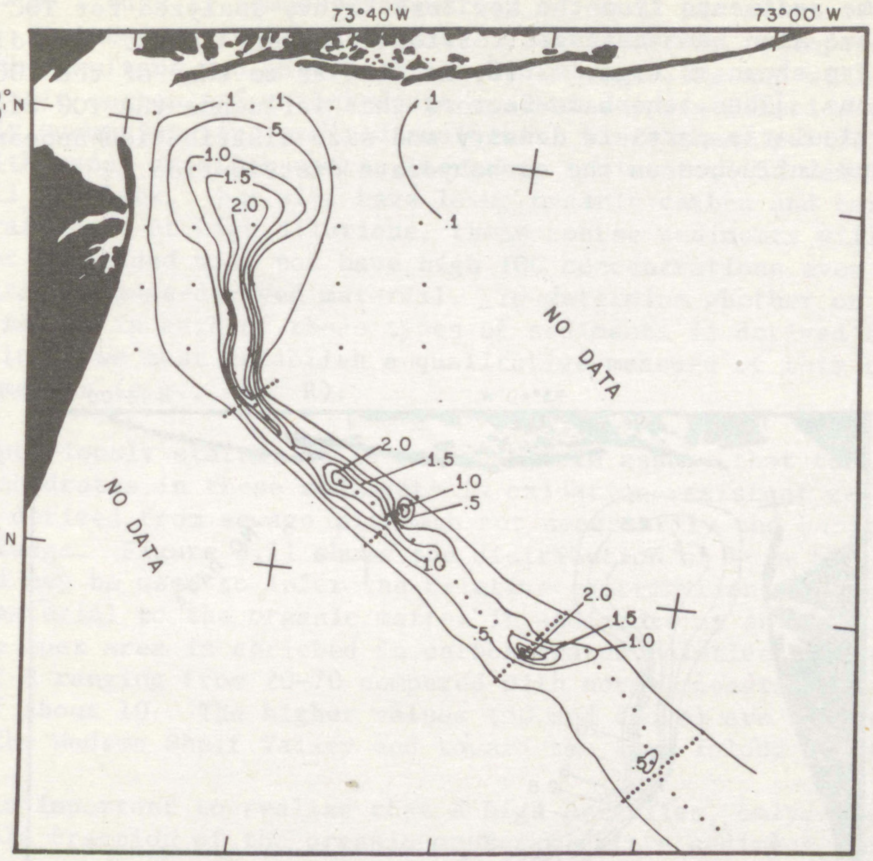



*Figure 3.9 The total organic carbon (% dry weight) in sediments of the New York Bight collected during August-September 1973. The dots represent the sampling stations.*

in the New York Bight is dumped sewage sludge. It ignores the terrigenous organic matter input, both natural and contaminant, and the material photosynthetically produced in the marine ecosystem itself. The latter has been estimated to be at least twice as large an input as the organic matter in dumped sewage sludge. Even in the absence of any input from man it is probable that the distribution pattern of TOC in the Bight sediments, although not the quantity, would be similar to that observed today. The distribution of TOC in sediments is inversely related to particle size (compare fig. 3.9 with fig. 2.5). Finer sediments contain more TOC than do the coarser sands. This relationship between TOC and particle size distributions is a normal feature of all coastal sediments.

The same sediments from the New York Bight, analyzed for TOC concentrations, have also been analyzed for total carbohydrates. The distribution pattern shown in figure 3.10, is similar to that of the TOC concentrations. [Thus, the same factors that influence the TOC distribution (particularly particle density and size distribution) appear also to be a major influence on the carbohydrate distribution.]

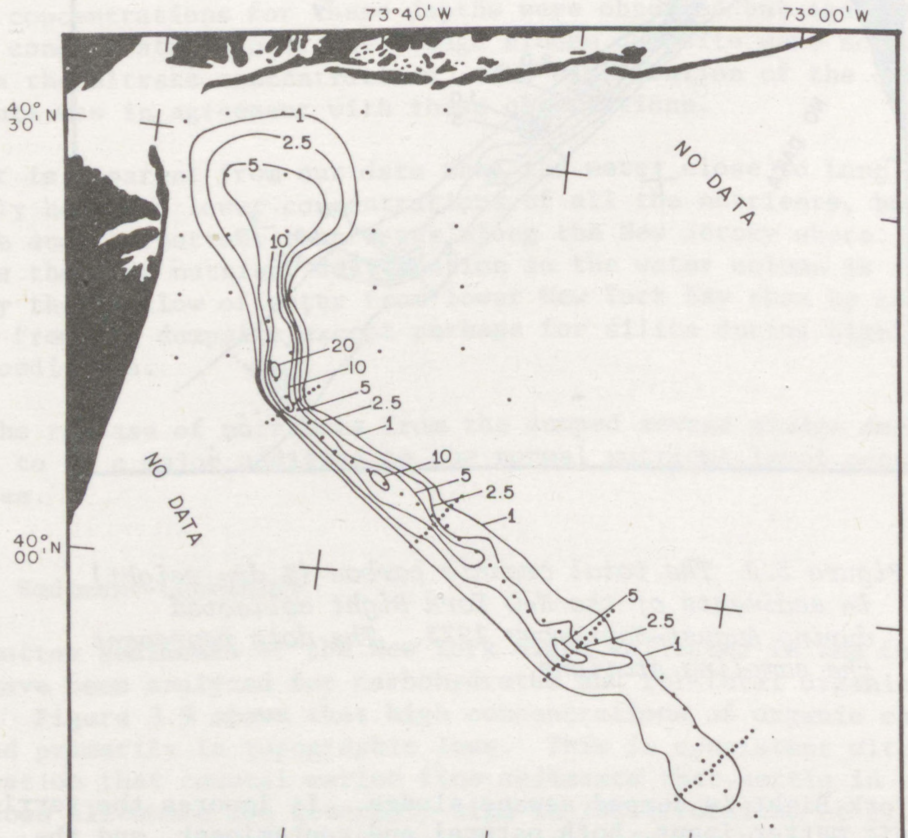



*Figure 3.10 The distribution of total carbohydrates (% dry weight x 1000) in sediments of the New York Bight collected August-September 1973. The dots represent sampling stations.*

Sewage sludge is composed primarily of small particles of organic matter. If these particles accumulate in depressions or topographic lows, the resultant mud will be black and sludge-like and will have a high organic carbon and carbohydrate content despite dilution with naturally occurring fine grained sediment. Where these particles are mixed with sandy or other coarse inorganic sediments, the resultant mud may still be black, but will have lower organic carbon and carbohydrate concentrations. At high dilutions, these coarse sediments will no longer appear black and will not have high TOC concentrations even though they contain sewage-derived material. To determine whether or not the organic matter in each of these types of sediments is derived from sewage sludge we must establish a qualitative measure of this type of organic matter (e.g., high R).

As previously stated, it is reasonable to assume that the bulk of the carbohydrates in these sediments is oxidation-resistant cellulolytic material derived from sewage although not necessarily the barge-dumped sewage sludge. Figure 3.11 shows the distribution of R in the New York Bight and may be used to infer the relative contribution of sewage-derived material to the organic matter in sediments at any location. The whole apex area is enriched in carbohydrates relative to TOC with values of R ranging from 20-70 compared with normal coastal sediment values of about 10. The higher values (50 and above) are located in the axis of the Hudson Shelf Valley and toward the Long Island shore.

It is important to realize that a high R implies, only, that an appreciable fraction of the organic matter within a sediment sample is derived from sewage. If this same sample contains very little total organic matter then the total amount of sewage-derived material in it must be small. As is the case for sediments near the Long Island shore, the TOC or organic matter content is generally very low and R is high. Therefore, it follows that although the organic matter in these sediments is probably derived from sewage, the total amount of sewage-derived material is low. Only in isolated pockets, where the TOC is high, can the sediments contain an appreciable fraction of sewage-derived material.

We would expect R to increase somewhat as materials are transported further from the dumpsite because of the increased exposure to microbial degradation in the water column. Comparison of the R's in sewage sludge and in sediments of the Christiaensen Basin, whose organic matter is believed to be primarily sewage-derived, substantiates the previously stated speculation that the ratio increases upon biodegradation. In addition, if the sewage material settles in a sandy environment as opposed to a mud environment, R will probably be higher because of the more rapid degradation and preferential loss of non-cellulolytic organic matter from the oxygenated sands.

The distribution of R, taking into account these changes, suggests that sewage derived materials are probably being entrained or transported within the hypothesized current gyre in the apex (see section I). The entrained particles would be successively deposited and resuspended by wave, tide, and current energy and would tend to accumulate in the topographic lows where such energy is at a minimum. There is such a topographic low at the head of the Hudson Shelf Valley where material with high R values is accumulating. The seaward extent of the current gyre is not well defined but R ratios indicate that sewage-derived materials are being transported to and accumulating in the Hudson Shelf Valley many miles offshore (fig. 3.11). It is not known how this material is

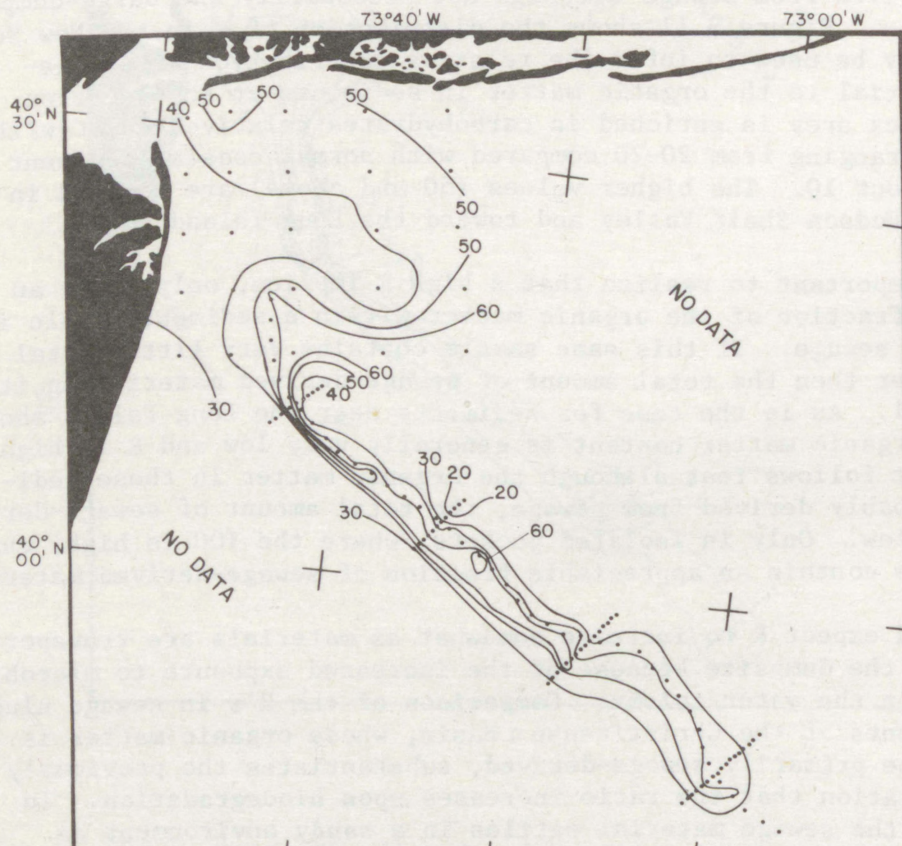



*Figure 3.11 The carbohydrate/TOC ratio in sediments of the New York Bight, Aug-Sept, 1973. The dots represent sampling stations.*

transported. The shelf valley may be acting as a conduit as suggested by the higher R values observed on the southern flank of the valley. Alternatively the fine material may simply be dispersing in a broad pattern offshore and accumulating in the topographic lows. Regardless of the mechanism involved the observed distribution strongly suggests that a significant proportion of the dumped sewage sludge is being transported away from the coastline into deeper water.

In addition to the data of figs. 3.9-3.11, samples from the MESA substrate monitoring program (locations shown in fig. 3.12) and recently collected samples from the south shore of Long Island (locations shown in fig. 3.13) have also been analyzed for TOC and carbohydrates. Preliminary results (Table 3.1 and 3.2) indicate that pockets of black mud, rich in TOC (~5%), do exist within 1½ miles of the Long Island beach. This TOC concentration is similar to that found close to the actual dumpsite. Within one-half mile of the beach other pockets of mud were found to contain sediments having a TOC concentration of approximately 2%. The more extensive sandy sediments in the immediate vicinity were observed to have a TOC varying from 0.04% to 0.3%.

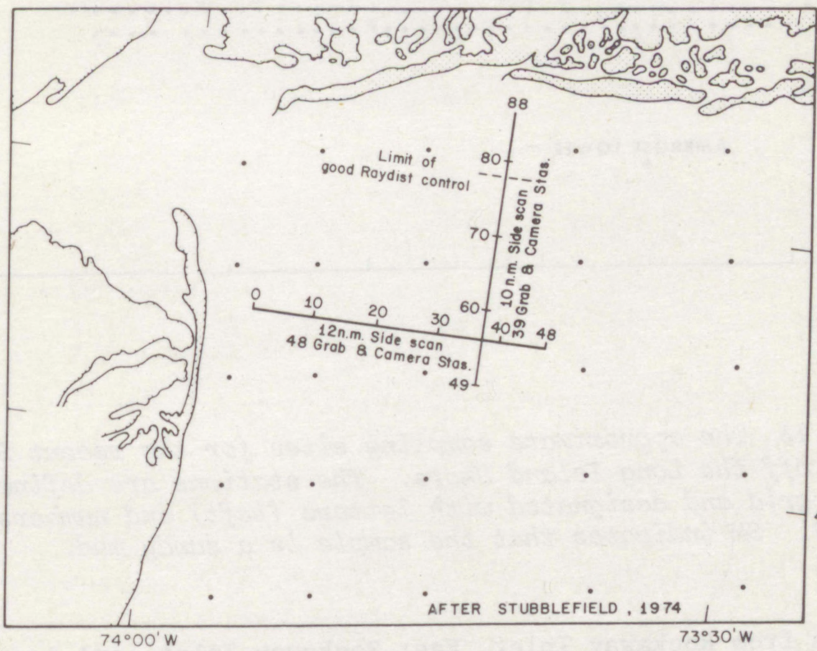



*Figure 3.12 SUMP Cruise-2 track lines. The numbers on the lines designate station positions.*

Generally, R is high for all of these samples; values range from 40 to 60, the same range observed for samples from the Christiaensen Basin. Thus, sediments close to the south shore of Long Island contain organic matter enriched in carbohydrate indicating a probable sewage source (either dumped sewage sludge or any other sewage discharge). This organic material has accumulated as thin layers in small pockets admixed with and covering silicate sands.

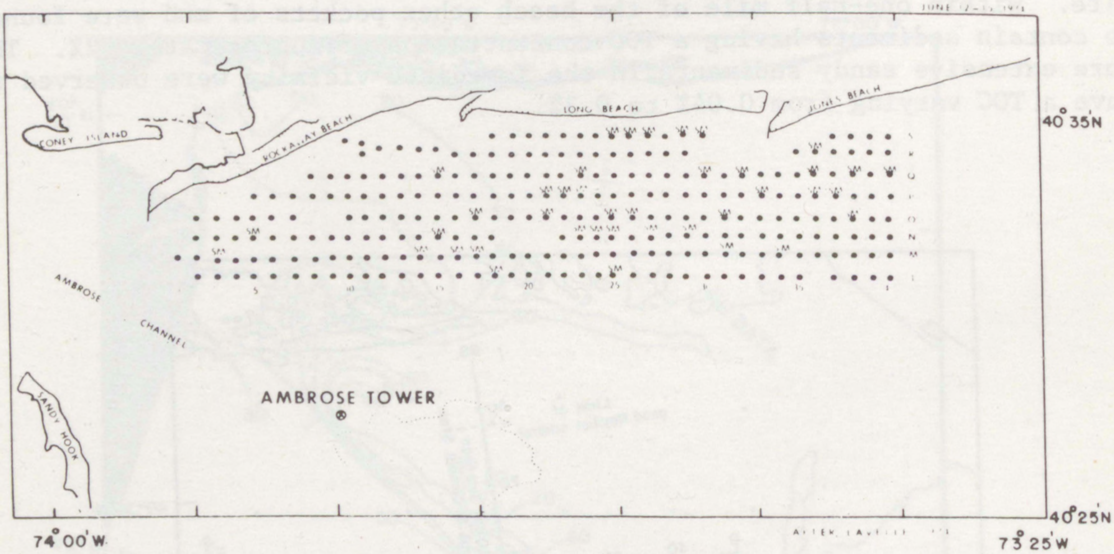



*Figure 3.13 The approximate sampling sites for the recent SIS cruise off the Long Island Shore. The stations are defined by the grid and designated with letters (left) and numbers (below). SM indicates that the sample is a sandy mud.*

Sediments from Rockaway Inlet, East Rockaway Inlet, and Jones Inlet were also analyzed for R (Table 3.2). The values are generally low (~20) within all the inlets despite some high organic carbon concentrations. This suggests that humic materials from the wetlands, other natural organic detritus, and possibly new sewage are major contributors to the organic matter in the sediments.

In summary, (1) The R ratio in the Bight apex, indicates that non-biodegradable carbohydrates, possibly derived from sewage, are significant contributors to the sedimentary organic matter. (2) The apex of the Bight seems to be enriched in carbohydrates (or sewage-derived materials) relative to the TOC as compared with the lower Hudson Shelf Valley and the New Jersey shore. (3) The dumped sewage sludge undergoes substantial alteration before and after settling to the sediment and/or admixture with natural nonorganic sediments. This is indicated by the large difference between the TOC concentrations of sewage sludge sediment in the Christiaensen Basin. (4) Isolated pockets of mud near the Long Island shore were found to have approximately the same TOC concentration and R as mud from the Christiaensen Basin, an indication that the Long Island mud is possibly derived in part from sewage. (5) It is not possible, using currently available techniques, to distinguish between sedimentary organic matter derived from barge-dumped sewage sludge or derived from other sources of treated or untreated sewage.

*Table 3.1 The Organic Chemistry Data for Sediments Collected on the SUMP II Cruise*

| Station # | % Carbohydrates | % TOC | (Carbohydrates/TOC) x100 |
|---|---|---|---|
| 9 | 0.160 | 0.460 | 35 |
| 11 | 0.26 | 2.99 | 42 |
| 13 | 0.413 | 1.40 | 30 |
| 15 | 0.283 | 0.644 | 44 |
| 21 | 0.948 | 2.45 | 39 |
| 23 | 1.025 | 1.96 | 52 |
| 25 | 0.997 | 1.64 | 61 |
| 28 | 0.731 | 1.26 | 58 |
| 29 | 1.48 | 2.85 | 52 |
| 31 | 2.20 | 5.08 | 43 |
| 33 | 1.89 | 3.85 | 49 |
| 35 | 1.99 | 3.04 | 65 |
| 58 | 0.143 | 0.352 | 41 |
| 62 | 0.230 | 0.409 | 56 |
| 66 | 0.435 | 0.840 | 52 |
| 69 | 0.294 | 0.477 | 62 |
| 78 | 0.021 | 0.053 | 40 |
| 82 | 0.077 | 0.168 | 47 |
| 85 | 0.062 | 0.115 | 54 |
| 88 | 0.063 | 0.099 | 64 |

*Table 3.2 Carbohydrates, TOC, and Carbohydrates/TOC in Sediment Samples Collected South of Long Island (SIS)*

| Station # | % Carbohydrates 1 | % Carbohydrates 2 | % TOC | (Carbohydrates/TOC) x 100 1 | (Carbohydrates/TOC) x 100 2 |
|---|---|---|---|---|---|
| §JI-1 | 0.0089 | 0.010 | 0.042 | 21 | 24 |
| §JI-2 | 0.014 | 0.015 | 0.106 | 13 | 14 |
| +ER | 0.018 | 0.016 | 0.089 | 20 | 18 |
| N-25 | 0.029 | 0.027 | 0.055 | 52 | 49 |
| N-24 | 0.036 | 0.037 | 0.083 | 43 | 45 |
| N-23 | 0.154 | 0.132 | 0.277 | 55 | 48 |
| *N-22 | 0.043 | 0.044 | 0.080 | 54 | 55 |
| *S-22 | 0.034 | 0.042 | 0.083 | 41 | 51 |
| S-27 | 0.322 | 0.394 | 0.597 | 54 | 66 |
| S-26 | 0.969 | 1.36 | 2.28 | 43 | 60 |
| *S-24 | 0.029 | 0.033 | 0.070 | 41 | 47 |
| S-30 | 0.127 | 0.142 | 0.211 | 60 | 67 |
| N- 5 | 0.047 | 0.047 | 0.088 | 53 | 53 |
| *R-24 | 0.844 | 0.808 | 1.49 | 57 | 54 |
| R-36 | 2.26 | 2.17 | 4.56 | 50 | 48 |
| M- 3 | 0.042 | 0.045 | 0.085 | 49 | 53 |
| M-14 | 0.419 | 0.403 | 0.770 | 54 | 52 |
| *M-19 | 0.086 | 0.086 | 0.152 | 57 | 57 |
| M-31 | 0.392 | 0.421 | 0.712 | 55 | 59 |
| M-34 | 0.088 | 0.107 | 0.226 | 39 | 47 |
| O-26 | 0.479 | 0.464 | 1.20 | 40 | 39 |
| P-21 | 0.896 | 1.28 | 2.31 | 39 | 55 |
| P-23 | 2.288 | 2.45 | 5.21 | 44 | 47 |
| Q-30 | 0.887 | 1.00 | 1.86 | 48 | 54 |
| Q-36 | 0.083 | 0.068 | 0.181 | 46 | 38 |
| Q-38 | 0.811 | 0.813 | 1.99 | 41 | 41 |

* - samples from sandy areas

§ - Jones Inlet samples

\+ - East Rockaway Inlet samples

## 3.4 REFERENCES


Carmody, D. J., J. B. Pearce, and W. E. Yasso, 1973. Trace metals in sediments of New York Bight. Mar. Poll. Bull., 4(9): 132-135.

Degens, E. T., A. Prashnowsky, K. O. Emery, and J. Pimenta, 1961. Organic materials in recent and ancient sediments of Santa Barbara Basin, California. Neues Jahrb. Geol. Palaontol. Monatsh., 1961, 413-426.

Froelich, P., B. Golden, and O. H. Pilkey, 1971. Organic carbon in sediments of the North Carolina continental rise. S. E. Geology., 13: 91-97.

Gross, M. G., 1969. New York City: A major source of marine sediment. Mar. Sci. Res. Center, SUNY Tech. Rept. No. 1, State University of New York, Stony Brook, New York.

Gross, M. G., 1970 a. Preliminary analysis of urban wastes - New York Metropolitan area. Mar. Sci. Res. Center, SUNY Tech. Rep. No. 5, State University of New York, Stony Brook, New York.

Gross, M. G., 1970 b. Analysis of dredged wastes, fly ash and waste deposits, New York metropolitan region. Mar. Sci. Res. Center, SUNY Tech. Rep. No. 7, State University of New York, Stony Brook, New York.

Gross, M. G., 1972. Geologic aspects of waste solids and marine waste deposits, New York metropolitan region. Am. Bull., 83: 3163-3176.

Hunter, J. V., and H. Heukelekian, 1965. The composition of domestic sewage fractions. J. Water Poll. Control Fed.,37: 1142-1163.

Kolattukudy, P. E., and R. E. Purdy, 1973. Identification of cutin, a lipid biopolymer, as significant component of sewage sludge. Envir. Sci. and Tech., 7: 619-622.

Meade, R. H., 1969. Landward transport of bottom sediments in estuaries of the Atlantic Coastal Plain. J. Sed. Pet., 39: 222-234.

Parsons, T. R., K. Stephens, and J. D. H. Strickland, 1961. On the Chemical composition of eleven species of marine phytoplankters. J. Fish. Res. Bd., Can., 18: 1011-1016.

Rogers, M. A., 1965. Carbohydrates in aquatic plants and associated sediments from two Minnesota lakes. Geochim. Cosmochim. Acta, 29: 183-200.

Segar, D. A., and R. E. Pellenbarg, 1973. Trace metals in carbonate/ organic rich sediments. Effects of industrialization and urbanization. Mar. Poll. Bull., 4(9): 138-142.

Walter, L., 1961. Composition of sewage and sewage effluents. Water and Sewage Works, Part 2. Scranton Pub. Co., Chicago, Ill., 478 pp.

Weinberger, L. W., D. G. Stephen, and F. M. Middleton, 1966. Solving our water problems - Water Renovation and Reuse. Annals of the N. Y. Academy of Sciences, 136: art. 5, 131.



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*Atlantic Oceanographic and Meteorological Laboratories (AOML):* Geology and geophysics of ocean basins and borders, oceanic processes, sea-air interactions and remote sensing of ocean processes and characteristics (Miami, Florida).

*Pacific Marine Environmental Laboratory (PMEL):* Environmental processes with emphasis on monitoring and predicting the effects of man's activities on estuarine, coastal, and near-shore marine processes (Seattle, Washington).

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*Atmospheric Physics and Chemistry Laboratory (APCL):* Processes of cloud and preciptation physics; chemical composition and nucleating substances in the lower atmosphere; and laboratory and field experiments toward developing feasible methods of weather modification.

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