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ENVIRONMENTAL GEOLOGIC STUDIES IN THE GEORGES BANK AREA, UNITED STATES NORTHEASTERN ATLANTIC OUTER CONTINENTAL SHELF, 1975-1977

Edited by

John M. Aaron

1980

Studies conducted in cooperation with the
BUREAU OF LAND MANAGEMENT

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INTRODUCTION

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This report is a summary of the first year of research activities by the U. S. Geological Survey (USGS) in the Georges Bank area of the Continental Shelf off the northeastern United States, in accordance with Memorandum of Understanding (MOU) AA550-MU6-29 between the USGS and the Bureau of Land Management (BLM). The report covers studies during the period from 1 September 1975 to 30 September 1977.

The purpose of these investigations is to provide to the BLM Outer Continental Shelf (OCS) Environmental Studies Program basic geologic and oceanographic environmental data to support management decisions relating to possible development of the oil and gas resources of the Continental Shelf. The general objectives of the USGS program are to: 1) measure the rate of sediment mobility over the seabed and monitor resultant changes in bottom morphology and texture; 2) determine the concentration, distribution, and flux of suspended particulate matter in the water column; 3) determine the vertical distribution of trace metals in the near-surface sediment at selected locations; 4) evaluate potential hazards to oil and gas development due to surficial and intermediate depth structure and mass sediment-transport events; and 5) support the activities of the prime physical oceanography and chemical/biological benchmark contractors by obtaining supplemental physical oceanographic data, analyzing samples of suspended sediment, and by helping to synthesize and interpret the geological data as it pertains to physical, biological, or chemical shelf processes.

A description of the methods, techniques, and instrumentation by which these objectives were addressed is reported herein, along with analytical results and syntheses and interpretations of the data. Not included, however, are reports from the tripod and current-meter program to study sediment mobility. Because of the need to understand the seasonal variability of processes responsible for sediment resuspension and transport on Georges Bank, it was deemed desirable to combine results from the first-year studies with those of the second year, and to present a data synthesis based on the longer period of observation. Accordingly, and by agreement with BLM, this aspect of the first-year sediment-mobility studies will be included in the final report under MOU AA551-MU8-24.

The sets of data generated by these studies are included, in microfiche form, in three appendices that are arranged as follows: 1) cruise reports for each of the six sampling and seismic cruises conducted by the USGS under this MOU (tripod/current-meter work excluded); 2) for Chapter 2: station and sample parameters, and results of analyses of suspended matter samples collected by the USGS, Woods Hole Oceanographic Institution, Energy Resources Company (ERCO), and Raytheon; 3) for Chapter 3: instrument settings, precision and accuracy data, method intercomparisons, and results of trace-element, textural, carbon-isotope, and clay-mineral analyses of hydraulically damped gravity cores. Original seismic records are on file in the Data Management Section, U. S. Geological Survey, Woods Hole, Massachusetts. Microfilm copies of these records can be purchased only from the National Geophysical and Solarterrestrial Data Center (National Oceanographic and Atmospheric Administration) in Boulder, Colorado 80302.

CHAPTER 2

SESTON IN NEW ENGLAND SHELF AND SLOPE WATERS

1976 - 1977

John D. Milliman[1], Michael H. Bothner, and Carol M. Parmenter

[1] Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

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SESTON IN NEW ENGLAND SHELF AND SLOPE WATERS

1976-1977

John D. Milliman, Michael H. Bothner, and Carol M. Parmenter

INTRODUCTION

The composition and distribution of, and temporal variations in suspended material in shelf waters off New England were documented through a series of cruises during 1976 and 1977. Among the questions asked were: In what areas and to what extent does bottom circulation resuspend and redistribute bottom sediments? What seasonal variations are seen in these processes? To what extent does biological activity control the quantity and composition of suspended particulates? Do we see any anthropogenic influx? To our knowledge, this study represents the first effort to document such parameters for suspended particulates in New England waters. Such information is important because dissolved pollutants, if added to the continental shelf waters, may be strongly sorbed by naturally occurring suspended material. Similarly, certain pollutants added in particulate form may be carried through the same cycle of deposition and resuspension as natural suspended matter.

Because of the interest in drilling on Georges Bank, this area received most of the attention during sampling. However, cruises also occupied stations on the shelf south of Nantucket Island and in the southern Gulf of Maine.

This report is based on data retrieved during four cruises by Environmental Resources Co. (ERCO), two cruises by Raytheon during 1977, and three other cruises by WHOI/USGS in 1976 (Table 2-1). Three hundred forty-eight stations were occupied and 907 samples taken during these cruises, exclusive of replicate samples taken at any one station.

Table 2-1. Cruises, dates, stations occupied and samples collected during the 9 cruises made in the New England area in 1976-77 as part of the USGS/BLM suspended particulate study.

Cruise	Dates	Stations Occupied	Total Samples
OCEANUS 13	8/13/76 - 8/23/76	65	174
OCEANUS 17	12/04/76 - 12/06/76	18	53
OCEANUS 20	12/30/76	8	21
ERCO I	2/11/77 - 3/04/77	35	102
ERCO II	5/05/77 - 5/24/77	41	123
ERCO III	8/17/77 - 8/31/77	40	118
ERCO IV	11/24/77 - 12/04/77	31	82
RAYTHEON I	9/7/77 - 9/13/77	62	135
RAYTHEON II	11/14/77 - 11/21/77	48	99
		348	907

METHODS

All samples were collected in 10 or 30-l Niskin bottles mounted on a rosette sampler. Normally, three samples were collected at each station: one at the surface, one at middepth, and one approximately 1-2 m above the bottom. Attached to the rosette sampler was a transmissometer which measured turbidity continuously throughout the water column. On all cruises, light transmission as a function of depth was displayed in real-time through a deck read-out, thus permitting an adjustment of the sample depth to include interesting maxima or minima in light transmission.

As soon as the rosette of sampling bottles was secured on deck (usually within 15 minutes after sampling at station depths <150 m), subsamples of approximately 4 liters were taken. Because the time between initial collection and subsampling was so short, the problem of larger particles preferentially settling from suspension (Gardner, 1977) was minimized. The 4-liter subsamples contained in graduated cylinders (with bottom withdrawals) were filtered by vacuum through in-line filter holders containing paired pre-weighed Millipore filters (nominal openings of 0.45 µ)[1]. The volume of water was agitated periodically in order to avoid the possibility of error due to settling of particles within the cylinder. Filters were then rinsed 6 to 8 times with filtered distilled water (to remove salt) and frozen until analysis.

In addition to the suspended particulate samples collected with

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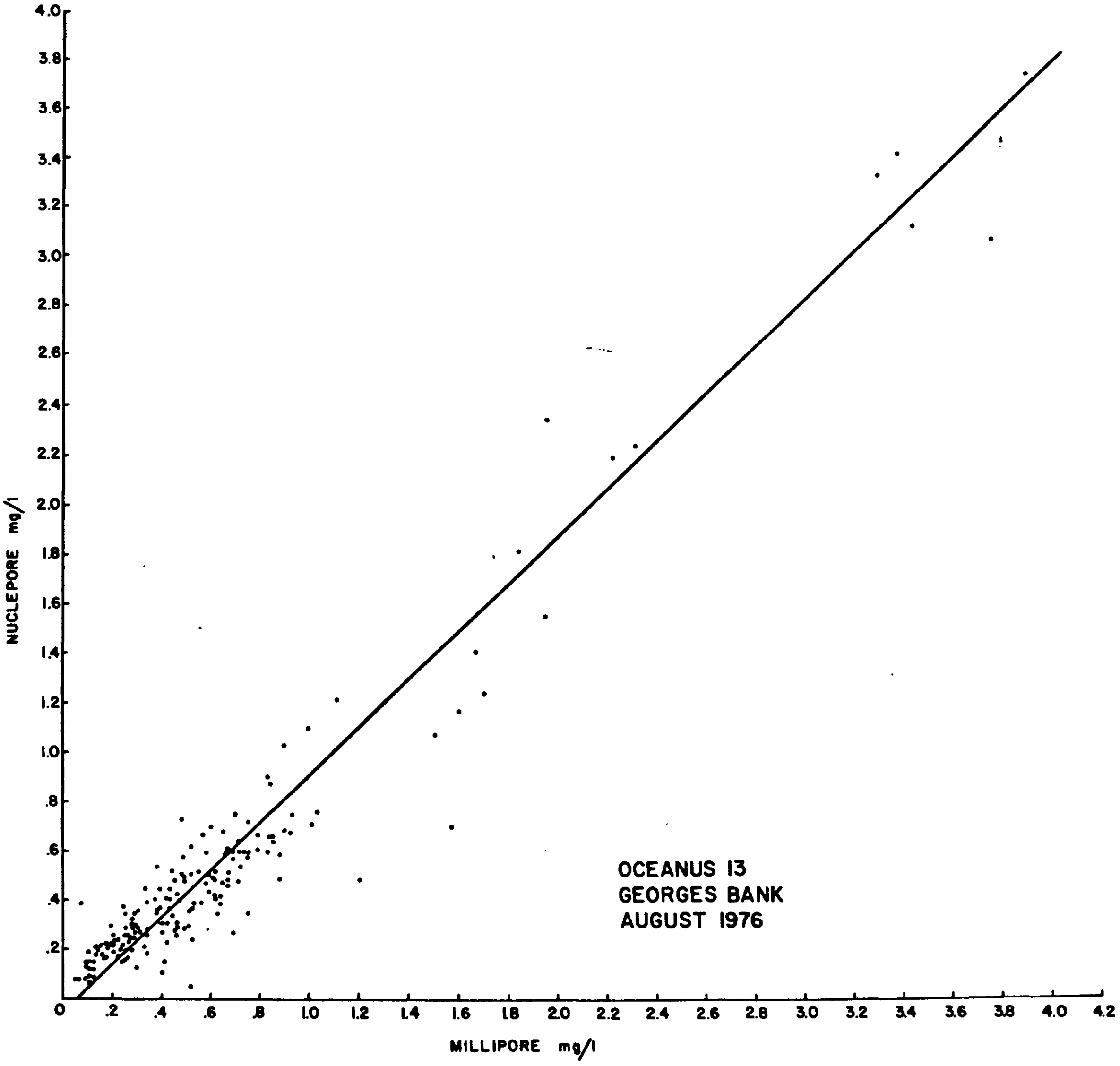
[1] A detailed comparison of particulate retention was conducted during a cruise on Georges Bank in August 1976. For waters with comparatively high concentrations of suspended particulates, the trapping abilities of Millipore filters appear to be equal to or better than Nuclepore filters (Figure 2-1) and Millipore filters have the added advantage of clearing with optical oils for viewing with a petrographic microscope.

Figure 2-1. Comparison of total suspended-matter concentrations determined on Millipore and Nuclepore filters both having pore diameters of 0.4 μm. Characteristics of regression have: $M = 1.04N + .07$, $r^2 = 0.94$.

Figure 2-1


NUCLEPORE mg/l
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
MILLIPORE mg/l
OCEANUS 13
GEORGES BANK
AUGUST 1976

Millipore filters, samples were collected on the OCEANUS cruises for analysis of particulate organic carbon, organic nitrogen, and chlorophyll on glass fibre filters. For organic carbon and nitrogen, 4 to 8 liters of water were passed through pre-ignited glass fibre filters (nominal pore opening of 0.5 μ) and immediately frozen until analysis. The filters were not rinsed with fresh water, which would cause bursting of organic membranes. As in collection of the suspended-matter samples, both organic carbon and nitrogen samples were collected through in-line filters. Chlorophyll samples were collected by filtering about 25 ml of seawater (buffered with $MgCO_3$) and then frozen in a desiccator until analysis.

Finally, water samples for laboratory analysis of dissolved nutrients were collected during the OCEANUS 13 and 17 cruises. Analyses (performed by Z. Mlodzinska, WHOI) included nitrate, nitrite, ammonia, phosphate, and silicate.

Upon return to the laboratory, seston filters were tested for remaining salt by rinsing with distilled water and introducing a silver nitrate solution into the rinse water; formation of a white precipitate indicated inadequate rinsing of the filters. After final rinsing, the filters were air-dried (generally only requiring 24-36 hours) and then weighed, the lower paired filter being used as a control (Manheim *et al*., 1970). After weighing, the filters were split in half, one part being ashed at 500°C to measure the combustible fraction of the suspended material. A cut of the remaining half was placed on a glass slide, immersed in optical oil, covered with a glass cover slide, and examined with a petrographic microscope to determine the constituents of the suspensate. More detailed examinations of remaining filter material were carried out with the scanning electron microscope with an X-ray fluorescence attachment for elemental analysis.

Organic carbon and nitrogen samples also were air-dried upon return to the laboratory and subsequently analyzed with a LECO carbon and nitrogen analyzer. The weight of the material upon the glass fibre filters was assumed to be equal to the product of the concentration of suspensate in the water sample (determined by total seston measured on Millipore filters) and the volume of water passed through the glass fibre filters. As will be seen in the following paragraphs, this proved a reliable assumption in most instances. Unfortunately, however, many nitrogen values proved erroneous, due to problems in combustion of organic material in the nitrogen analyzer.

RESULTS

August 1976

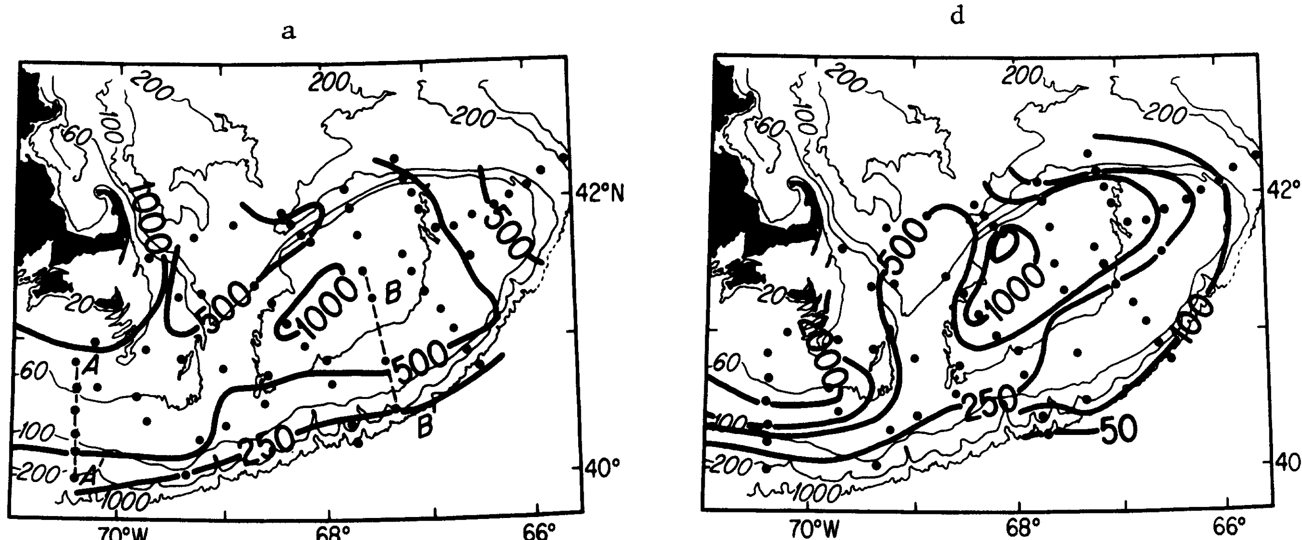
The most comprehensive collection of suspended particulates was taken during OCEANUS 13, 13 to 23 August 1976; shortly after passage of Hurricane Belle through New England. A total of 174 samples was collected from 65 stations.

The areal distribution of total particulates, percent combustibles and noncombustible concentrations (Figure 2-2) show 2 different suspended matter regimes. The first is over Georges Bank and the second is west of Great South Channel and south of Nantucket. On Georges Bank, the concentrations of total particulates in surface and bottom waters are very similar, although the inorganic fraction is typically higher in the bottom samples.

West of Great South Channel, where the waters are stratified (Figure 2-3), bottom waters contain far greater concentrations of both total particulates and noncombustibles than the surface waters (Figures

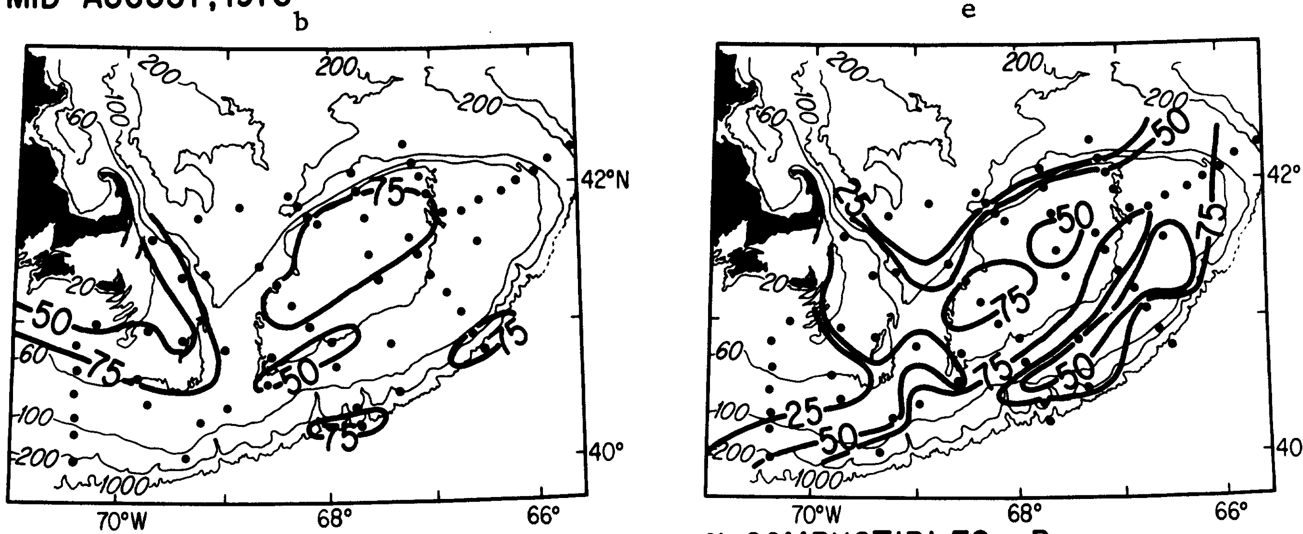
Figure 2-2. Areal distribution of suspended particulate matter in surface (left) and near-bottom (right) during August 1976. Top illustrations (a and d) represent distributions of total particulates; middle plots (b and c) percent combustibles; and bottom plots (c and f) noncombustible concentrations. (Transect A-A' indicates position of cross-section shown in Figures 2-3 and 2-8, B-B' for Figure 2-7).

Figure 2-2



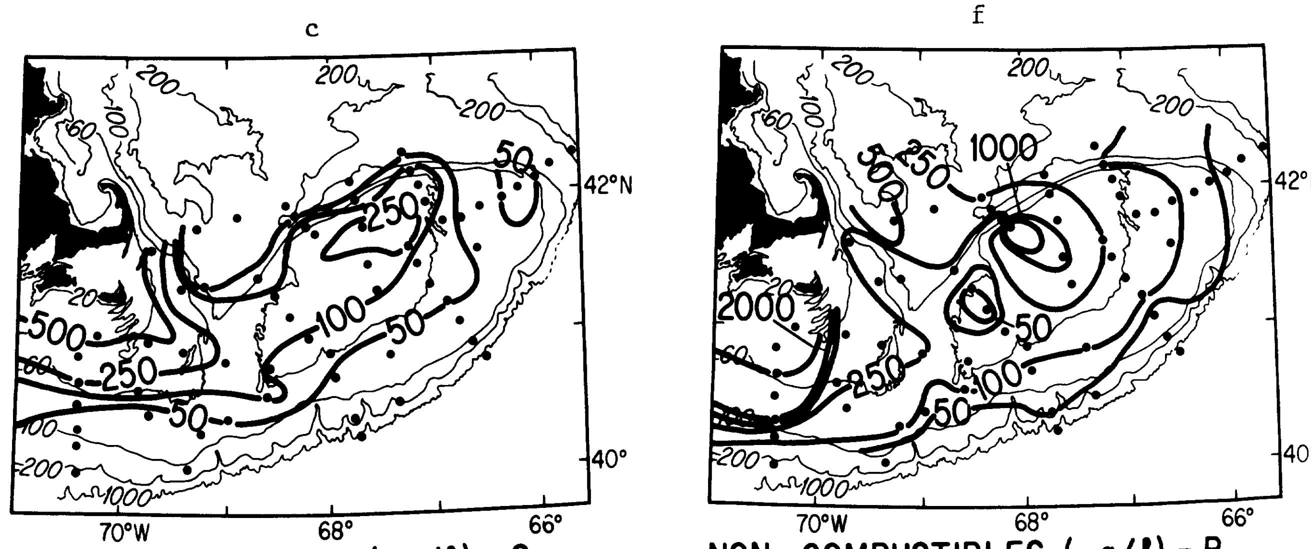
TOTAL PARTICULATES (μg/ℓ) - S
MID AUGUST, 1976

TOTAL PARTICULATES (μg/ℓ) - B



% COMBUSTIBLES - S

% COMBUSTIBLES - B

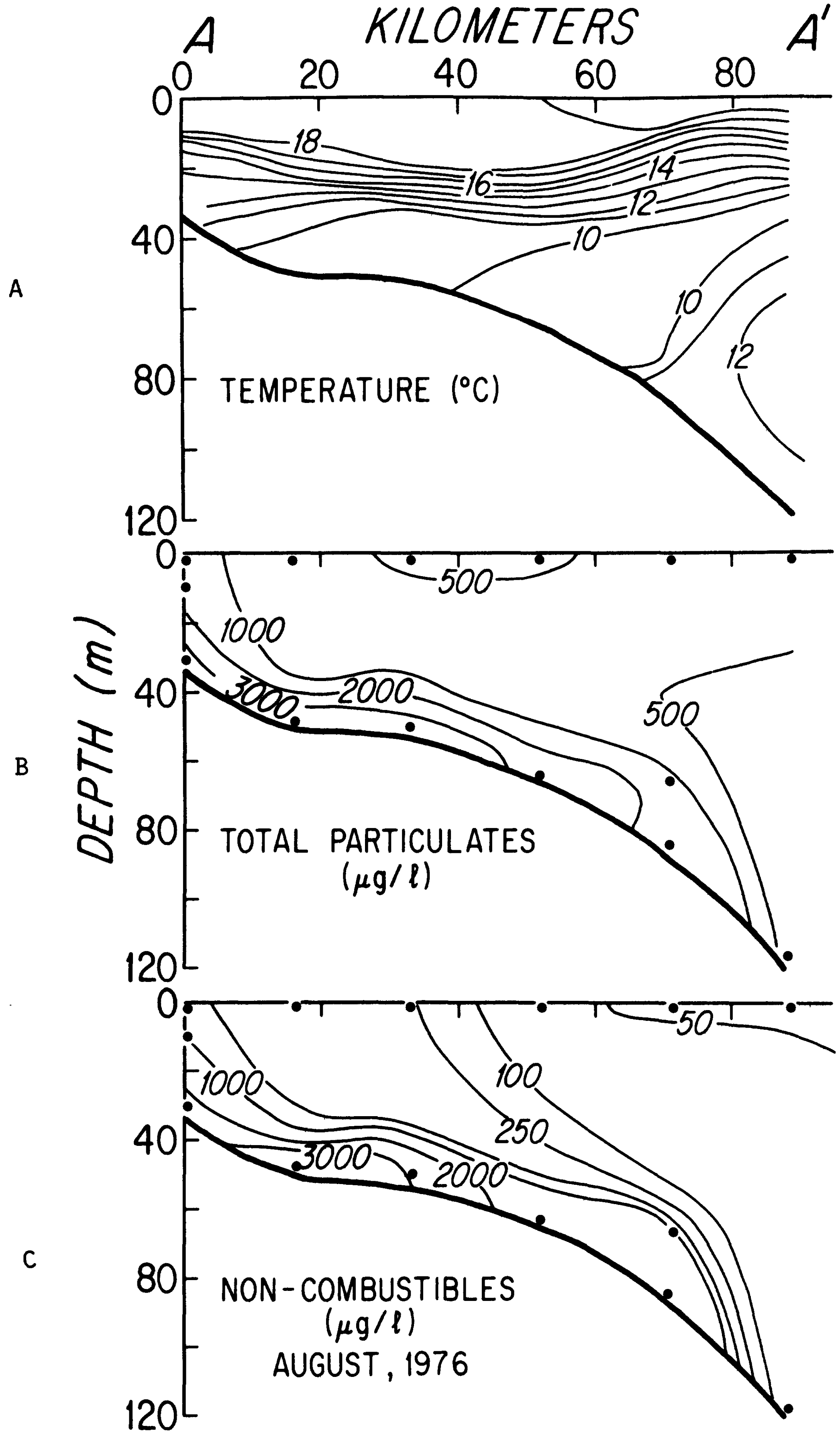


NON - COMBUSTIBLES (μg/ℓ) - S

NON - COMBUSTIBLES (μg/ℓ) - B

Figure 2-3. Vertical profile of temperature (a); total particulate (b); and noncombustible (c) concentrations along transect A-A' (Figure 2-2) south of Nantucket Island during August 1976.

Figure 2-3


A
KILOMETERS
A'
0
20
40
60
80
DEPTH (m)
0
40
80
120
18
16
14
12
10
10
12
TEMPERATURE (°C)
A
500
1000
2000
3000
500
TOTAL PARTICULATES
(μg/ℓ)
B
50
1000
100
250
3000
2000
NON-COMBUSTIBLES
(μg/ℓ)
AUGUST, 1976
C

2-2 and 2-3). Concentrations of noncombustibles exceeded 3,000 µg/l, or about 10-20 times those measured on Georges Bank. The strong stratification of waters in this area, however, did not allow significant vertical transport of particulates above the pycnocline. High concentrations of suspended matter in bottom waters extend seaward to a depth of about 110m--the approximate zone where slope water impinges upon the bottom (Figure 2-3).

Transmissometer profiles south of Nantucket show an increasing turbidity with depth in near-bottom water in agreement with the higher concentration of suspended matter measured (Figure 2-4). This increased turbidity is interpreted to result from active resuspension of bottom sediment which may be modern in age (based on C^{14} ages in cores from this area; M. H. Bothner, unpublished data). The good agreement between extinction coefficient as measured with the transmissometer and suspended-matter concentration of bottom-water samples is shown in Figure 2-5.

During August 1976 relatively high turbidity in near-bottom waters was also observed at the south end of Great South Channel and in waters with greater than 100 m depth north of Great South Channel. Bottom turbidity is a typical feature of the area south of Nantucket and north of Great South Channel during all of the sampling periods discussed in this report.

Turbidity maxima at the surface or mid depths are common in all areas of Nantucket Shoals and Georges Bank, and are due to increased concentrations of plankton. Highest concentrations typically occur in the areas of the thermocline where there is a favorable balance of sunlight and nutrients.

The nutrients NO_3, PO_4, and SiO_2 are greatly depleted in surface

Figure 2-4. Turbidity in the water column during August 1976. T indicates a turbidity maximum or increase. T^+ = strong; T^- = weak; C = no maximum or increase. Numbers refer to depth range (m) of turbid layer. A turbidity increase at the bottom indicated by underlined maximum depth.

Figure 2-4

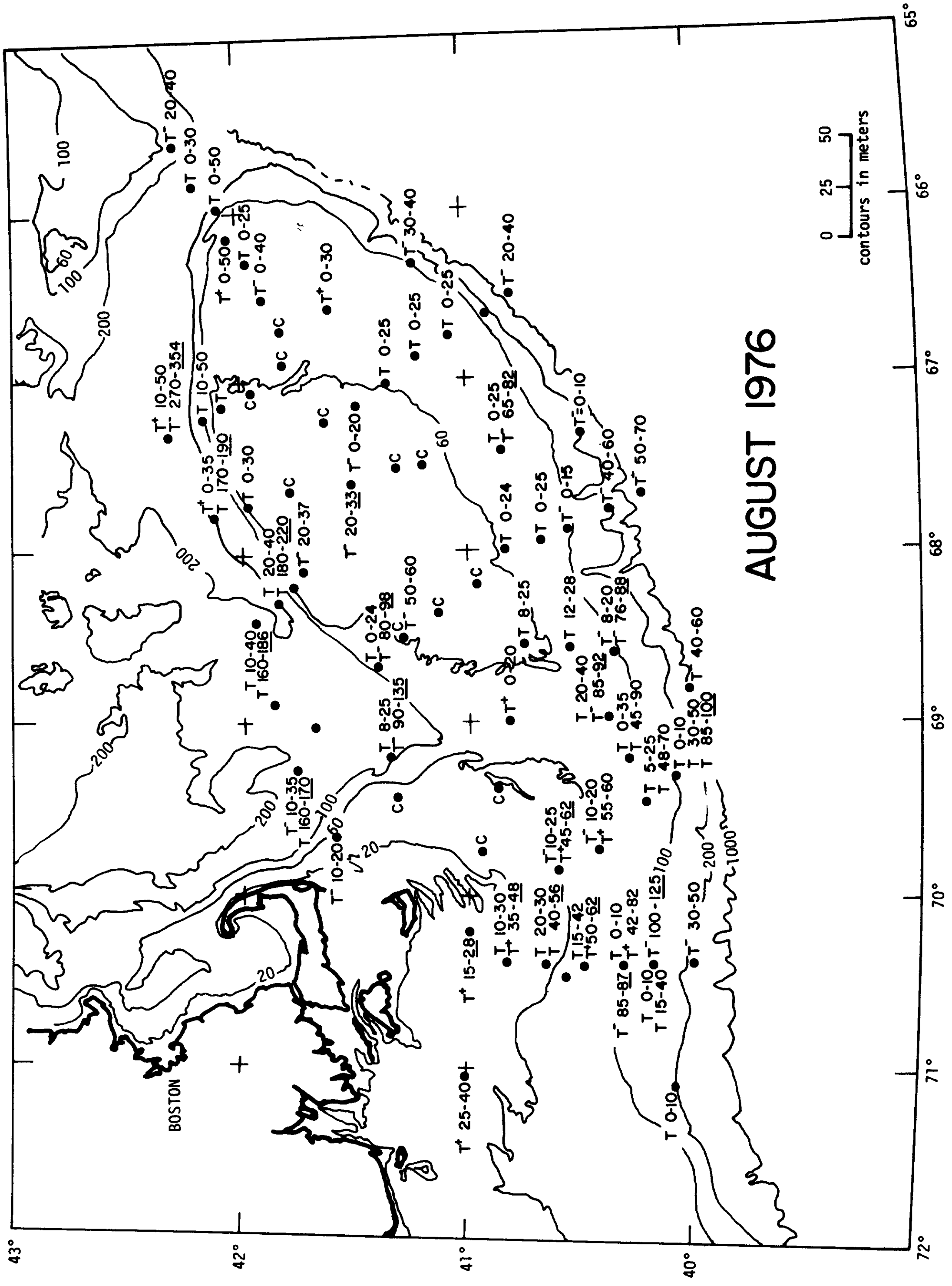
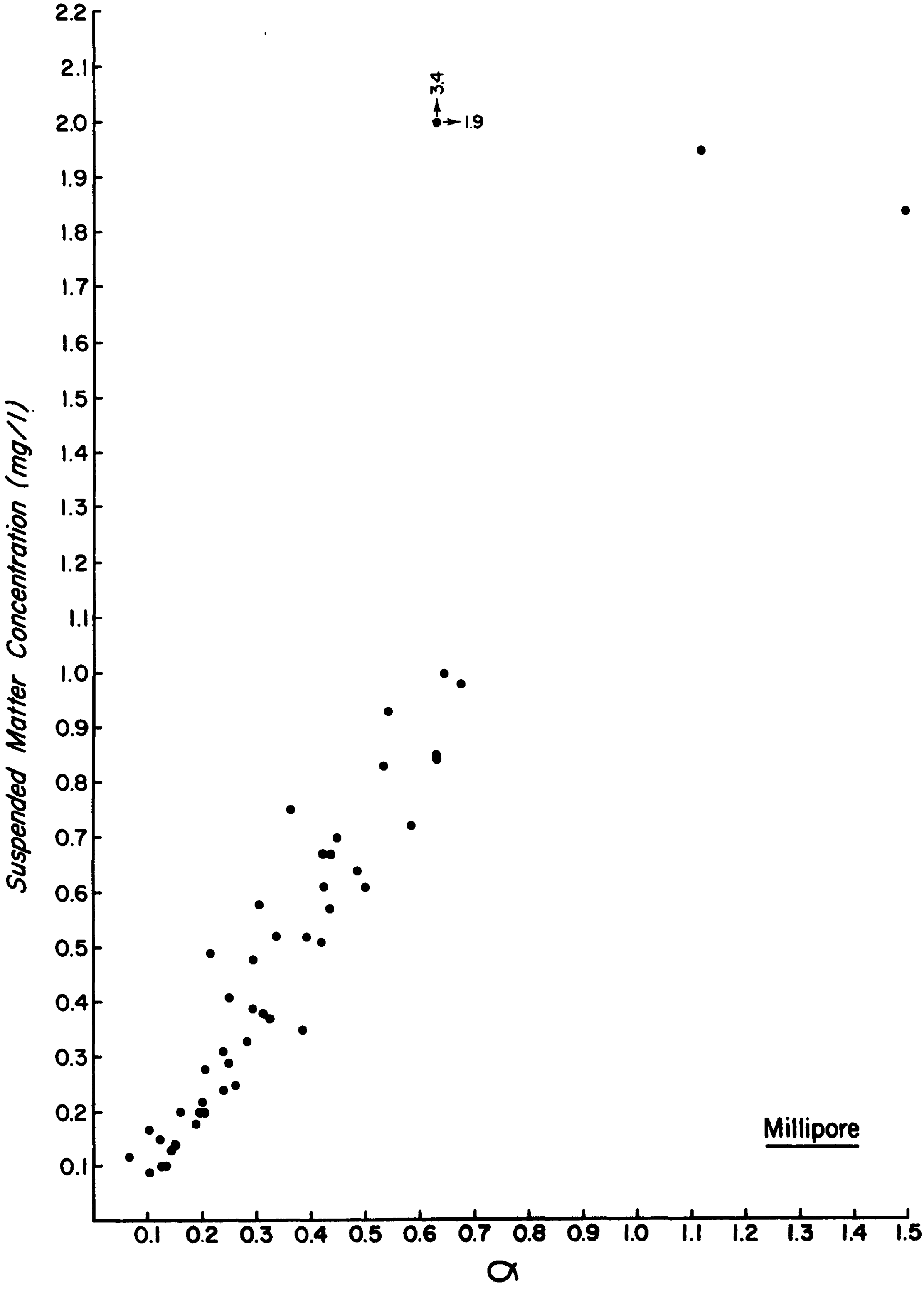

AUGUST 1976
0 25 50
contours in meters
BOSTON
43°
42°
41°
40°
72°
71°
70°
69°
68°
67°
66°
65°
100
200
60
20
1000

Figure 2-5. Relationship between extinction coefficient (α) and total suspended-matter concentrations in bottom-water samples during August 1976. Alpha is defined as ln (T/Tc), where T is transmission measured and Tc is calculated transmission of clear seawater.


Suspended Matter Concentration (mg/l)
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
3.4
1.9
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
α
Millipore

waters in comparison with deeper waters because of photosynthesis (Figure 2-6). Bottom-water values are also low on Georges Bank, where tidal currents maintain a thoroughly mixed water column and the water is shallow enough to permit photosynthesis throughout the water column. The deeper bottom waters have greatly increased nutrient concentrations and serve as the source of nutrients to the productive waters in and above the thermocline in this area. Anomalously high nutrient concentrations in bottom waters exist in the area of fine-grained sediments south of Nantucket Island (Schlee, 1973). This area may be receiving modern sediment which contains higher concentrations of silicious biogenic material as well as clay minerals and organic matter. The flux of nutrients is apparently much higher than other areas of similar depth in this study area.

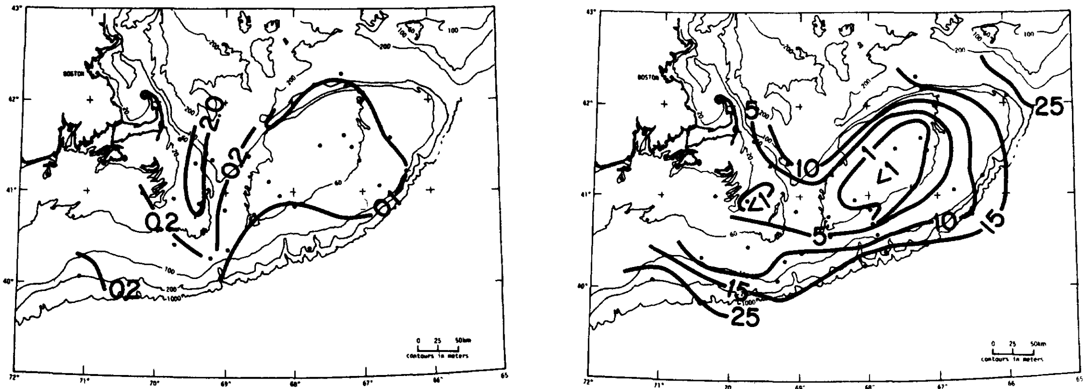
Figure 2-6 shows an increase in NO_3 and PO_4 and to a lesser extent SiO_2 in surface waters between Nantucket Island and Great South Channel. This area is also characterized by a marked temperature minimum that R. Limeburner _et al._ (unpublished data) interpret as an area of upwelling. This area may be responsible for stimulating additional production of phytoplankton which would add to the seston load in this area. Additional data are being analyzed to determine how often this feature is present.

December 1976

Three cruises on OCEANUS (17, 19 and 20) were made in December of 1976. The first was devoted to recovery and placement of current meters as well as collecting hydrographic information; only a few suspended matter samples were collected. The second two cruises were in response to the Argo Merchant disaster. Although none of the cruises collected enough samples to warrant areal plots of the data, extremely valuable

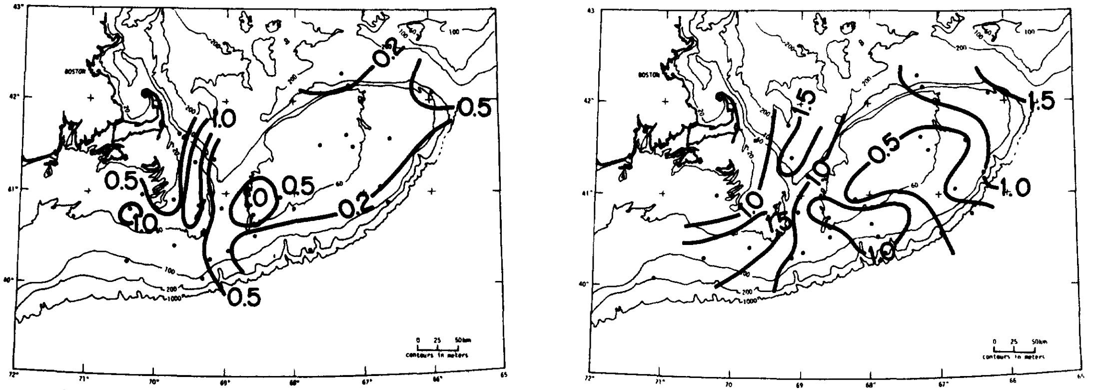
Figure 2-6. Areal distribution of nutrients in surface (left) and near-bottom (right) waters during August 1976.

Figure 2-6



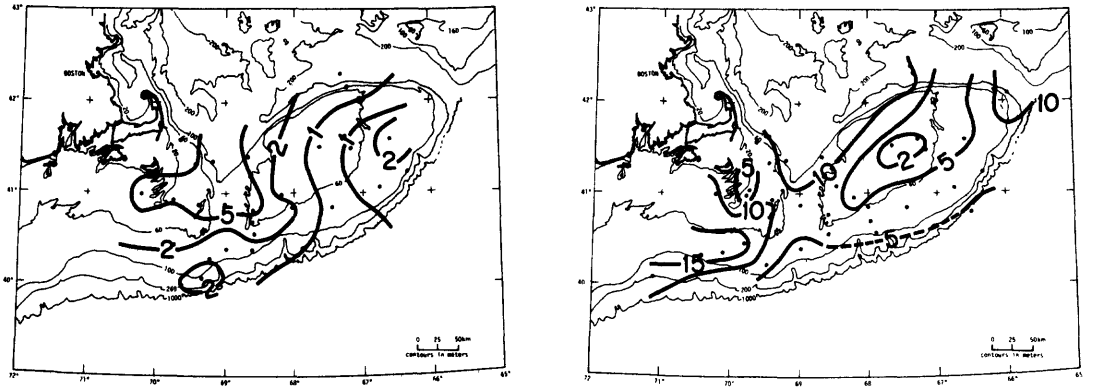
NO_3 (µg at/l)-S
AUGUST, 1976

NO_3 (µg at/l)-B



PO_4 (µg at/l)-S

PO_4 (µg at/l)-B



S_iO_2 (µg at/l)-S

S_iO_2 (µg at/l)-B

profiles were taken in the area of high suspended particulates noted during the August cruise and on Georges Bank (during OCEANUS 17) and are discussed in the following paragraphs.

The profile off the southeast side of Georges Bank (Figure 2-7) is based on only 3 stations, yet an interesting trend is seen. First, although bank waters are cold and vertically mixed, warmer slope water is seen moving onto the outer edge of the bank (Figure 2-7a). Second, although the amount of suspended particulates is relatively small and appears to decrease with increasing water depth, in terms of noncombustibles a near-bottom maximum is seen (Figure 2-7c), probably due to resuspension in response to impingement of the slope water.

A profile taken off Nantucket Island on December 30 showed well-mixed shelf waters, with impingement of warmer slope water on the outermost shelf and upper slope (Figure 2-8a). Total suspendeds were far greater during this time than have been measured at any time or any place in either the middle or northern Atlantic programs. Concentrations on the inner shelf exceeded 10,000 µg/l. This is particularly significant with respect to oil spills into seawater because suspended-matter concentrations of about 3,000-5,000 µg/l are influential in sinking crude oil to the bottom (R.L. Kolpack, oral communication and Kolpack, 1971).

As reflected in the low combustible percentages and increasing turbidity at the bottom (Figure 2-7c), most of this material was resuspended bottom sediment. In contrast to the high concentrations (particularly relative to surface waters) on the inner shelf, the middle shelf had more or less uniform concentrations throughout the water column, whereas on the outermost shelf and upper slope, near-bottom concentrations again exceeded those in overlying waters. In all

Figure 2-7. Vertical profiles of temperature (a); total particulate (b); and noncombustible (c) concentrations along a transect (Figure 2-2, B-B') on Georges Bank December 1976.

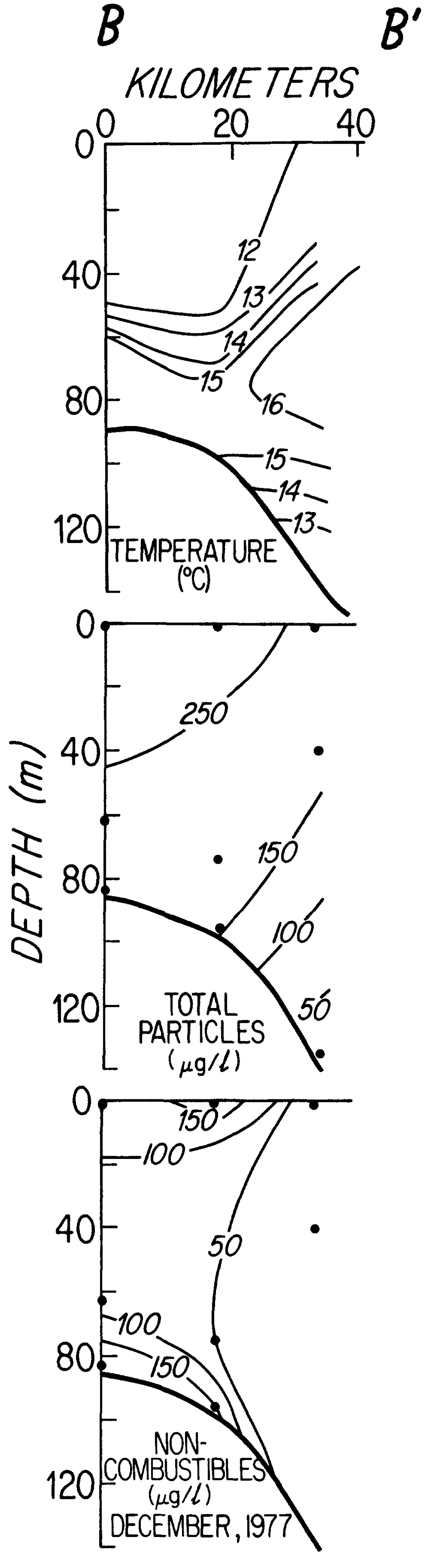
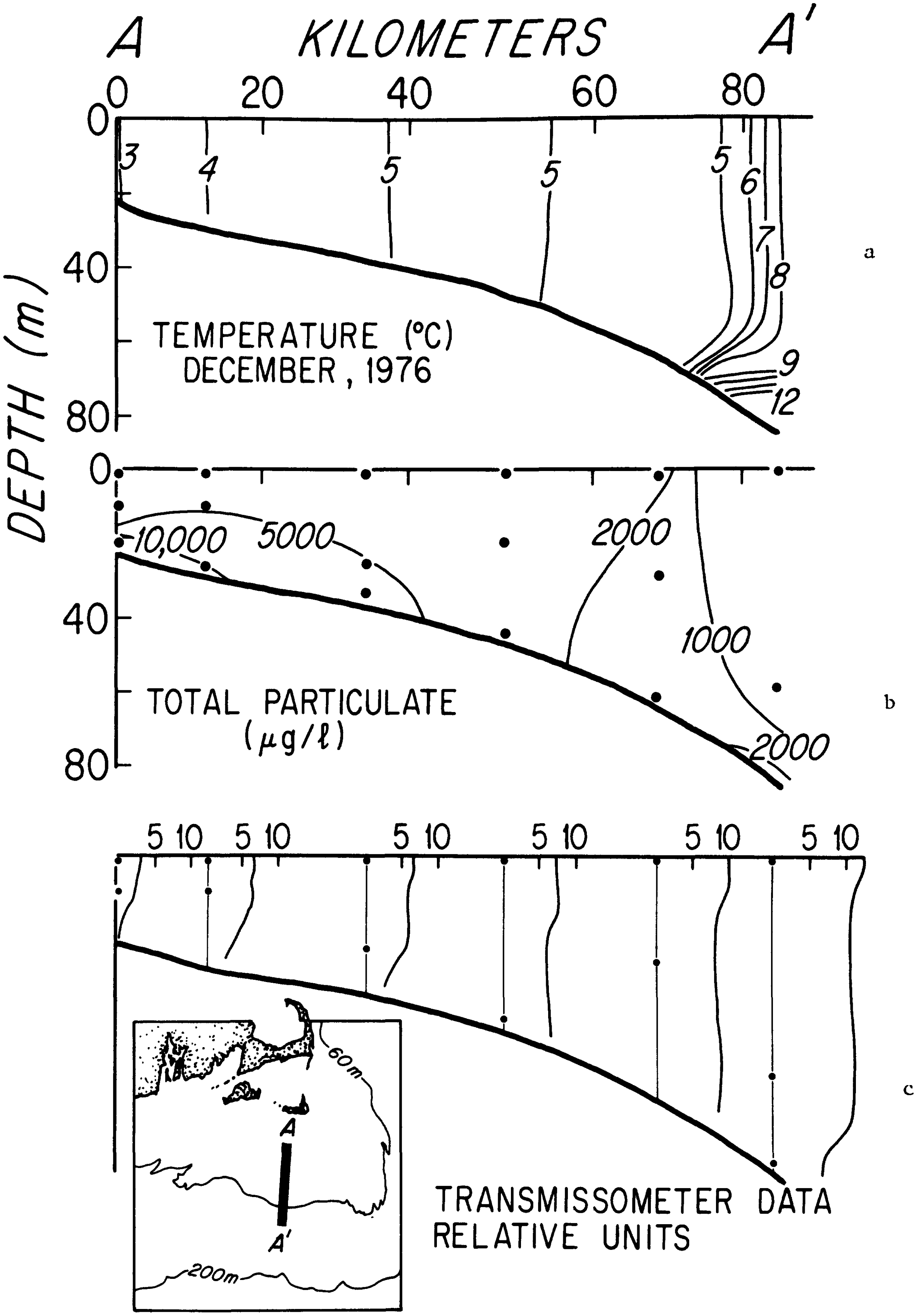

B
B'
KILOMETERS
0
20
40
0
40
80
120
12
13
14
15
16
15
14
13
TEMPERATURE
(°C)
0
40
80
120
250
150
100
50
TOTAL
PARTICLES
(μg/l)
DEPTH (m)
0
40
80
120
150
100
50
100
150
NON-
COMBUSTIBLES
(μg/l)
DECEMBER, 1977

Figure 2-8. Vertical profiles of temperature (a); total particulate concentrations (b); and relative transmission (c) along a transect A-A' (Figure 2-2) south of Nantucket Island December 1976.


A
KILOMETERS
A'
0
20
40
60
80
DEPTH (m)
3
4
5
5
5
6
7
8
9
12
TEMPERATURE (°C)
DECEMBER, 1976
a
10,000
5000
2000
1000
2000
TOTAL PARTICULATE
(µg/ℓ)
b
5 10
TRANSMISSOMETER DATA
RELATIVE UNITS
c
60m
A
A'
200m

probability the mid- and inner shelf concentrations reflect storm mixing of shelf waters (as suggested by the uniform temperature profile), whereas the near-bottom suspensions on the outer shelf reflect the impingement of slope water (compare Figures 2-8a and 2-8c). It is interesting to note, however, that highest concentrations on the inner shelf fall landward of the mud patch, a point that will be discussed later.

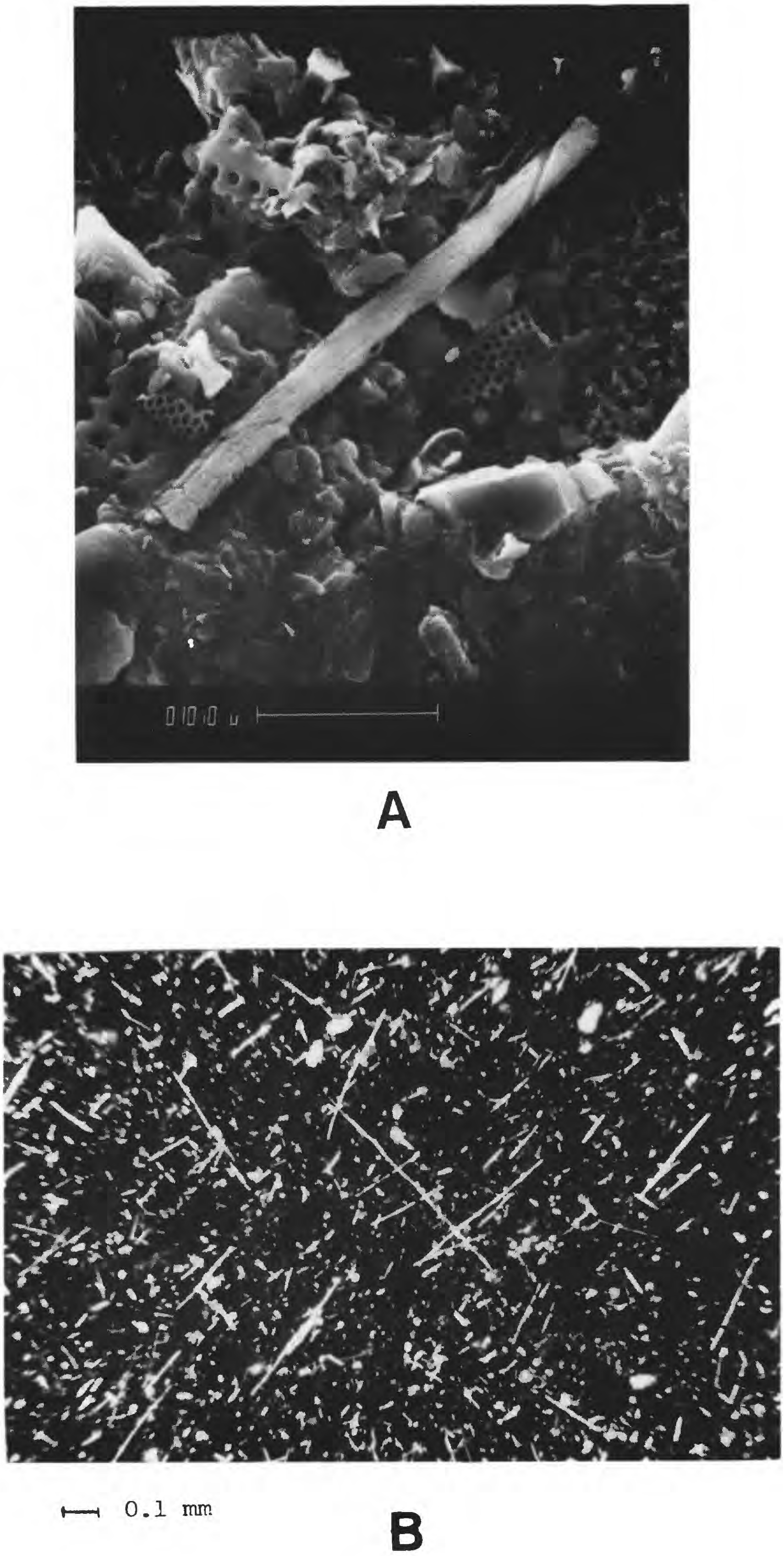
Needles of calcium carbonate (Figure 2-9) (actually laths derived from the disaggregation of molluscan shells) are prominent components of the seston throughout the water column in this area. The presence of the molluscan laths confirms that bottom sediment is resuspended into the water column. During warmer months, these laths occur in much smaller concentrations in bottom and mid-depth waters and are essentially absent in surface waters. Apparently not only is less material resuspended during the spring-fall, but also the strong pycnocline prevents upward transport of these needles into surface waters. The breakdown of stability in winter and the increased storm turbulence combine to make the concentrations highest in winter months. In contrast, waters on Georges Bank generally have small amounts of molluscan carbonate laths throughout the water column during all months. We suggest that the high concentrations seen off Nantucket in the winter reflect seasonal resuspension of laths that have collected throughout the year. Such concentrations never are reached on Georges Bank because resuspension is continual, thus precluding any build-up within the surficial sediment.

February-Early March 1977

Because of bad weather, ship problems, and the fact that this was ERCO's first collecting cruise, the sampling period in the winter of

Figure 2-9. Aragonite needles originating from degrading molluscan shells and resuspended in the water column in areas south of Nantucket Island (Station 20-1, 10 m).

Figure 2-9



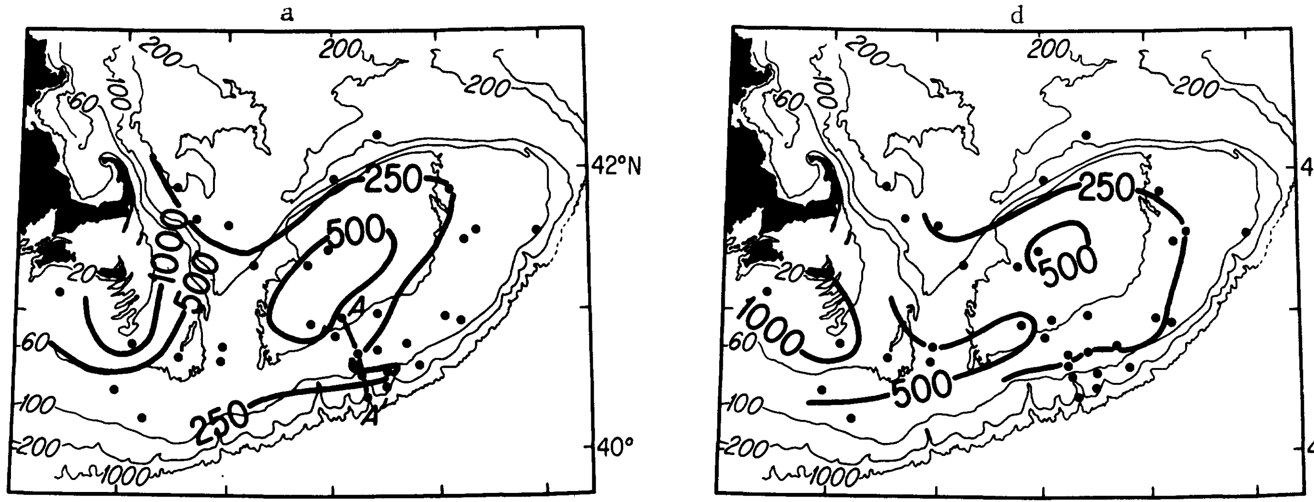
1977 was considerably longer than for most cruises (11 February to 4 March) thus minimizing the synoptic aspect of these samples. During this interval, 35 stations were occupied and 102 samples recovered.

Because of the well-mixed nature of the shelf waters (Figure 2-11), surface and near-bottom concentrations of seston were more or less equal (Figure 2-10). On Georges Bank, concentrations generally were less than 500 µg/l (except on the central part of the shoal, where values reached as high as 760 µg/l). On the shelf south of Nantucket, all measured near-bottom concentrations exceeded 500 µg/l (Figure 2-10d). The combustible fraction was considerably smaller than that seen during August (locally less than 25% even in surface waters), partly indicating lower productivity and partly showing the resuspension of organic-poor bottom sediment. As a result, concentrations of noncombustibles on Georges Bank were generally greater than those seen during August. However, in the shoal areas on the northern parts of the banks, concentrations in near-bottom waters were less than those measured in August, perhaps reflecting the fact that the August cruise had sampled the area soon after a major storm.

Although concentrations of total suspendeds were more or less uniform throughout the water column on Georges Bank, higher concentrations of noncombustibles (i.e., resuspended bottom sediment) were noted in bottom waters (Figures 2-11b, c). The fact that concentrations south of Nantucket Island were not as great as those seen in August or December of the previous year may be explained by the sparse sampling of this area by ERCO or by the fact that during sampling, weather was more calm than during either of the former cruises. Although concentrations of bottom suspended matter were lower, the turbidity profiles south of Nantucket and Martha's Vineyard showed

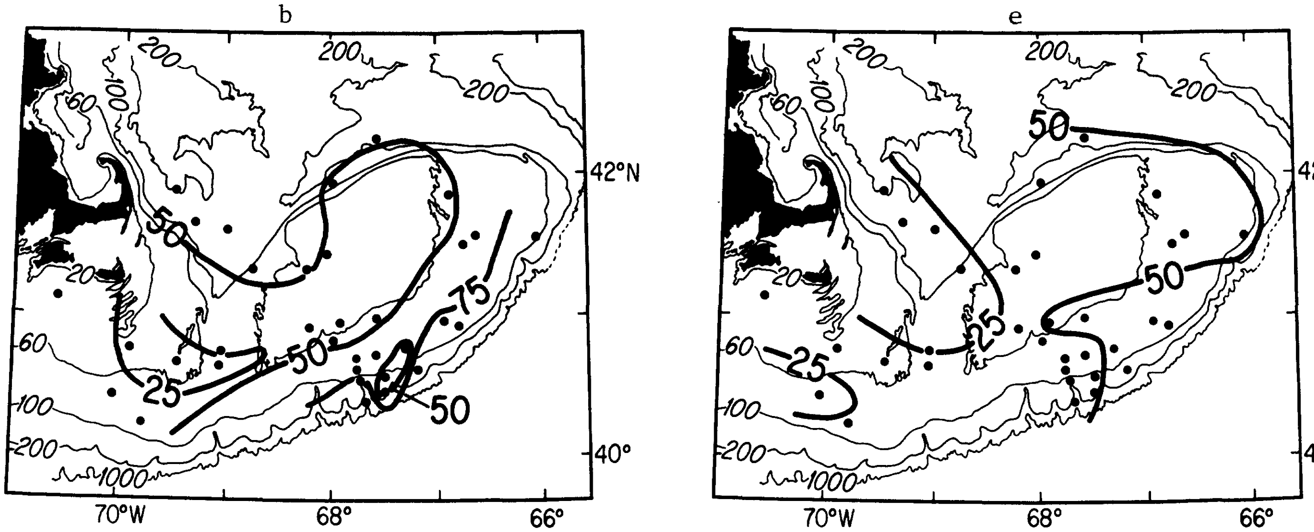
Figure 2-10. Areal distribution of suspended particulate matter in surface (left) and near-bottom (right) during February-early March 1977. Top illustrations (a and d) represent distributions of total particulates; middle plots (b and e) percent combustibles; and bottom plots (c and f) noncombustible concentrations. (Transect A-A' (map a) indicates position of cross-section shown in Figure 2-11.)

Figure 2-10



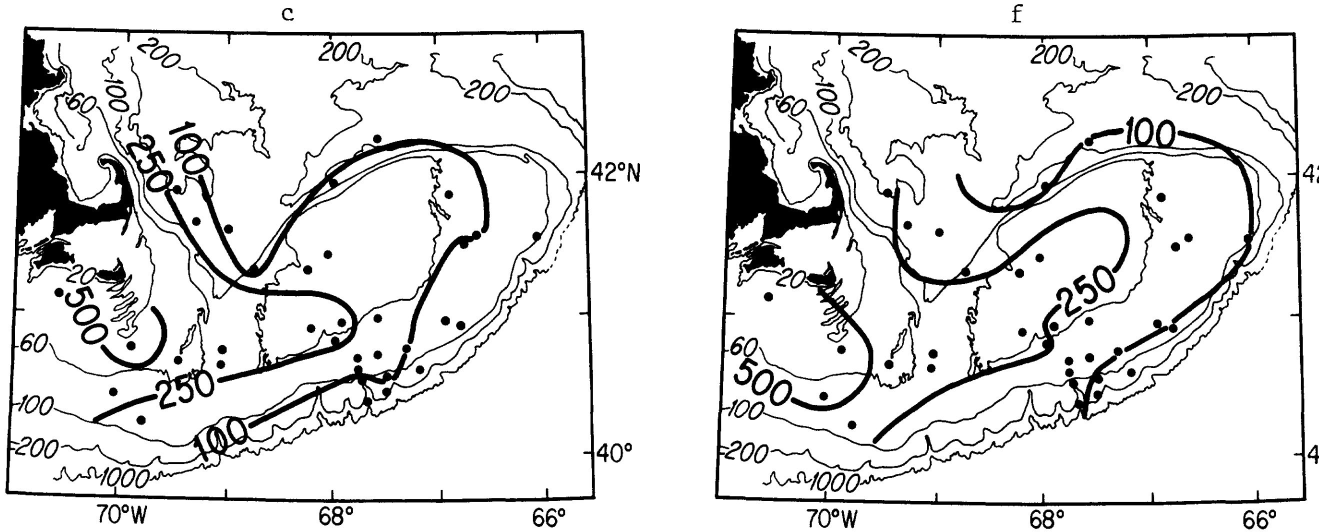
TOTAL PARTICULATES (μg/ℓ) - S
MID FEB. - EARLY MARCH, 1977

TOTAL PARTICULATES (μg/ℓ) - B



% COMBUSTIBLES - S

% COMBUSTIBLES - B

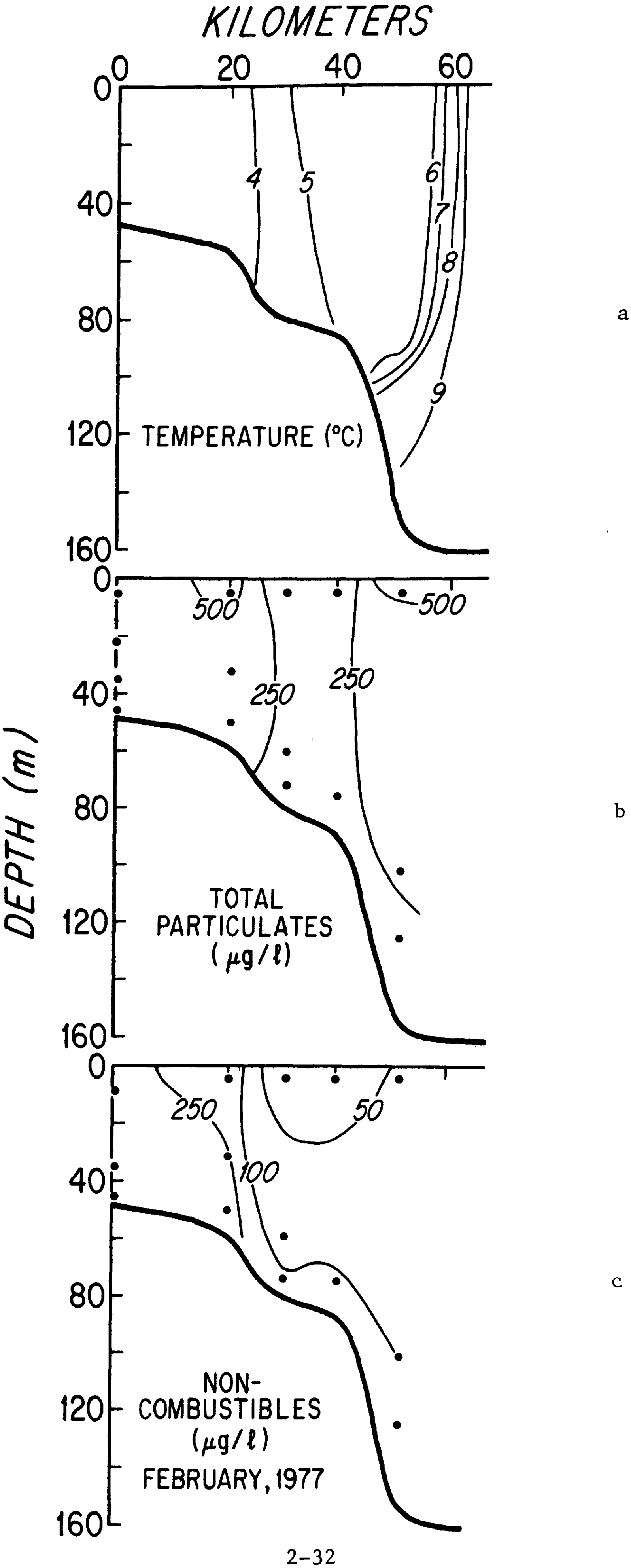


NON-COMBUSTIBLES (μg/ℓ) - S

NON-COMBUSTIBLES (μg/ℓ) - B

Figure 2-11. Vertical profile of temperature (a); total particulate (b); and non-combustible (c) concentrations along a transect (Figure 2-10, A-Á) on Georges Bank during February 1977.

Figure 2-11


KILOMETERS
0
20
40
60
DEPTH (m)
0
40
80
120
160
4
5
6
7
8
9
TEMPERATURE (°C)
a
500
250
250
500
TOTAL PARTICULATES (µg/ℓ)
b
250
50
100
NON-COMBUSTIBLES (µg/ℓ)
FEBRUARY, 1977
c

the characteristic increase in near-bottom waters. As in former cruises, carbonate laths were seen to form a significant part of the noncombustible fraction in Nantucket waters but little on Georges Bank.

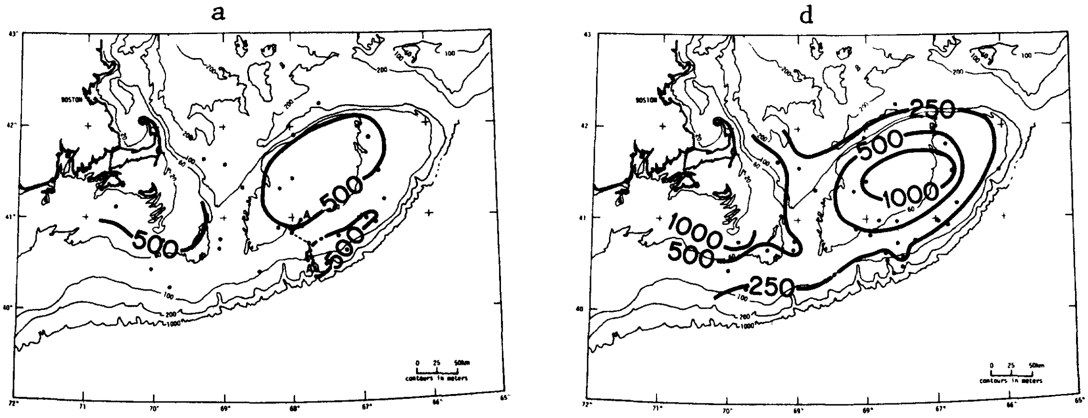
Samples recovered from stations on the south-central flanks of Georges Bank commonly contained Pleurosigma and Raphoneis diatoms, as well as numerous coccoliths at all depths. Overall, however, diatom concentrations in this area were low during the winter sampling. The greatest concentrations of diatoms and coccoliths were over the central shoal areas of the bank and south of Nantucket shoals. High concentrations of the diatoms Thalassiosira, Thalassionema, Pleurosigma, and Raphoneis (the latter often found clustered on silt-size particles) were found at all levels. Mineral components were also found in bottom, mid-, and surface samples, a further indication of the well-mixed character of the water mass at this time (Figure 2-13). Numerous carbonate laths were observed in suspended matter samples to the south of Nantucket shoals, and only trace amounts were observed across the bank. Samples taken to the north of Georges Bank, in the southern Gulf of Maine, revealed low diatom cell concentrations and contained no coccoliths. Coccoliths and coccolithophorids were restricted to samples taken over shoal areas and along the southern flanks of the bank. The seasonal trend in the distribution of coccoliths will be described in a later section of this report.

Early Mid-May 1977

By early May, the waters on Georges Bank had begun warming significantly (Figure 2-14), and spring blooms of plankton were dominating the suspended particulates. Concentrations of total suspendeds on Georges Bank were somewhat higher than those seen during February (Figures 2-12a, d), primarily the result of higher biological

Figure 2-12. Areal distribution of suspended particulate matter in surface (left) and near-bottom (right) during early-mid-May 1977. Top illustrations (a and d) represent distributions of total particulates; middle plots (b and c) percent combustibles; and bottom plots (c and f) noncombustible concentrations. (Transect A-A' (map a) indicates position of cross-section shown in Figure 2-14.)

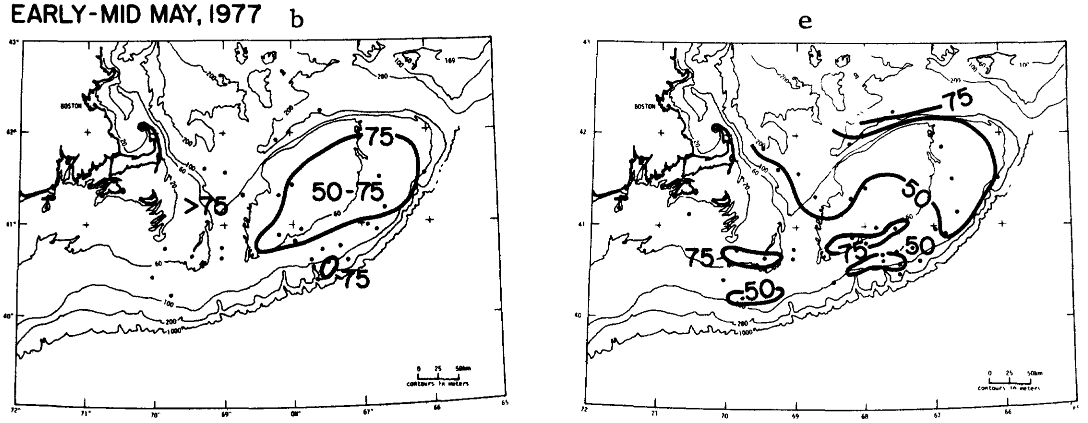
Figure 2-12



TOTAL PARTICULATES (µg/l)-S

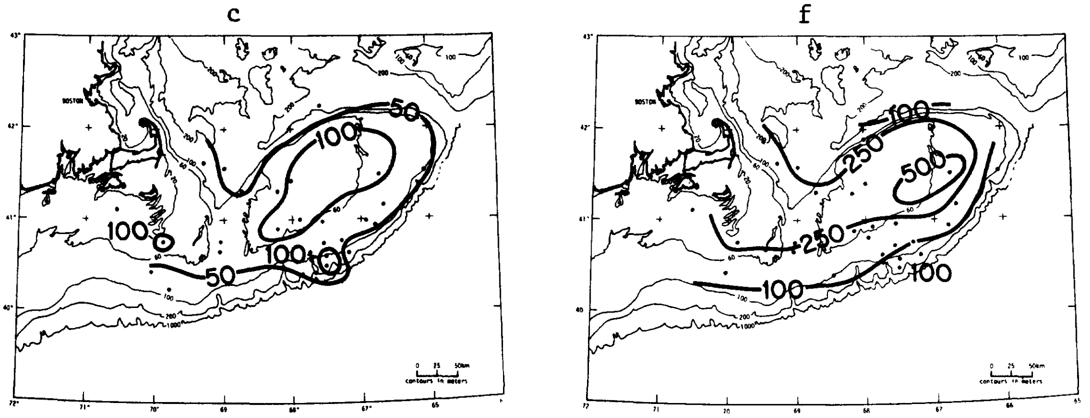
EARLY-MID MAY, 1977

TOTAL PARTICULATES (µg/l)-B



% COMBUSTIBLES-S

% COMBUSTIBLES-B



NON-COMBUSTIBLES (µg/l)-S

NON-COMBUSTIBLES (µg/l)-B

Figure 2-13. Scanning-electron-microscope photographs of:

a. Sediment quartz grain associated with benthic diatom (Raphoneis) found in surface sample of Station 11 (February 19, 1977).

b. Typical diatoms found in surface waters at Station 38 (February 28, 1977) included Thalassiosira (Ta) and Thalassionema (Tn).

Figure 2-13

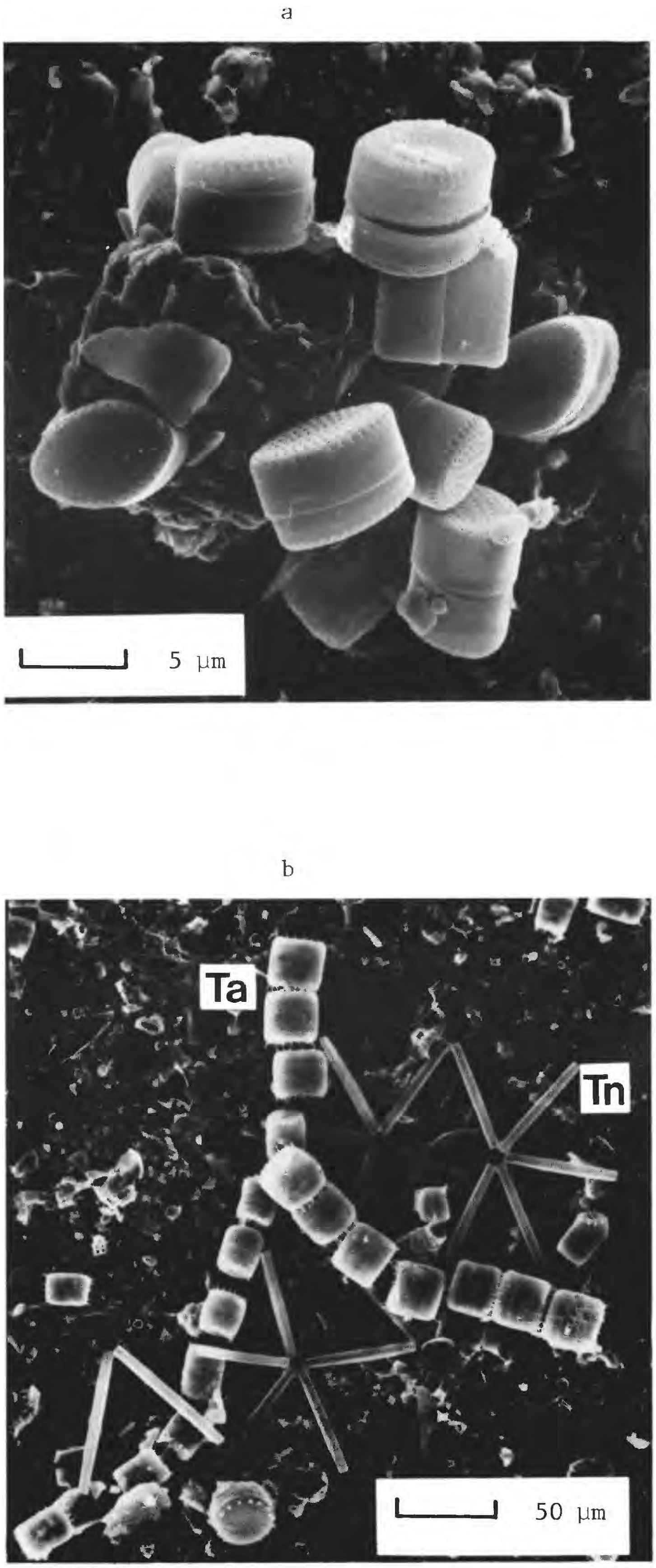
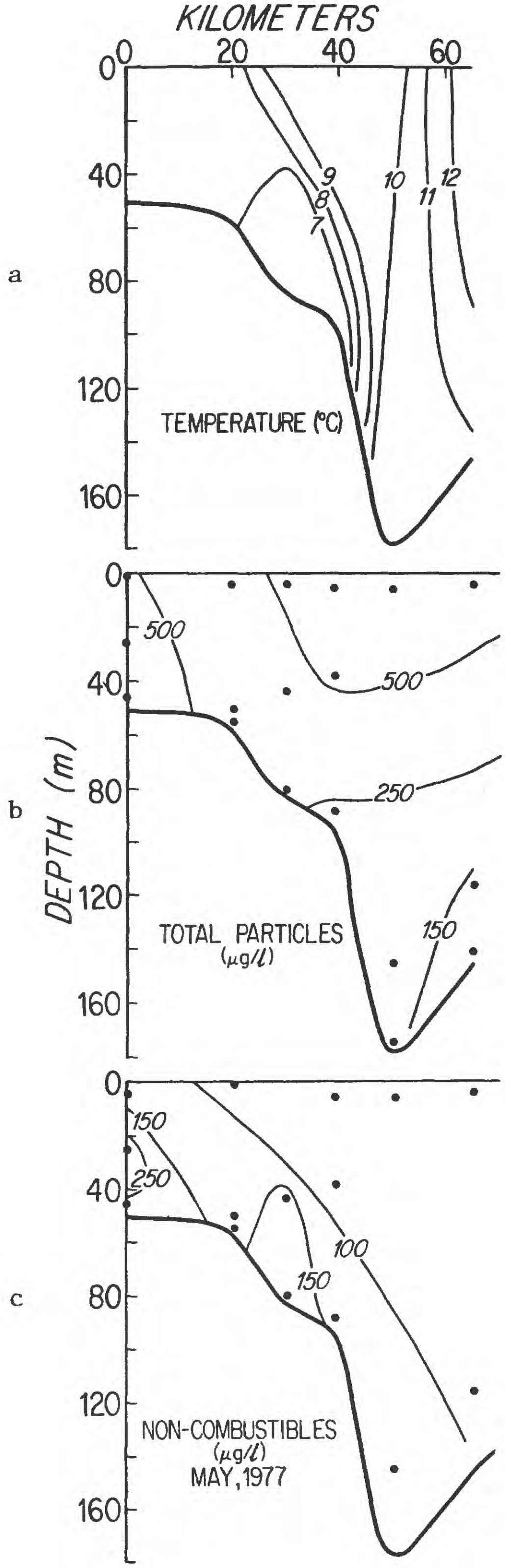


Figure 2-14. Vertical profile of temperature (a); total particulate (b); and non-combustible (c) concentrations along a transect (Figure 2-12, A-Á) on Georges Bank.

Figure 2-14


KILOMETERS
0
20
40
60
0
40
80
120
160
9
8
7
10
11
12
TEMPERATURE (°C)
a
DEPTH (m)
0
40
80
120
160
500
500
250
150
TOTAL PARTICLES
(μg/l)
b
0
40
80
120
160
150
250
100
150
NON-COMBUSTIBLES
(μg/l)
MAY, 1977
c

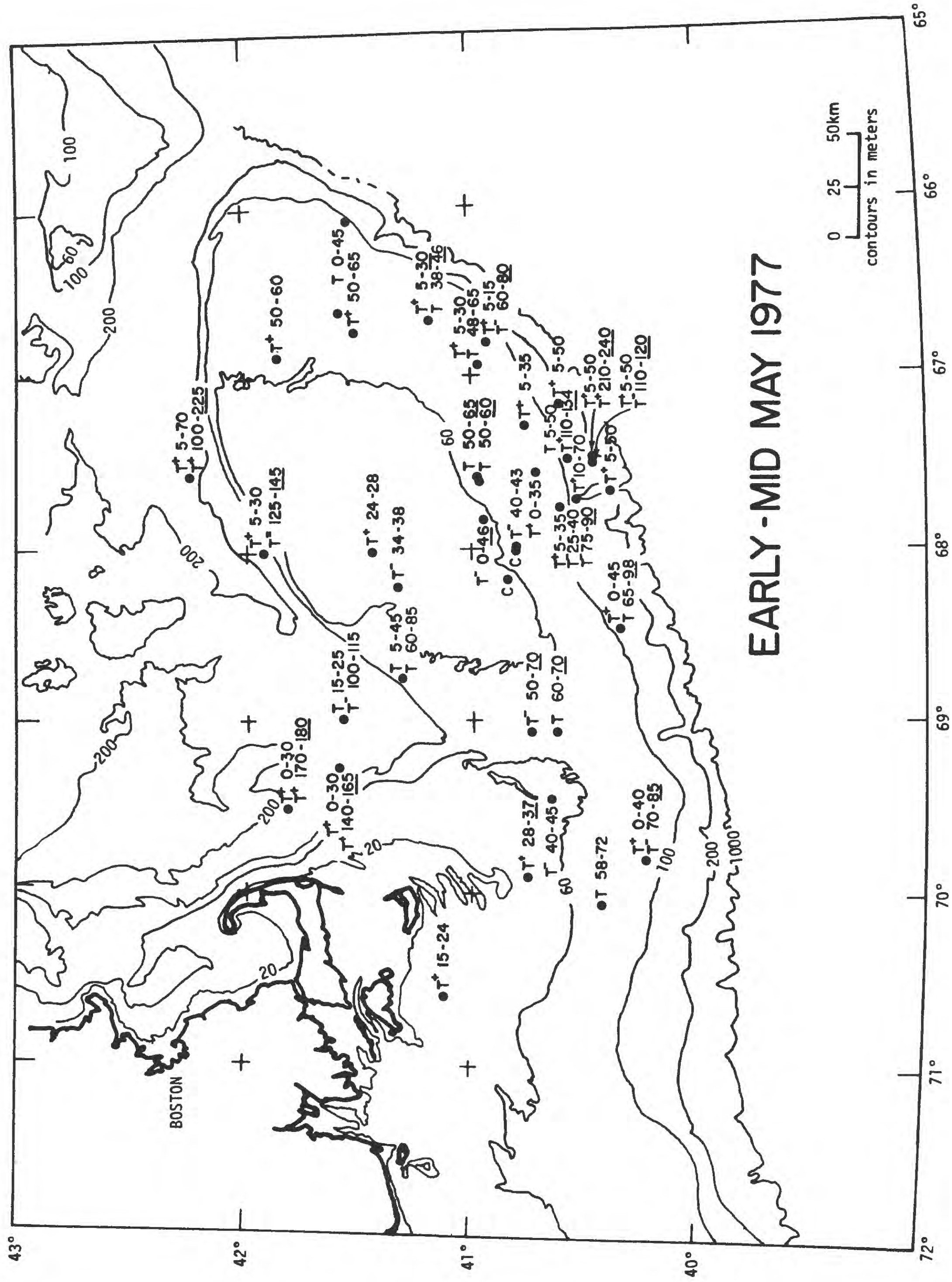
productivity. Surface particulate samples contained 75-85% combustibles (Figure 2-12b), and the percentage of noncombustibles in bottom waters was higher than during February (Figure 2-12f). This high amount of noncombustible material in near-bottom waters is best explained by both resuspension of bottom waters and the abundance of diatom frustules produced during spring bloom. Increasing turbidity in near-bottom waters, an indication of active resuspension, was observed south of Nantucket Island, in Great South Channel, in the southern Gulf of Maine, and on the southern flank of Georges Bank (Figure 2-15).

Although few samples were taken from the Nantucket Shelf, the high levels of suspended particulates were not seen during early May. Moreover, the carbonate laths that characterize winter conditions were no longer as evident in bottom waters and almost completely absent from surface waters, suggesting that resuspension, although present, was lower than during earlier cruises. Resuspension presumably is caused both by wind-induced waves and currents in shallower waters and by impingement of the slope water upon the shelf edge (Figure 2-14). Deeper circulation in the Gulf of Maine and the availability of fine-grained surface sediments may account for the persistent high turbidity in bottom waters observed north of Great South Channel.

Spring diatom blooms were observed over the central areas of the bank in shoal areas less than 60 m deep. Greatest concentrations of cells were observed in mid- and bottom samples, surface samples being notably low in whole cell concentrations. A bloom of <u>Pleurosigma</u>, <u>Coscinodiscus</u>, and <u>Rhizosolenia</u> extended from the central shoal areas of Georges Bank to Nantucket, approximately between the 40- to 60-m contours. South of the 60-m contour across the southern part of the bank, diatoms were sparse, the dominant form being <u>Coscinodiscus</u>

Figure 2-15. Turbidity in the water column during May 1977. T indicates a turbidity maximum or increase. T^+ = strong; T^- = weak; C = no maximum or increase. Numbers refer to depth range (m) of turbid layer. A turbidity increase at the bottom indicated by underline maximum depth.

Figure 2-15

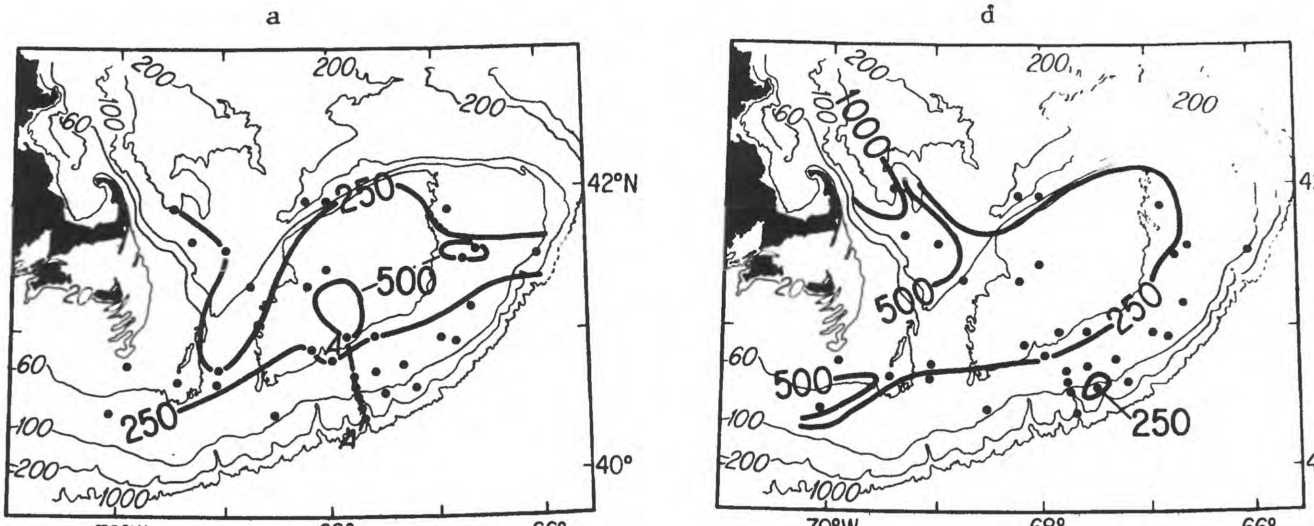

EARLY-MID MAY 1977
BOSTON
0 25 50km
contours in meters
43°
42°
41°
40°
72°
71°
70°
69°
68°
67°
66°
65°
20
60
100
200
1000
T+ 15-24
T+ 28-37
T 40-45
T 58-72
T+ 0-40
T 70-85
T+ 0-30
T+ 140-165
T+ 0-30
T+ 170-180
T 15-25
T 100-115
T 50-70
T 60-70
T 5-45
T 60-85
T+ 24-28
T- 34-38
T+ 5-30
T+ 125-145
T+ 5-70
T 100-225
T 0-46
C
T+ 40-43
T 0-35
T 50-65
T 50-60
T+ 0-45
T 65-98
T+ 5-35
T 25-40
T 75-90
T 5-50
T 110-134
T 10-70
T+ 5-50
T 210-240
T 5-50
T 110-120
T+ 5-50
T+ 5-35
T+ 5-50
T+ 5-30
T 48-65
T+ 5-15
T 60-80
T+ 5-30
T 38-46
T+ 50-60
T 0-45
T+ 50-65

gigantea which was locally prominent at a few bottom and mid samples. However, the frustules of this form often were broken or slightly dissolved and may be evidence of resuspension shown by increased turbidity in near-bottom waters (Figure 2-15). Surface samples in this area were generally devoid of diatoms and contained only broken frustules. As in February-early March, coccoliths and coccolithophorids were observed in deeper water (greater than 60 to 100 m) stations along the southern flank, but their numbers were slightly reduced, and compared with February, their distribution shifted laterally southward, as well as vertically downward to mid- and bottom samples. Stations north of the bank contained numerous minute diatoms in the bottom samples which appeared to be the form *Syringidium*, but the cells were too small to identify accurately using the light microscope. A second bloom observed at several stations sampled along the eastern flanks of the bank was dominated by *Rhizosolenia*, *Coscinodiscus*, and *Chaetoceros*. Again, compared with the February-March sampling period, mineral constituents were lower, being locally restricted to mid- and bottom samples of shoal areas.

Mid-August 1977

By mid-August, bank waters had reached their maximum temperatures (surface values exceeding 15°C), and had become partly stratified (Figure 2-17). Surface particulates were dominated by biogenic components generally containing 80 to 90% combustibles whereas near-bottom samples generally contained 55 to 80% combustibles (Figures 2-16b, e). As a result, noncombustible concentrations on Georges Bank were far lower than those seen during May, with maximum values about 170 µg/l (Figure 2-16f). This level of suspended-matter concentration contrasts strongly with the observations made in August of 1976, when

Figure 2-16. Areal distribution of suspended particulate matter in surface (left) and near-bottom (right) during August 1977. Top illustrations (a and d) represent distributions of total particulates; middle plots (b and e) percent combustibles; and bottom plots (c and f) noncombustible concentrations. (Transect A-A' indicates position of cross-section shown in Figure 2-17.)



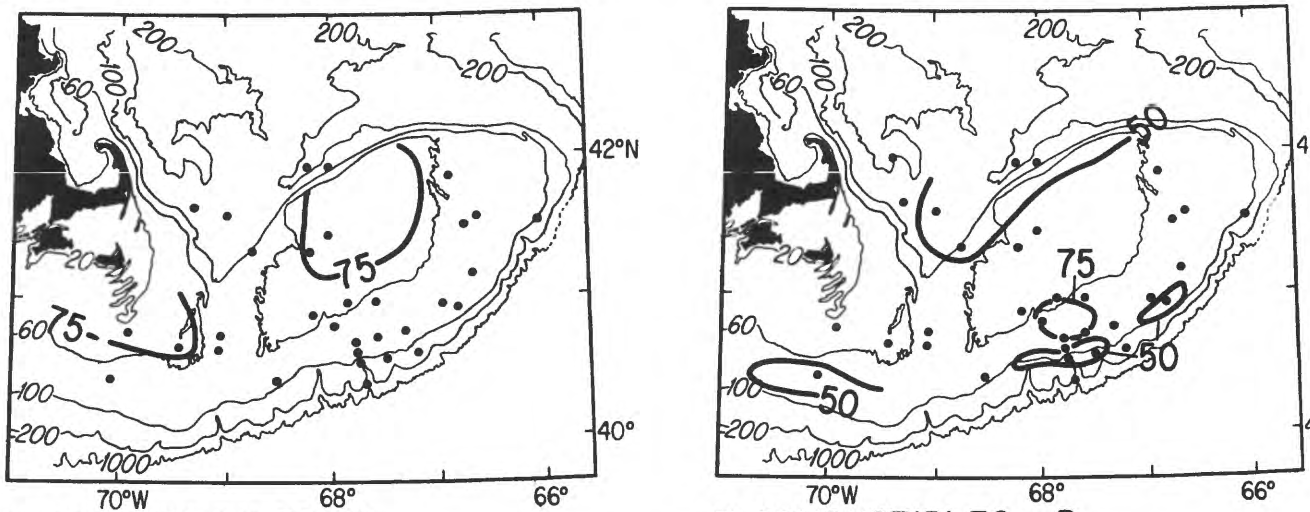
TOTAL PARTICULATES (μg/ℓ)-S

TOTAL PARTICULATES (μg/ℓ)-B

MID-AUGUST, 1977

b

e

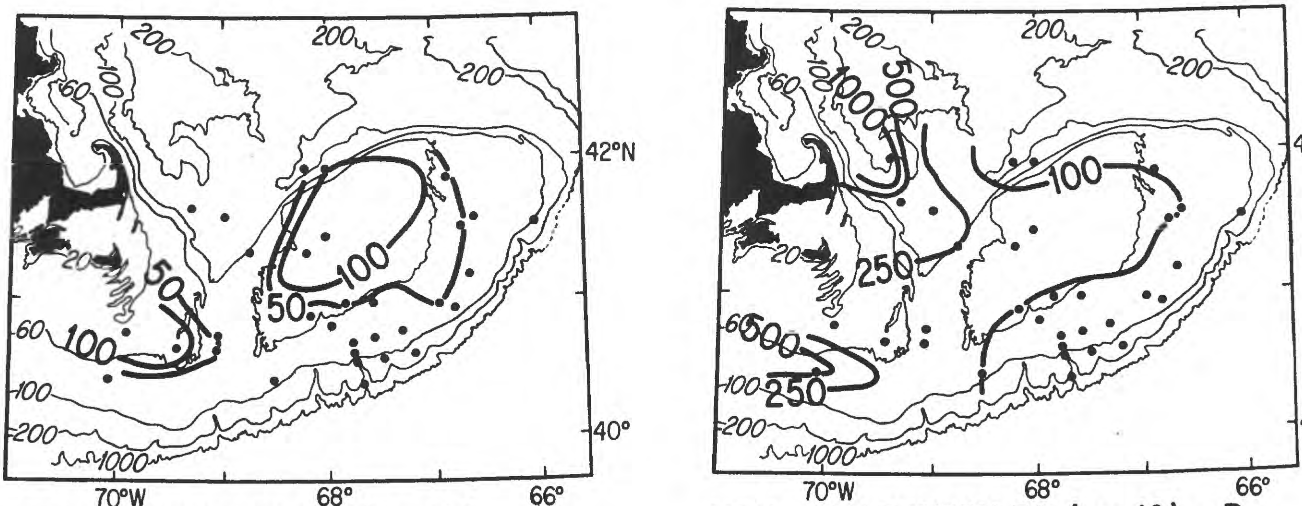


% COMBUSTIBILES - S

% COMBUSTIBLES - B

c

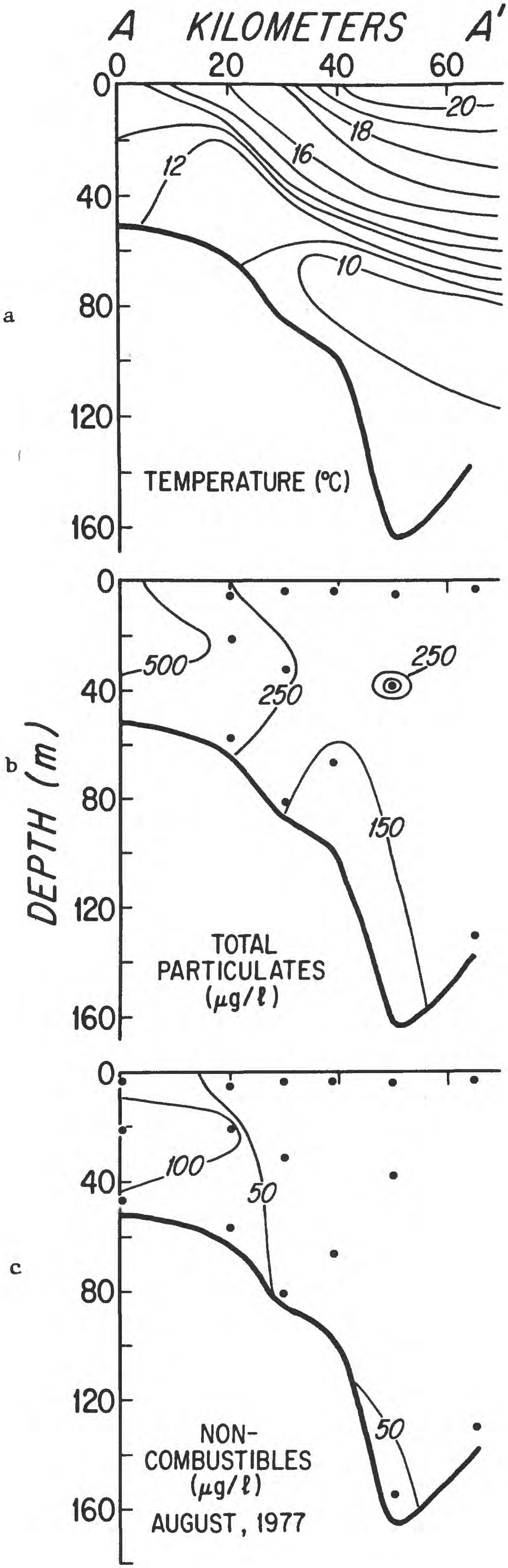
f



NON-COMBUSTIBLES (μg/ℓ) - S

NON-COMBUSTIBLES (μg/ℓ) - B

Figure 2-17. Vertical profile of temperature (a); total particulate (b) and non-combustible (c) concentrations along a transect (Figure 2-16, A-Á) on Georges Bank.


A KILOMETERS A'
0
20
40
60
0
40
80
120
160
20
18
16
12
10
TEMPERATURE (°C)
a
0
40
80
120
160
500
250
250
150
TOTAL PARTICULATES (μg/ℓ)
b
DEPTH (m)
0
40
80
120
160
100
50
50
NON-COMBUSTIBLES (μg/ℓ)
AUGUST, 1977
c

near-bottom values on the bank exceeded 1,000 µg/l (Figure 2-2). We explain this difference by the passage of Hurricane Belle through New England during 1976 and the subsequent mixing of bottom waters. Because slope water did not impinge upon the bottom, little evidence of bottom resuspension is seen on the outer shelf in August 1977. This is concluded from both the concentration and composition of suspended matter and from the transmissometer profiles which show no increase in turbidity in near-bottom waters in this area (Figure 2-18). Turbidity maxima observed at mid-depths in this area correlate with maxima in dissolved O_2. The O_2 profile and the abundant diatoms at mid-depth (Figure 2-19) indicate that living phytoplankton is responsible for the turbidity making up this turbidity maximum.

Highest bottom concentrations of near-bottom noncombustibles were found on the outer shelf south of Nantucket and in the northern part of Great South Channel. Strong turbidity increases measured in near-bottom waters also support the concept of active resuspension in these areas.

August samples generally contained low concentrations of diatoms at most depths. Diatoms occurred in highest concentrations at mid- and bottom samples of shoreward stations to the south of Nantucket (stations 1, 2, and 3), as did the silicoflagellate Distephanus. Coscinodiscus gigantea, Melosira, and occasionally Thalassiosira and Navicula were dominant forms at these stations. Coccoliths and coccolithophorids were observed only at bottom samples from a few deeper water stations along the southern flank (stations 8, 4, and 28).

The gradual reduction in coccolithophorid concentrations from winter to summer, with distributions displaced southward off the bank, is further substantiated by August samples. The migration of coccolithophorids on an apparent seasonal basis is shown in Figure 2-20.

Figure 2-18. Turbidity in the water column during August 1977. T indicates a turbidity maximum or increase. T^+ = strong; T^- = weak; C = no maximum or increase. Numbers refer to depth range (m) of turbid layer. A turbidity increase at the bottom indicated by underlined maximum depth.

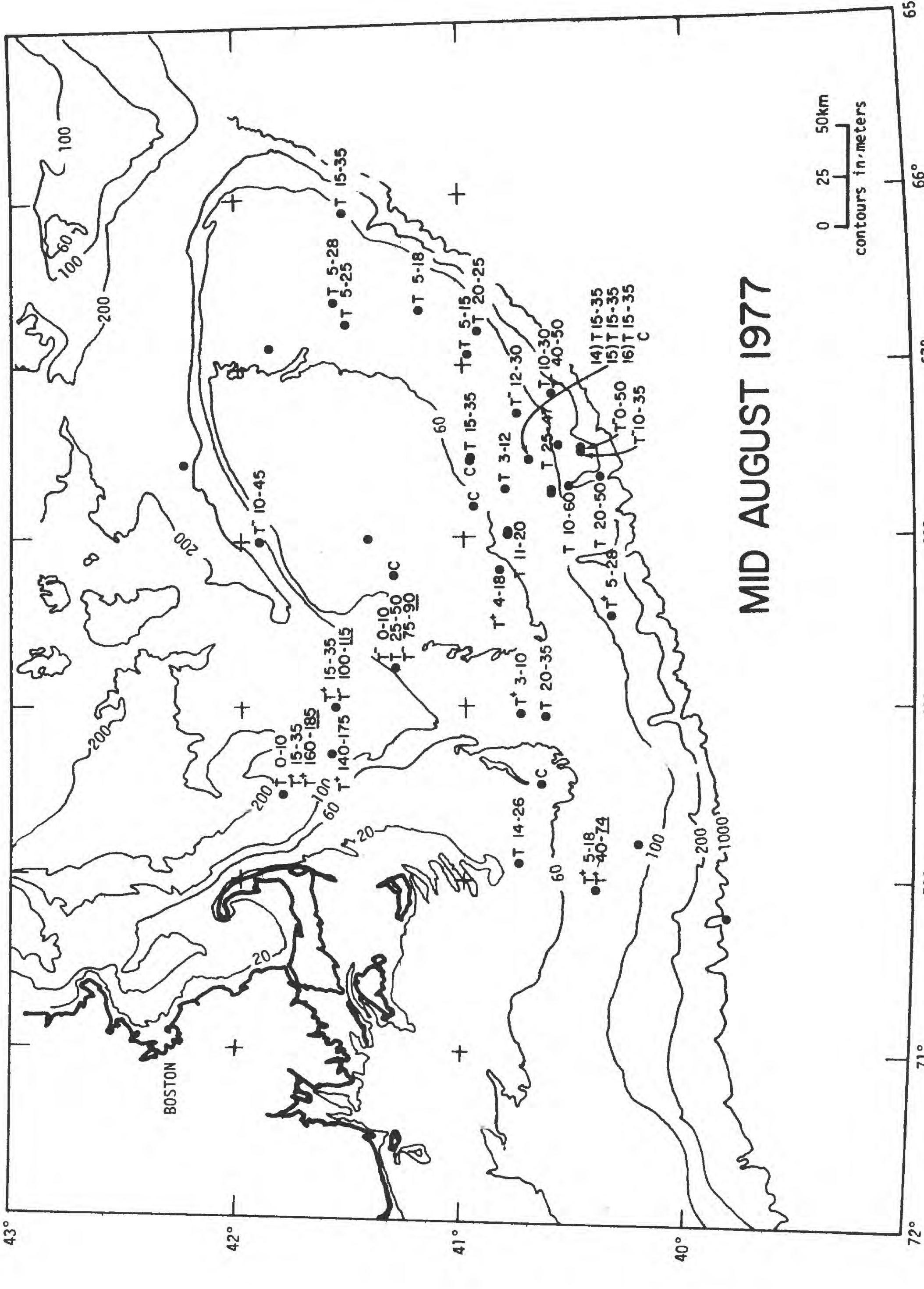
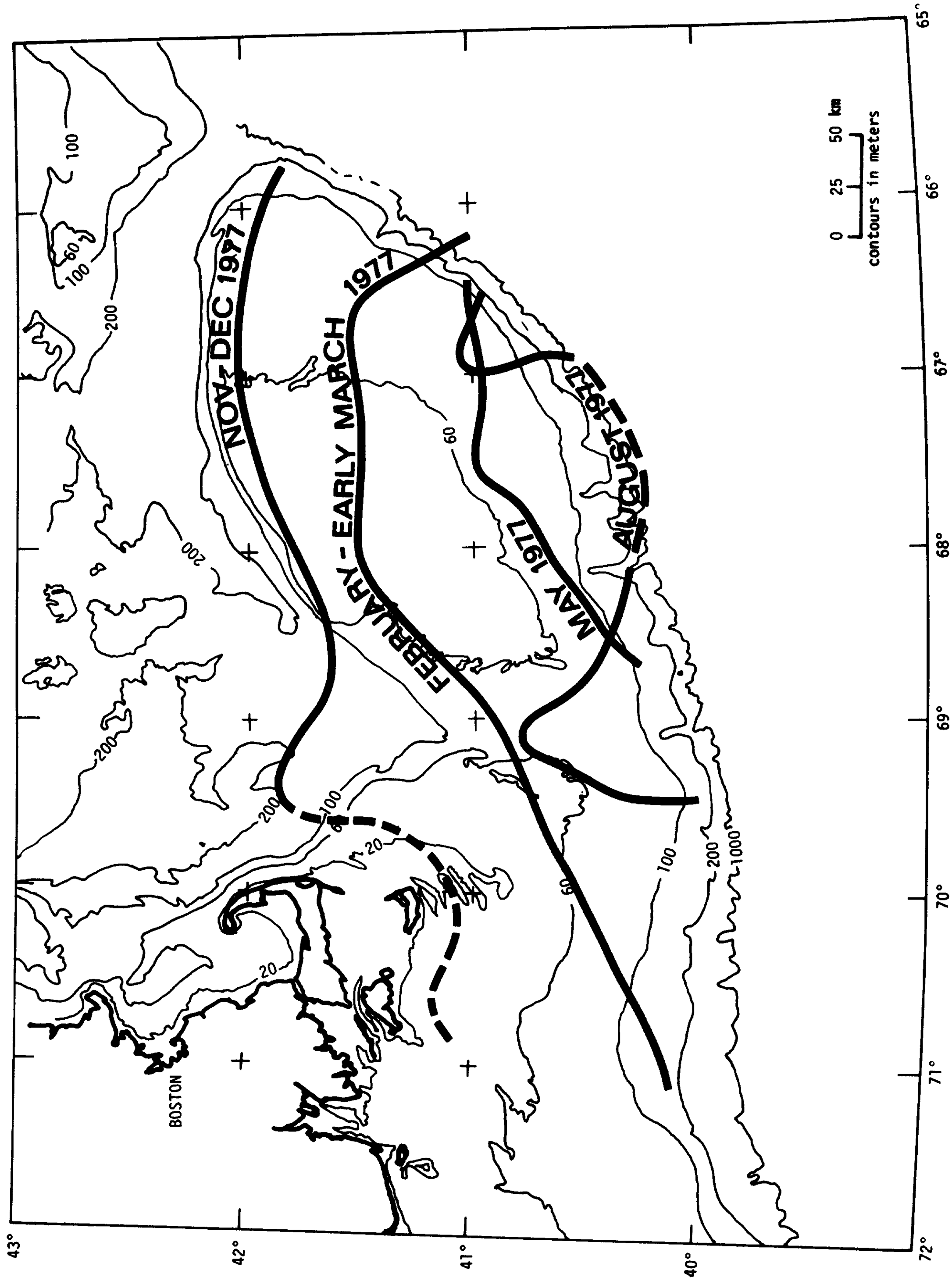

MID AUGUST 1977
BOSTON
0 25 50km
contours in meters
43°
42°
41°
40°
72°
71°
70°
69°
68°
67°
66°
65°
20
60
100
200
1000
T 15-35
T 5-28
T 5-25
T 5-18
T 5-15
T 20-25
T 10-45
C T 15-35
T 3-12
T 12-30
T 10-30
40-50
14) T 15-35
15) T 15-35
16) T 15-35
C
T 0-50
T 10-35
T 25-47
T 10-60
T 20-50
T 5-28
T 11-20
T 4-18
C
T 0-10
T 25-50
T 75-90
T 15-35
T 100-115
T 0-10
T 15-35
T 160-185
T 140-175
T 3-10
T 20-35
C
T 14-26
T 5-18
T 40-74

Figure 2-19. Diatom frustules (Coscinodiscus) in high concentration at middepth at Station 38, 26 m, August 22, 1977.


200 μm

Figure 2-20. Seasonal changes in the northern limit of coccoliths in suspended-matter samples.


NOV-DEC 1977
FEBRUARY - EARLY MARCH 1977
MAY 1977
AUGUST 1977
BOSTON
0 25 50 km
contours in meters
100
60
200
20
1000
65°
66°
67°
68°
69°
70°
71°
72°
43°
42°
41°
40°

Unlike February-early March, little mineral material was found in either mid- or surface samples, reflecting the well-stratified conditions in the water column.

Early September 1977

The first Raytheon cruise sampled extensively over Georges Bank but excluded sampling of the shelf south of Nantucket. On the bank itself, the situation noted in August remained more or less the same. Low concentrations of suspended particulates were dominated by combustibles (generally greater than 80%); noncombustibles were usually less than 50 µg/l (Figures 2-21b, c). Near-bottom values were somewhat lower in combustible percentages and higher in noncombustibles (Figures 2-21e, f), but generally showed similar patterns to those seen during the previous month, the notable exception being resuspension noted along the outer shelf both to the north and south of the bank.

Highest concentrations during this month were noted in the near-bottom waters just north of Great South Channel, where noncombustible concentrations exceeded 1,600 µg/l (as compared with values of less than 50 µg/l in surface waters). A similar resuspension of bottom material had been noted on previous cruises.

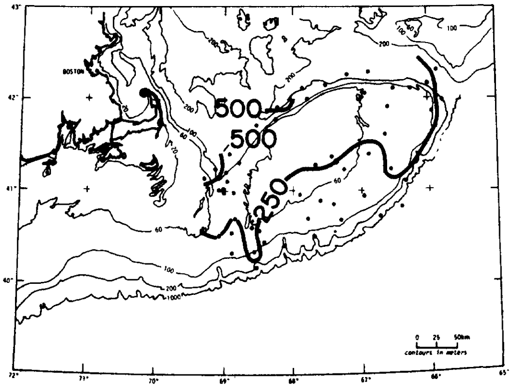
Late November 1977

By late November, winter conditions had returned, as evidenced by the breakdown in the thermocline (Figure 2-23), as well as the lower percentages of combustibles in both surface and near-bottom waters (Figures 2-22b, e). Winter mixing of the waters resulted in relatively high concentrations of noncombustibles in both surface and near-bottom waters on the central part of the bank. Transmissometer profiles indicated increasing turbidity in near-bottom waters on the southeastern flank of Georges Bank between the 60 and 200 m isobaths (Figure 2-24).

Figure 2-21. Areal distribution of suspended particulate matter in surface (left) and near-bottom (right) during September 1977. Top illustrations (a and d) represent distributions of total particulates; middle plots (b and e) percent combustibles; and bottom plots (c and f) noncombustible concentrations.

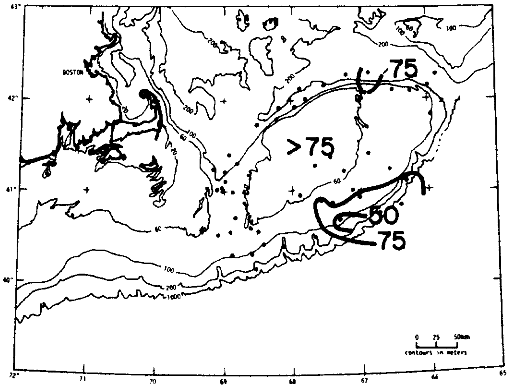
Figure 2-21

a



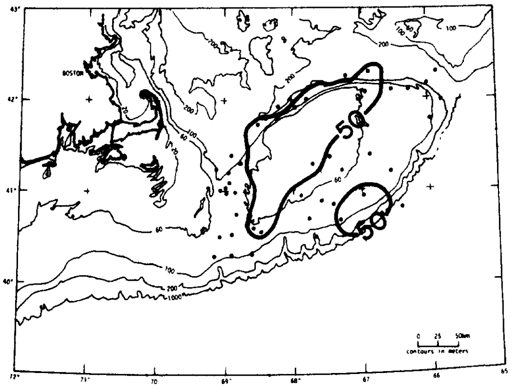
TOTAL PARTICULATES (µg/l)-S
EARLY SEPTEMBER, 1977

b



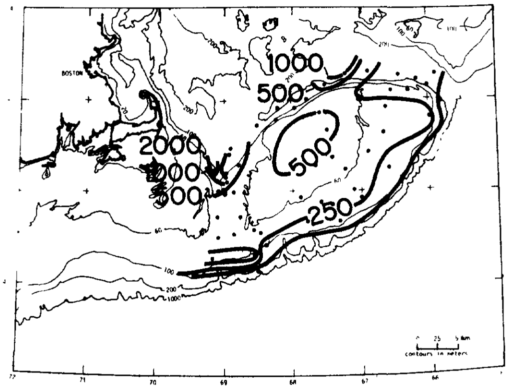
% COMBUSTIBLES-S

c



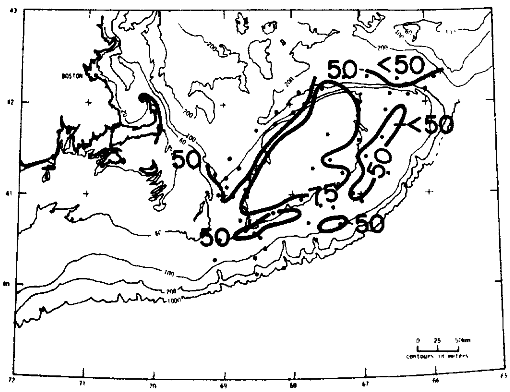
NON-COMBUSTIBLES (µg/l)-S

d



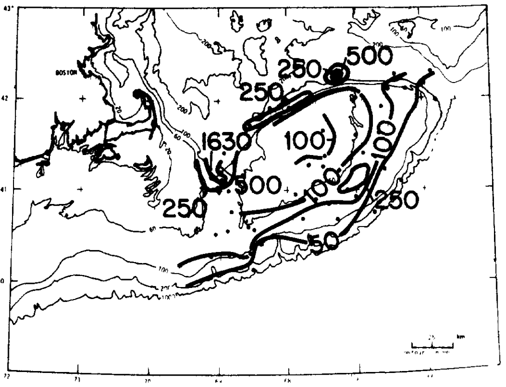
TOTAL PARTICULATES (µg/l)-B

e



% COMBUSTIBLES-B

f

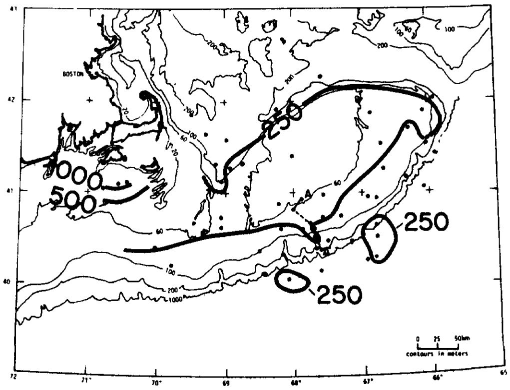


NON-COMBUSTIBLES (µg/l)-B

Figure 2-22. Areal distribution of suspended particulate matter in surface (left) and near-bottom (right) during late November 1977. Top illustrations (a and d) represent distributions of total particulates; middle plots (b and e) percent combustibles; and bottom plots (c and f) noncombustible concentrations. (Transect A-A' indicates position of cross-section shown in Figure 2-23.)

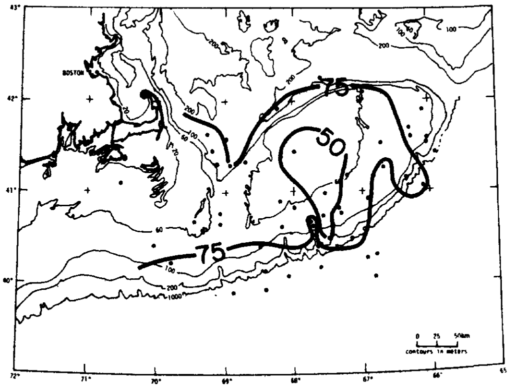
Figure 2-22

a



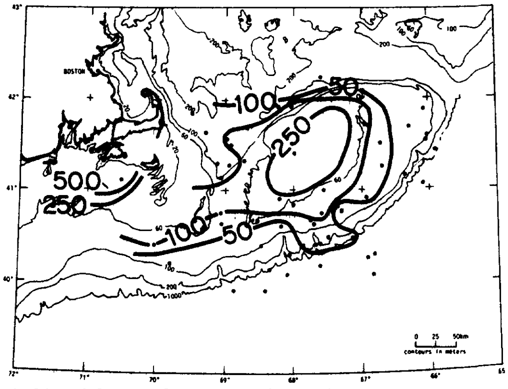
TOTAL PARTICULATES (µg/l)-S
LATE NOVEMBER, 1977

b



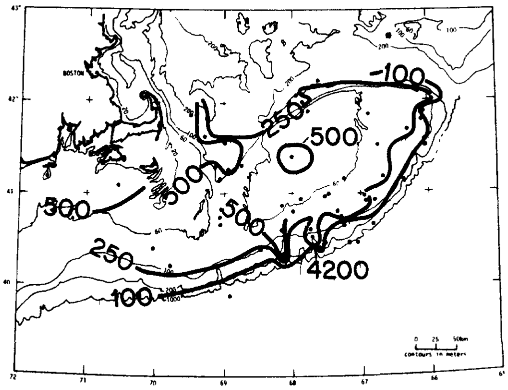
% COMBUSTIBLES-S

c



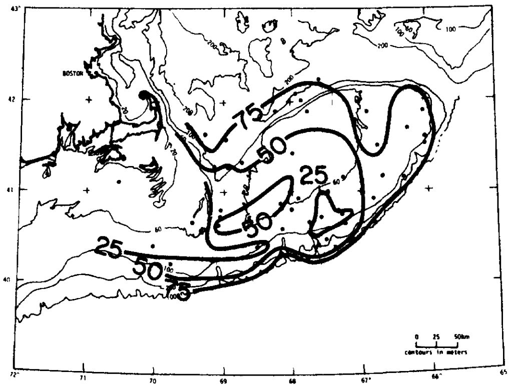
NON-COMBUSTIBLES (µg/l)-S

d



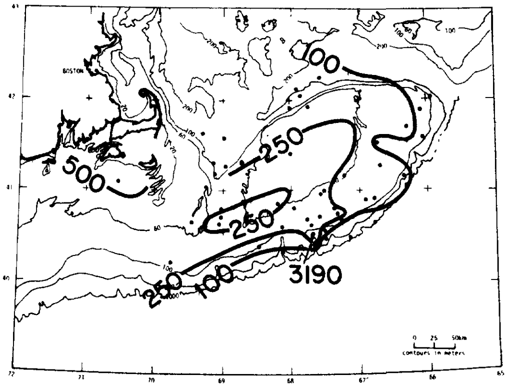
TOTAL PARTICULATES (µg/l)-B

e



% COMBUSTIBLES-B

f



NON-COMBUSTIBLES (µg/l)-B

Figure 2-23. Vertical profile of temperature (a); total particulate (b); and noncombustible (c) concentrations along a transect (Figure 2-22) on Georges Bank.

Figure 2-23

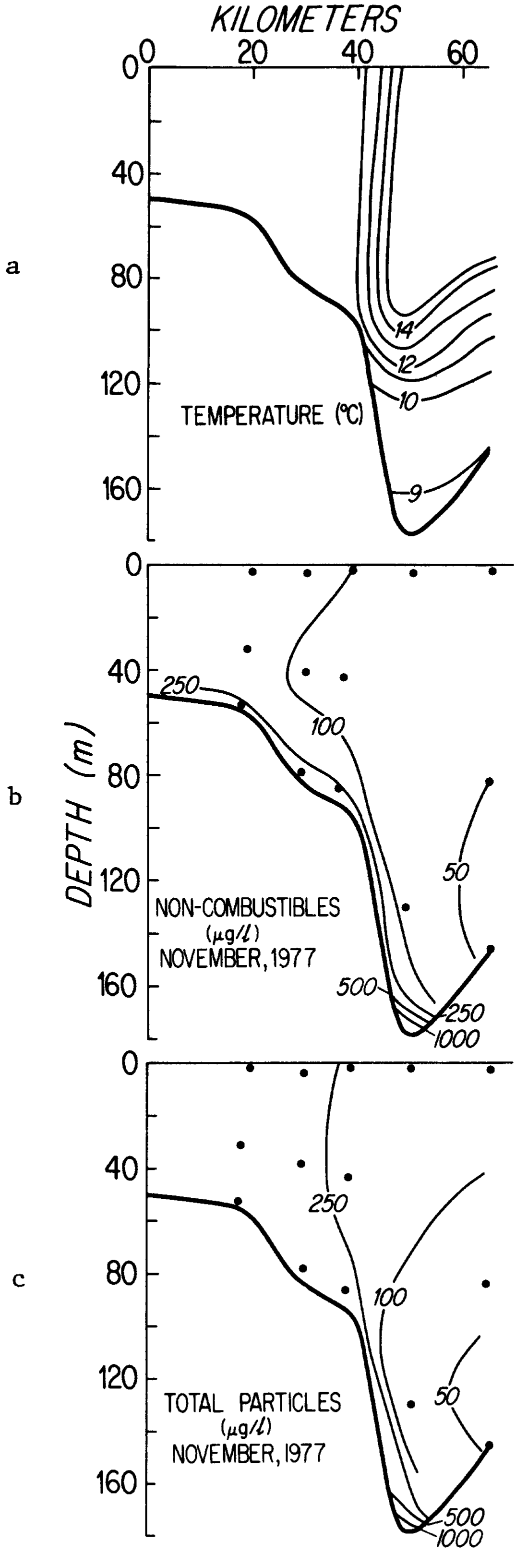
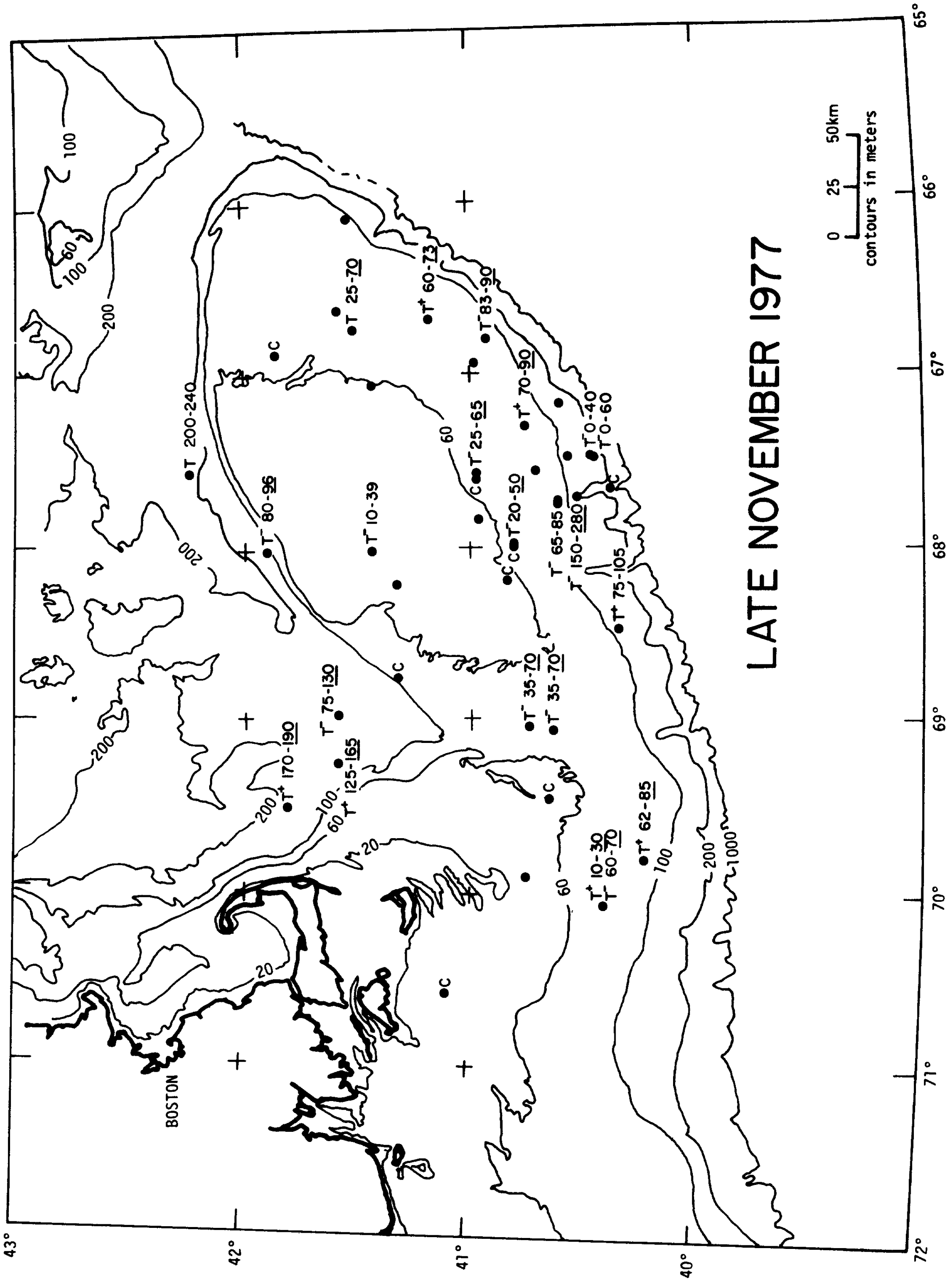

KILOMETERS
0
20
40
60
DEPTH (m)
0
40
80
120
160
a
TEMPERATURE (°C)
14
12
10
9
b
NON-COMBUSTIBLES (µg/ℓ) NOVEMBER, 1977
250
100
50
500
250
1000
c
TOTAL PARTICLES (µg/ℓ) NOVEMBER, 1977
250
100
50
500
1000

Figure 2-24. Turbidity in the water column during November 1977. T indicates a turbidity maximum or increase. T^+ = strong; T^- = weak; C = no maximum or increase. Numbers refer to depth range (m) of turbid layer. A turbidity increase at the bottom indicated by underlined maximum depth.

Figure 2-24


LATE NOVEMBER 1977
0 25 50km
contours in meters
BOSTON
43°
42°
41°
40°
72°
71°
70°
69°
68°
67°
66°
65°
T 200-240
T 80-96
T 10-39
T 25-70
T 60-73
T 83-90
T 25-65
T 20-50
T 70-90
T 0-40
T 0-60
T 65-85
T 150-280
T 75-105
T 35-70
T 35-70
T 75-130
T 170-190
T 125-165
T 62-85
T 10-30
T 60-70
C
100
200
60
20
1000

A profile of light transmission (and light scattering) with total suspended matter concentrations, as seen in Figure 2-25, is typical for the southern Gulf of Maine during all the seasonal cruises. Photomicrographs of suspended matter at 3 depths (Figure 2-26) show the higher proportion of clay-like material in bottom waters resulting from resuspension of bottom sediments.

Samples from the ERCO cruise showed a marked increase in the abundance and areal distribution of coccoliths, coccolithophorids, and diatoms. In addition, mineral fragments were particularly abundant in bottom samples across the south-central flanks of Georges Bank and in shoal areas. Prominent diatom forms were Actinocyclus, Coscinodiscus, and Thalassiothrix; Thalassiosira with Chaetoceros, Pleurosigma, Raphoneis, and Melosira were observed in lesser concentrations. Surface, middle, and bottom samples from stations within the central shoal areas contained diatoms in relatively equal concentrations, in contrast to August when a marked vertical variation in diatom abundance was observed. Coccoliths were widely distributed over the bank in high concentrations. In shoal areas, concentrations of coccoliths, like those of the diatoms were roughly the same from surface to bottom. In deeper waters along the southern flanks and to the northeast, highest concentrations of coccoliths were at bottom and mid-depths; only trace amounts were found at the surface. Tintinnids composed almost entirely of coccoliths also were observed (Figure 2-27).

SUMMARY

Shelf and slope waters off New England show both the highest and lowest seston concentrations off the eastern United States. The highest concentrations (15,000 µg/l) were measured on the shelf south of

Figure 2-25. Profile of suspended matter, light transmission, light scattering (nephels), and temperature at a station in the southern Gulf of Maine, where turbidity increase in near-bottom water was observed during each seasonal cruise. Photomicrographs of the suspended-matter samples are shown in Figure 2-26.

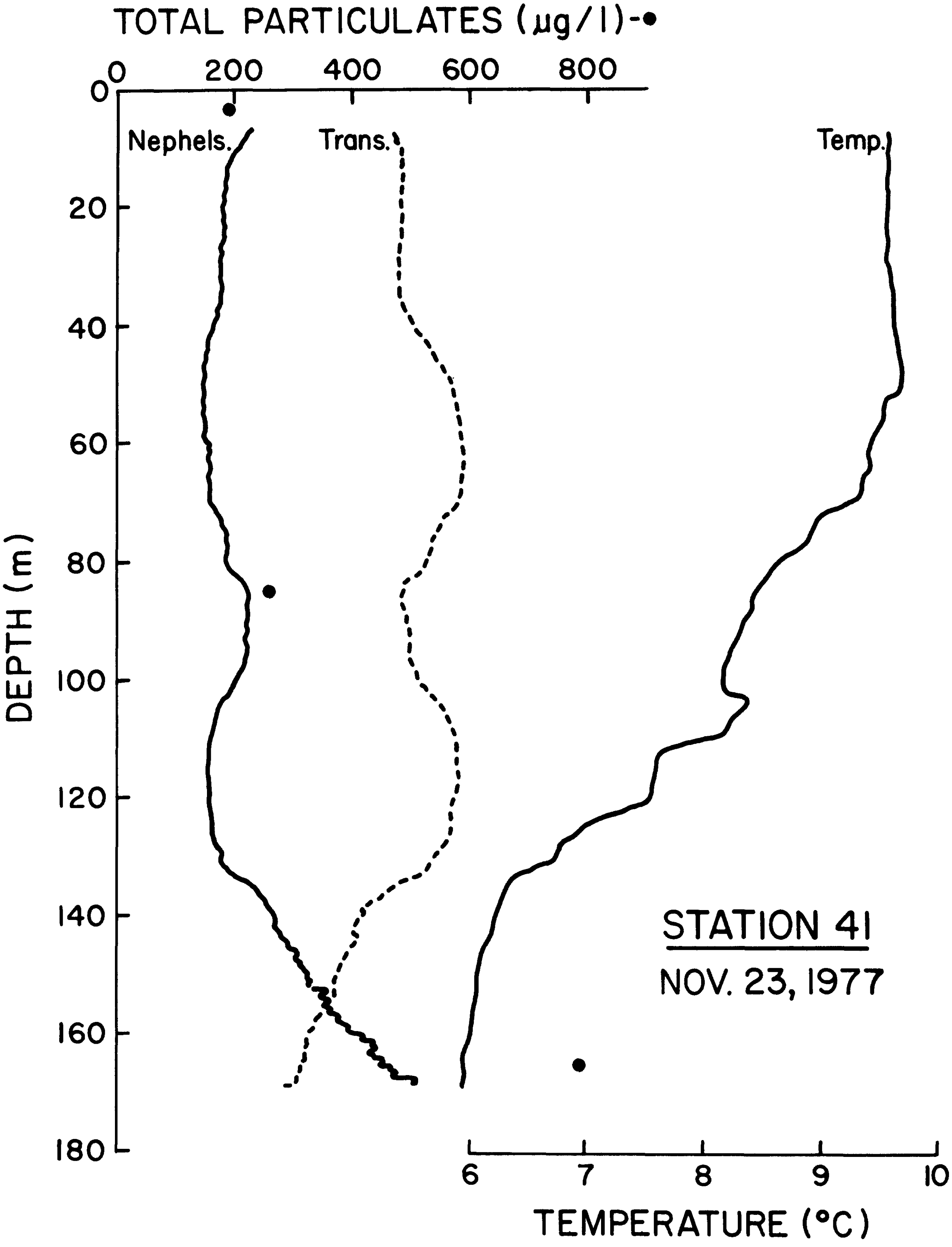

TOTAL PARTICULATES (μg/l)-●
0
200
400
600
800
0
20
40
60
80
100
120
140
160
180
DEPTH (m)
Nephels.
Trans.
Temp.
STATION 41
NOV. 23, 1977
6
7
8
9
10
TEMPERATURE (°C)

Figure 2-26. Scanning electron photomicrograph of suspended-matter samples collected at Station 41, March 23, 1977. Surface and middepth samples (a and b) are largely biogenic material (diatoms, organic fragments, and organic coatings). The bottom-water sample (c) contains relatively much more clay-like material undoubtedly resuspended from bottom sediment.

Figure 2-26

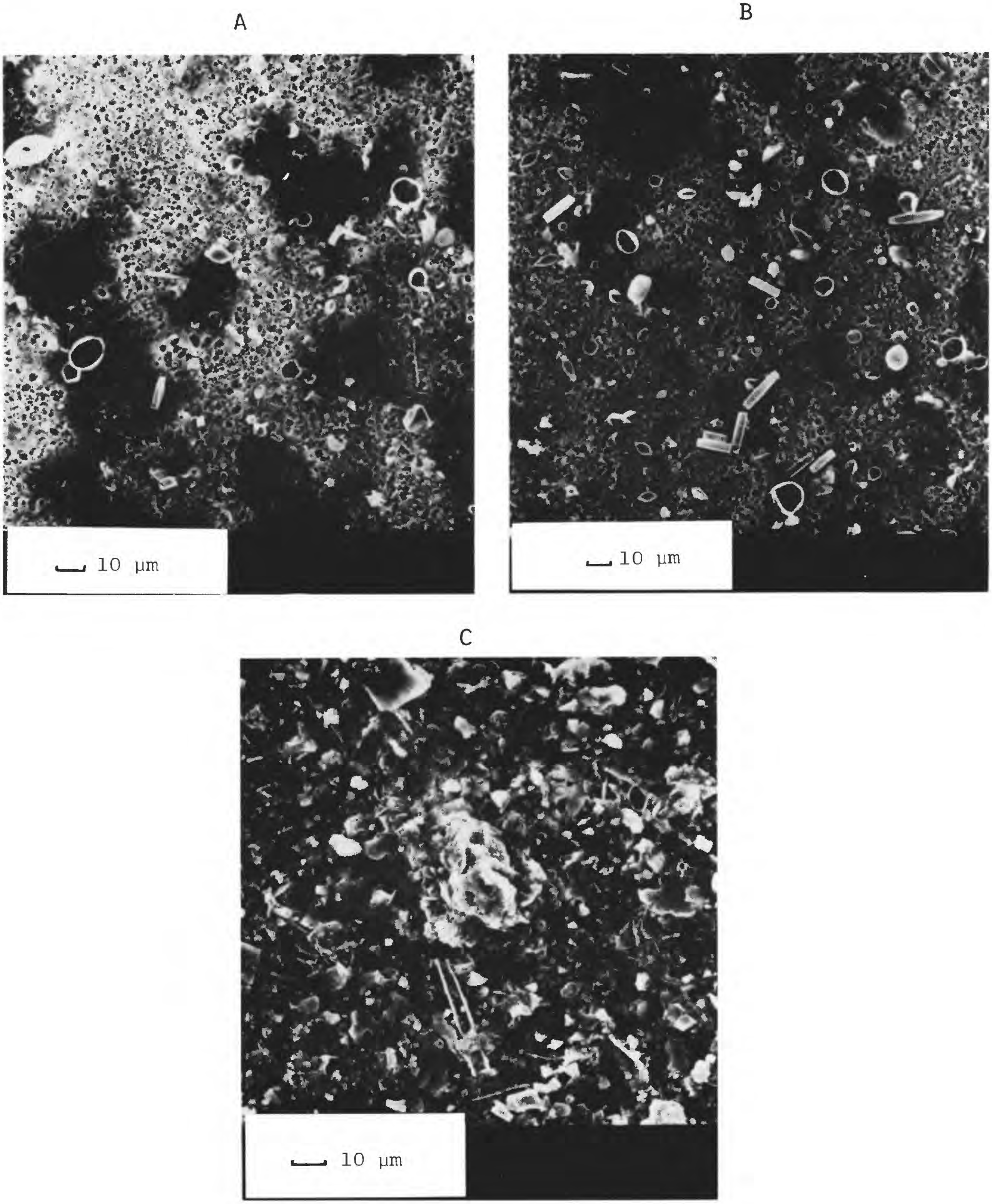
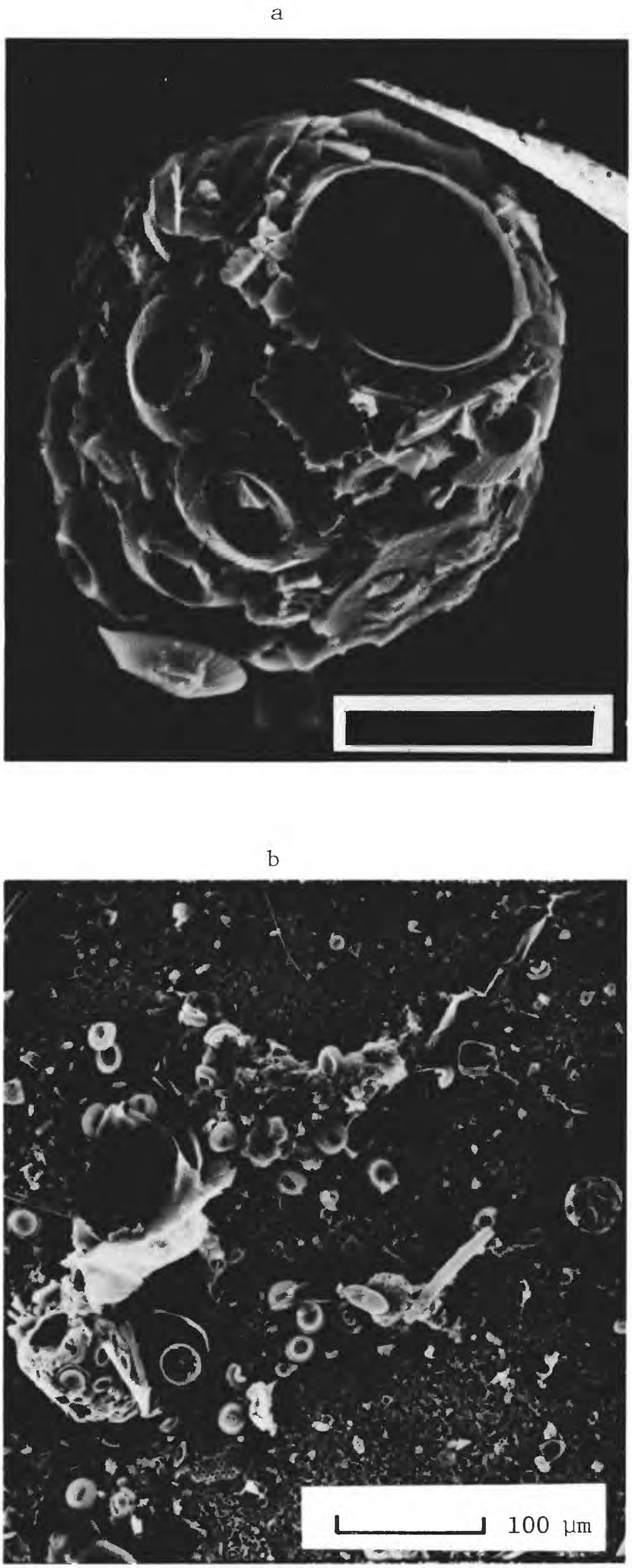


Figure 2-27. a. Tintinnid chambers made up primarily of coccoliths with other fragments such as diatom frustule and clay particles.

b. Coccolithophorid, tintinnid, diatom fragments, and clay particles. Both figures from Station 37, bottom (39 m), November 24, 1977.

Figure 2-27



Nantucket Island during the winter. These concentrations are significant because they exceed the estimated levels of suspended matter (3,000-5,000 µg/l) which may cause crude oil to sink to the bottom. Typically the lowest values of total suspended material were found in slope waters at the shelf edge at concentrations of 50 µg/l.

The sources of suspended matter are predominantly from biological production and to a lesser extent from resuspension of bottom sediment. The relative importance of these two sources varies with seasonal changes in the biological cycle and stability of the water column as well as with major storms which can have an overriding influence during any season. In comparison, rivers and atmospheric inputs are minimal, as neither of these sources is apparent from the distribution or composition of suspended matter.

An increase in lithogenic material in surface waters was observed during winter as a result of the decrease in stability and consequent increase in mixing. We also observed a seasonal change in the amount and composition of phytoplankton. Coccoliths decreased gradually from winter to summer on Georges Bank and were replaced by diatoms. Zones of high coccolith concentrations seemed to migrate southward off the bank and reside in greater depths in the water column during warmer months.

Two areas of continuously active sediment resuspension were observed in this study: one area in the southwest part of the Gulf of Maine north of Great South Channel and the second south of Nantucket Island. Resuspension was also observed with the transmissometer and with suspended-matter samples on the southeast flank of Georges Bank.

The area north of Great South Channel was not sampled in great detail on all cruises, but stations having high bottom-water concentrations and relatively high turbidity were consistently observed.

The influence of flow through Great South Channel in maintaining or transporting these high suspended-matter concentrations is not known.

The area south and west of Nantucket Island at water depths greater than 60 m is covered with silty clay sediments as much as 6 m thick (Schlee, 1973). This area is characterized by increased turbidity in the near-bottom water and high concentrations of noncombustible particulates. Whether the mud patch is a sediment source (Schlee, 1973) or a sediment sink is in question. Preliminary Pb^{210} and C^{14} age data obtained by one of us (MHB) suggest that the mud patch is a present-day sink for sediments. If this hypothesis is confirmed by more detailed studies presently underway, then this area of anomalous fine-grained sediments takes on new significance because it would represent a major depositional site for sediments and sediment-related pollutants introduced by offshore development activity. A modern age for the mud patch also raises some interesting questions about the source and transport routes of sediments contributing to this feature. New England rivers at present add little sediment to the marine environment (Meade _et al_., 1975). A more likely source is the large area of Georges Bank and Nantucket Shoals northeast of the mud patch. Although typically covered with sand, finer grained sediments present in low concentrations may be winnowed from these areas, especially during storms, and transported with the net southwestward drift to the area south of Nantucket.

LITERATURE CITED

Gardner, W.D. 1977. Incomplete extraction of rapidly settling particles from water samples: Limnol. Oceanogr. vol. 22, pp. 764-768.

Kolpack, R.L. 1971. Chapter 10, Summary _in_ Kolpack, R.L., ed., Biological and oceanographical survey of the Santa Barbara Channel oil spill 1969-1970: Physical, chemical and geological studies, Allan Hancock Foundation, Univ. of Southern California, vol. 2, 477 p.

Manheim, F.T., R.H. Meade, and G.C. Bond. 1970. Suspended matter in surface waters of the Atlantic continental margin from Cape Cod to the Florida Keys: Science 167:371-376.

Meade, R.H., P.L. Sachs, F.T. Manheim, J.C. Hathaway, and D.W. Spencer, 1975. Sources of suspended matter in waters of the Middle Atlantic Bight: Jour. Sed. Petrol., 45, 171-188.

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

CHAPTER 3

TEXTURE, CLAY MINERALOGY, TRACE METALS, AND AGE OF CORED SEDIMENTS FROM THE NORTH ATLANTIC OUTER CONTINENTAL SHELF

Michael H. Bothner, Elliot C. Spiker, Wayne M. Ferrebee, and Douglas L. Peeler

CHAPTER 3

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TEXTURE, CLAY MINERALOGY, TRACE METALS, AND AGE OF CORED SEDIMENTS FROM THE NORTH ATLANTIC OUTER CONTINENTAL SHELF

Michael H. Bothner, Elliot C. Spiker, Wayne M. Ferrebee,
and Douglas L. Peeler

INTRODUCTION

The purpose of this study was to determine the natural variability in texture, clay mineralogy, and trace metals in sediment cores from the Georges Bank area which may be the site of future offshore resource exploration and development. Radiocarbon analyses of the sediment were used to determine the age of specific horizons in these sediments and to determine the rates of sediment accumulation.

An understanding of the natural variability of trace-metal concentrations in sediment cores is important in assessing the impact of new trace-metal additions which may result from offshore development activities. Identification of areas of net sediment accumulation as well as areas of nondeposition are important in predicting where new pollutants associated with sediment may be deposited.

METHODS

Sampling

Sediment cores for this study were collected in September 1975 aboard the R/V FAY with a vibracoring apparatus and with a hydraulically damped gravity corer. Station locations are indicated in Figure 3-1. The vibracorer utilized a pneumatic hammer to drive the core barrel as much as 6 m into the sediment. This penetration was achieved at the expense of disturbing the surficial sediment in some cases. The hydraulically damped gravity corer was used to collect short cores (up

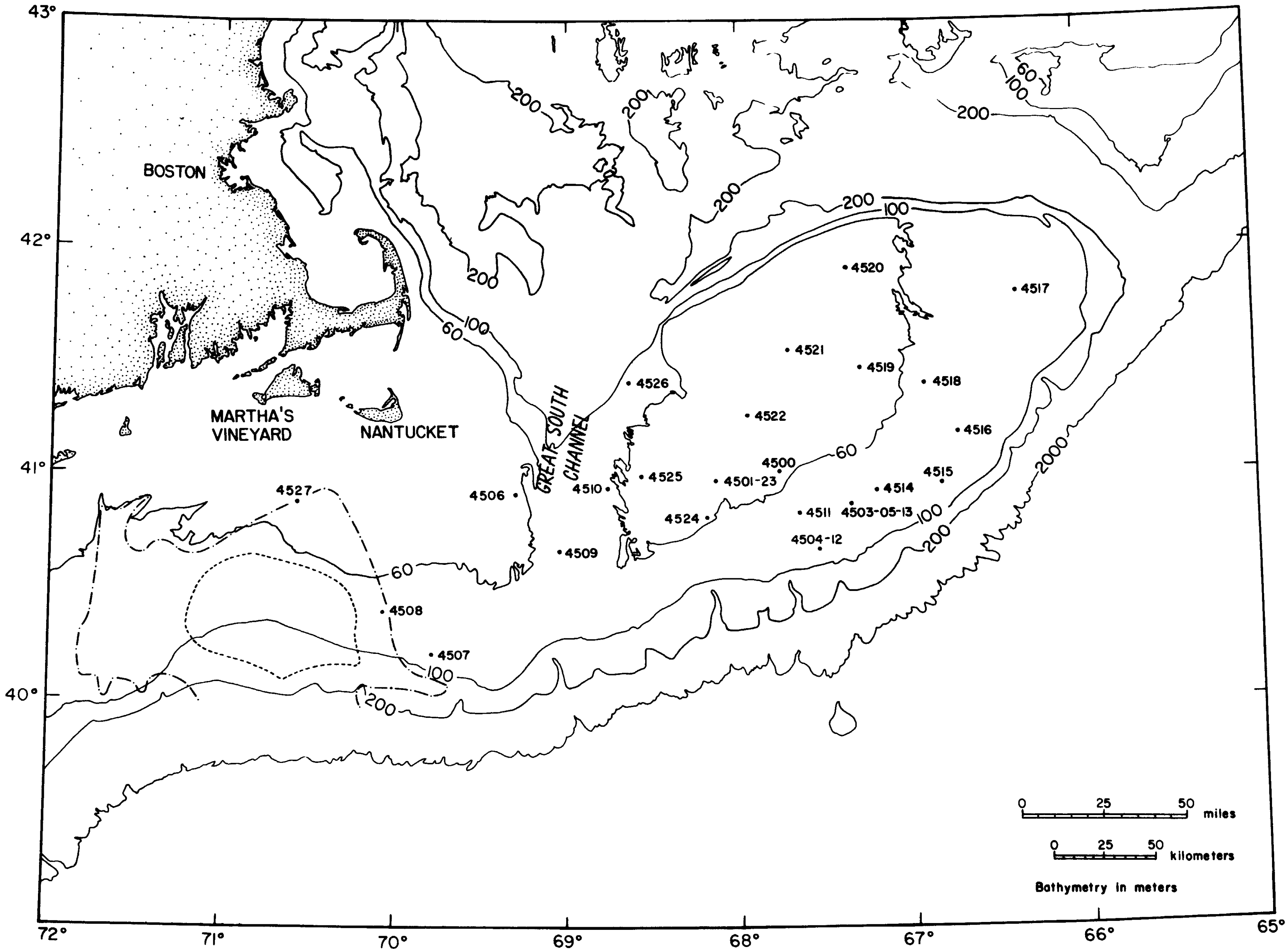

Figure 3-1. Station locations for vibracores and hydraulically damped gravity cores collected in September 1975. Dashed contours south of Martha's Vineyard outline area of anomalously fine-grained sediment (Schlee, 1973): —•—• muddy sand; ---silt.

to 70 cm) with minimum disturbance of material at the water-sediment interface. Collection of the undisturbed surficial sediment is important because recently added trace metals or other contaminants tend to be concentrated at the water-sediment interface.

Vibracore samples were collected in plastic core liners which were cut into 150 cm sections aboard ship and stored at 3°C until analysis. After the cruise, in the USGS laboratory at Woods Hole, the cores were split, described, and subsampled for sediment texture and trace metals on the basis of textural changes. Hydraulically damped gravity cores were frozen in an upright position immediately after collection. In the laboratory, the samples were extruded from the fiberglass core barrels, allowed to thaw, and subsampled for trace-metal and textural analysis. Samples for radiocarbon analyses were selected from depth intervals in vibracores which had sufficient organic carbon or shell material for dating. Because of the larger sample volumes required, radiocarbon samples could not be obtained from hydraulically damped gravity cores.

Textural Analyses

Textural analyses were performed on sediments after larger shell fragments (>3 mm) had been removed. Conventional techniques used included sieving, settling tube (Schlee, 1966), and pipetting. Because of the smaller size of the hydraulically damped gravity core samples, the settling tube could not be used to resolve the sand fraction and results are limited to percent gravel, sand, silt, and clay.

Clay Mineralogy

An aliquot of the clay size fraction was separated during the size analysis procedure and filtered with suction onto a silver filter. Filter samples were analyzed by X-ray diffraction after exposure to ethylene glycol, and again after heating to 400°C and 550°C (Hathaway, 1972). Clay mineral percentages were determined semiquantitatively on the basis of X-ray diffraction intensities with the relationships similar to those derived by Biscaye (1965).

Trace Metals

At least 5 samples from each of 10 vibracores and 10 hydraulically damped gravity cores were analyzed for trace metals. All samples were analyzed for the trace metals zinc, copper, and chromium with a partial leach technique. Samples from 2 cores (10 samples) were completely dissolved and analyzed for barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), vanadium (V), and zinc (Zn).

The partial leaching technique involves weighing out a 2 gram sample into an acid-washed beaker containing 15 ml of 5N HNO_3. The covered beakers were swirled for 2 hours at room temperature and the solution was then filtered through a Nuclepore filter (0.4 mm pore diameter) held in an all-glass filter assembly. The solution was then diluted to 50 ml and transferred to polypropylene bottles which had been pre-leached with 5N HNO_3 at 60^oC for 12 hours. The concentrations of Cr, Cu, and Zn were determined by flame atomic absorption. Machine settings, conditions used, and detection and sensitivity limits for this method are given in Appendix 3, Tables 3-1 and 3-2.

The 10 samples analyzed for all 9 trace metals were ground in an agate disk mill until small aliquots would pass a 100 mesh sieve. The samples were then sent to laboratories at the USGS where they were analyzed for trace metals after complete sample dissolution under the direction of Frederick O. Simon.

The complete dissolution technique required heating approximately 1 gram samples on a hot plate at 150^oC for 16 hours (overnight) with 5 ml

$HClO_4$ (perchloric acid), 5 ml HNO_3, and 15 ml HF in covered teflon beakers. Then, the beakers were uncovered and solutions were evaporated to dryness. The salts were dissolved in HCl and diluted to 100 ml (final HCl conc ∿ 1N). The resulting solutions were analyzed for all 9 trace metals by flame or flameless atomic absorption. Instrumental methods and sensitivities are reported in Appendix 3, Tables 3-1 and 3-2.

Precision and accuracy for the partial leach method was determined by analyzing 5 aliquots of the original sample; the USGS standard rocks G2 and MAG 1; and NBS standard plastic clay and bovine liver. The results, Appendix 3, Table 3-3, indicate precision better than 10% except for Cu in the replicate samples where 1 data point degrades the precision from 11 to 21%. The accuracy of the partial leach method cannot be evaluated until standard materials are analyzed by other investigators using the same technique. Although trace-metal analyses following a weak acid leach were performed on surface sediments from this general area by the Energy Resources Co. (S. Piotrowicz, unpublished data), this technique utilized acetic acid instead of nitric acid and thus is not directly comparable. The analytical precision for the complete dissolution technique was determined on surface sediments from the mid-Atlantic Continental Shelf having similar texture and mineralogy as that on Georges Bank (Bothner, 1979). The results of analyzing 5 aliquots from each of two samples are given in Appendix 3, Table 3-4. Calculated coefficients of variation are generally less than 10% except for those elements present at concentrations near the detection limit of the technique (Cd and Cu).

Accuracy was determined by the analysis of a number of USGS standard rocks in the same analytical run with samples. The mean values reported in Appendix 3, Table 3-5 are within two standard deviations of published recommended values (Flanagan, 1973) for GSP-1, AGV-1, and G2 with the exception of nickel which is somewhat lower. The nickel values obtained for these rocks, however, and all elements listed for BCR-1 are within the range of values determined by other investigators (Flanagan, 1969). With regard to the marine mud standard (MAG-1), the values reported by Manheim et al. (1976) are within 2 standard deviations of the values reported in Appendix 3, Table 3-5.

Carbon Analysis

Organic carbon concentrations were determined on a Leco carbon analyzer in which acid-leached samples ($CaCO_3$ removed) are combusted and the volume of the released CO_2 is measured.

Determination of sediment age by the radiocarbon method was carried out at the USGS in Reston, Virginia. The technique is based on the collection of CO_2 from the sample following complete combustion, conversion to C_2H_2, and counting the beta emission of ^{14}C (Suess, 1954). Activity is compared to the activity of oxalic acid standard.

RESULTS AND DISCUSSION

Texture

Sand is the most prominent size class of sediments at all depths in cores collected from the Georges Bank area, with the exception of a few samples from cores south of Cape Cod where silt is predominant (Figure 3-2, Appendix 3, Table 3-4). Gravel is common on the Bank, reaching as much as 35% of the total sediment in some core horizons. Gravel was absent from the three most westerly stations south of Cape Cod.

The textural distribution with depth in cores is very similar to the surface texture reported at the same locations by Schlee (1973), and

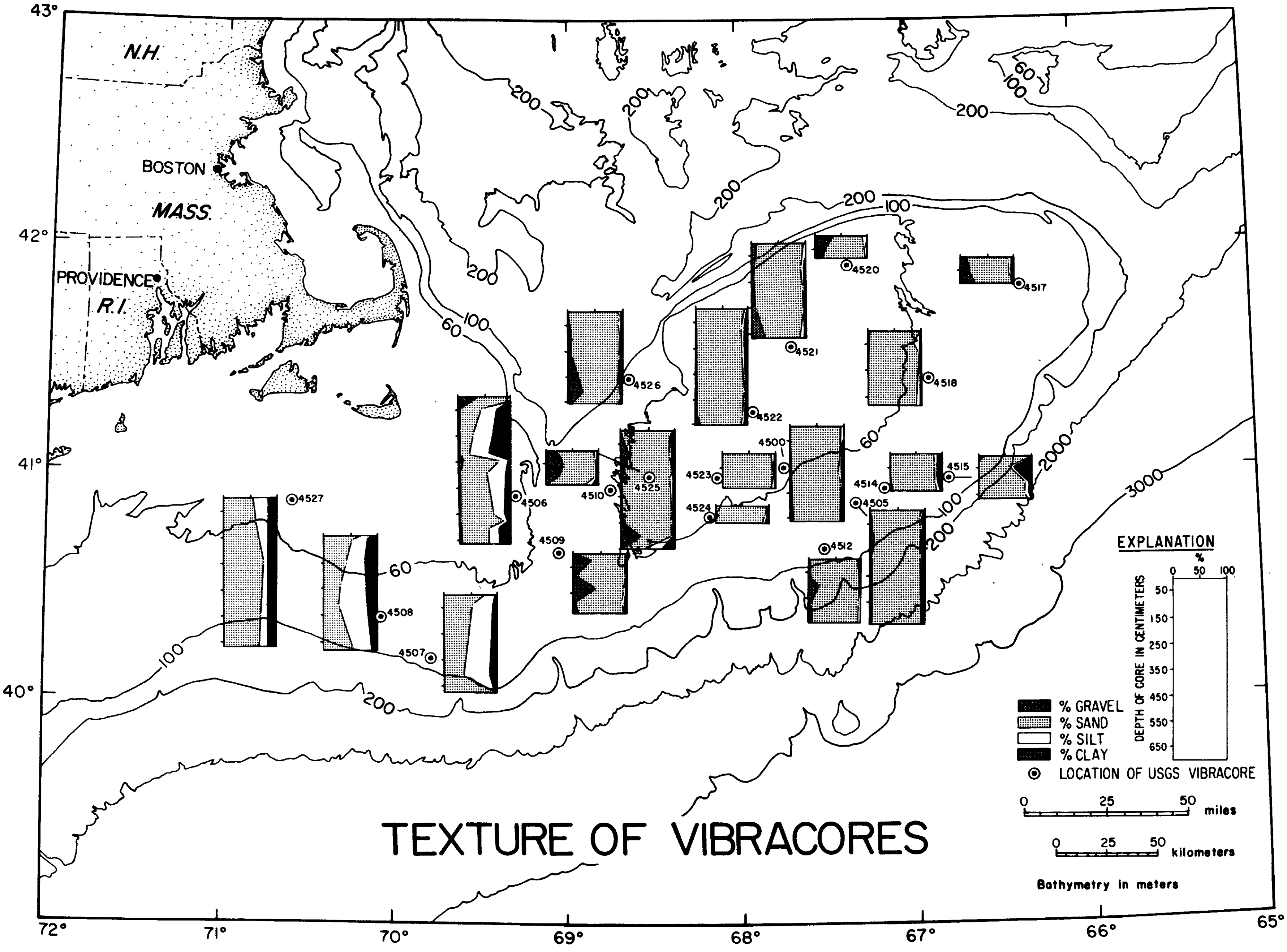

Figure 3-2. Texture of vibracores collected on Georges Bank September 1975.

Piotrowicz (1978). There is some variability with depth in the vibracores. The shorter hydraulically damped gravity cores show much less variability in texture (Appendix 3, Table 3-7), which may reflect the efficiency of sediment mixing by organisms and currents over the core length.

As expected, these coarse-grained sediments are low in organic carbon and, except for areas containing concentrated shell hash, are low in carbonate carbon (Appendix 3, Table 3-8). In 33 samples, the mean organic carbon content was 0.08 ± 0.05% (one standard deviation).

Core 4506, west of Great South Channel, contained till-like sediments throughout its 6 m length (Figure 3-2). The sediments were characterized by about 5% (average) gravel and by generally more than 20% each of the sand, silt, and clay size classes. In addition, visual and bulk X-ray examination of the core revealed the frequent occurrence of angular cobbles more than 10 mm in diameter. This sample is located on the estimated position of the ice front at maximum glacial advance as inferred from texture of surface sediments (Schlee and Pratt, 1970).

The radiocarbon dates on organic matter in this core range from 20,000 years at 135 cm to 35,340 years at 560 cm. This suggests that deposition of this till-like material took place during the Late Wisconsin.

Clay Mineralogy

The results of semiquantitative analyses of the major clay mineral groups indicates that illite is predominant, with moderate amounts of chlorite and small concentrations of kaolinite (Appendix 3, Table 3-9). Montmorillonite is present only as a trace or is absent. There appears to be no consistent difference with depth within the hydraulically damped cores or vibracores with respect to the clay mineral assemblage.

There is low variability in the clay mineral assemblage with depth in these samples, indicated by the small standard deviation for illite among all samples (mean 59% ± 6%).

These samples from Georges Bank fall in an area not well covered in an earlier study of the clay mineralogy on the Atlantic Continental Margin (Hathaway, 1972). The additional information provided by samples from the sandy areas of the Bank confirms that the clay mineral assemblage observed by Hathaway on the upper slope and in the Gulf of Maine extends across the shelf. The new data are consistent with the concept that illite and chlorite are indicative of largely unweathered material that was eroded from Paleozoic and older rocks from the northern Appalachian region and transported to the Continental Shelf during glacial periods (Hathaway, 1972).

Trace Metals

The low concentrations of leachable Cr, Cu, and Zn (Table 3-1) are characteristic of an area having uncontaminated coarse-grained sediments. Similarly, the concentrations of the nine metals analyzed following complete decomposition are also low (Table 3-2a). All the values obtained in this study are lower than average crustal abundances (Table 3-2b).

A comparison was made of the metal concentrations obtained by the partial leach and total decomposition method. The nitric acid leach removes an average of 21% ± 2% (one standard deviation) of the total zinc, and 27% ± 16% of the total chromium. Copper levels were below detection limits in most cases but one sample indicated that less than 15% of the total copper was leachable with the nitric acid technique.

Variations in trace-metal concentrations with depth in near-surface sediments were examined for evidence of anthropogenic increases.

Table 3-1. Trace metals in sediment cores from Georges Bank: partial leach technique.

				ppm		
Sample	Latitude	Longitude	Sediment Depth (cm)	Dry Weight Cr	Dry Weight Cu	Dry Weight Zn
4500B	41°01.3'N	67°44.3'W	50	1.4	< .3	< .2
			84	1.9	< .3	.5
			175	1.4	< .3	.5
			366	1.4	< .3	< .2
4501H	41°00.1'N	68°09.2'W	0 - 1	1.4	< .3	.4
			5	1.4	< .3	.3
			9	1.4	< .3	< .2
			13	1.4	< .3	< .2
			17	1.4	< .3	< .2
4503D	40°50.0'N	67°25.1'W	0 - .5	1.4	< .3	2.2
			5	1.4	< .3	1.5
			10	1.4	0.8	1.5
			20	1.9	< .3	1.6
			30	4.8	< .3	2.3
4505C	40°51.8'N	67°23.6'W	26	2.4	0.8	2.1
			66	2.4	< .3	1.6
			81	1.4	< .3	.4
			180	.9	< .3	< .2
			277	1.0	< .3	< .2
4506D	40°54.1'N	69°17.7'W	18	1.9	--	4.7
			47	3.3	5.6	11.2
			142	2.9	6.2	12.2
			246	1.9	1.7	3.9
			290	1.9	3.0	6.2
			451	1.9	3.0	6.7
4507E	40°11.3'N	69°47.2'W	0 - 1	2.9	1.2	7.4
			4.5	3.3	1.0	8.7
			9	2.9	1.2	7.3
			13.5	3.8	1.7	9.5
			18	3.8	1.2	6.6
4508A	40°21.9'N	70°03.6'W	0.5 - 1	4.5	1.7	8.7
			7	4.8	1.7	8.8
			12	4.8	1.7	8.3
			17.5	4.8	1.7	7.3
			23	4.8	1.7	8.0
4508B	40°21.9'N	70°03.5'W	9	3.8	1.4	7.7
Subsample #1			110	5.9	1.7	9.3
Subsample #2			110	5.7	1.7	9.2
Subsample #3			110	5.7	1.9	8.9
Subsample #4			110	5.7	2.7	9.0
Subsample #5			110	5.7	2.1	8.7

Table 3-1. Trace metals in sediment cores from Georges Bank: partial leach technique (continued).

				ppm		
Sample	Latitude	Longitude	Sediment Depth (cm)	Dry Weight Cru	Dry Weight Cu	Dry Weight Zn
4508B	40°21.9'N	70°03.5'W	184	5.2	2.7	10.6
			271	5.5	3.2	10.7
			428	4.3	1.9	6.9
4509C	40°39.6'N	69°02.8'W	25	1.4	< .3	0.8
			83	1.4	< .3	1.6
			136	1.4	0.8	1.1
			187	1.4	< .3	0.4
			229	1.4	< .3	0.3
4509F	40°39.6'N	69°02.8'W	0 - 5	1.4	< .3	2.2
			3.5	1.4	< .3	1.4
			7	1.4	< .3	1.2
			11	1.4	< .3	1.1
			18	1.4	< .3	1.1
4510A-2	40°55.3'N	68°44.5'W	14	1.4	< .3	< .2
			148	1.4	< .3	< .2
			254	1.4	< .3	0.4
			347	1.4	< .3	0.3
			406	1.4	< .3	< .2
			409	1.4	< .3	0.5
			457	2.9	4.2	10.1
4512C	40°38.9'N	67°31.7'W	7 - 10	1.4	< .3	.5
			72 - 75	1.2	< .3	< .2
			100	1.4	< .3	< .2
			170	1.0	< .3	< .2
			245	1.4	< .3	< .2
4516B	41°11.2'N	66°42.8'W	0 - .5	1.4	< .3	0.7
			2.5	1.4	< .3	0.3
			5	1.0	< .3	0.7
			7.5	1.0	< .3	0.6
			9.5	< .9	< .3	0.3
4518A	41°23.7'N	66°53.9'W	9	1.4	< .3	0.5
			34	1.0	< .3	< .2
			80	1.0	< .3	< .2
			139	1.0	< .3	< .2
			282	1.4	< .3	< .2

Table 3-1. Trace metals in sediment cores from Georges Bank: partial leach technique (continued).

				ppm		
Sample	Latitude	Longitude	Sediment Depth (cm)	Dry Weight Cr	Dry Weight Cu	Dry Weight Zn
4521B	41°32.6'N	67°40.3'W	0 - 1	1.4	< .3	< .2
			5	1.4	< .3	0.3
			10	1.0	< .3	0.4
			15	1.0	< .3	< .2
			20	1.0	< .3	< .2
			25	1.0	< .3	< .2
4522D	41°15.6'N	67°56.7'W	0 - .5	1.0	< .3	< .2
			3.5	1.4	< .3	< .2
			6.5	1.4	< .3	< .2
			10	1.4	< .3	0.3
			14	1.4	< .3	< .2
4524C	40°47.9'N	68°11.1'W	0.5 - 1	1.4	< .3	0.4
			3	1.9	< .3	0.3
			6	1.4	< .3	< .2
			9	1.4	< .3	< .2
			12	1.4	< .3	< .2
4525C	40°59.5'N	68°32.1'W	3	1.4	< .3	.5
			15	1.0	< .3	.4
			55	1.0	< .3	0.4
			97	1.9	0.8	1.6
			123	1.9	1.0	4.7
4526B	41°24.5'N	68°37.8'W	1	2.4	< .3	3.8
			7	2.5	< .3	3.7
			14	2.9	< .3	2.6
			21	2.4	< .3	2.3
			28	2.9	< .3	2.3
4526E	41°24.5'N	68°37.7'W	98	1.9	0.8	5.6
			170	1.4	< .3	2.4
			260	< .9	< .3	2.9
			309	1.4	< .3	1.6
			354	1.4	1.7	7.2

Table 3-2a. Trace metals in sediment cores from Georges Bank: complete dissolution technique.

Station	Sediment Depth (cm)	ppm Ba	Cd	Cr	Cu	Fe*	Ni	Pb	V	Zn
4503D	0 - .5	100	<.1	18	< 2	5.2	2	9	17	9
	5	<100	<.1	18	< 2	5.0	< 2	8	14	8
	10	<100	<.1	16	< 2	4.5	< 2	7	11	7
	20	120	<.1	15	< 2	6.3	2	6	18	9
	30	140	<.1	16	2	8.6	4	8	22	12
4512C	7 - 10	<100	<.1	3	< 2	1.4	< 2	3	2	2
	72 - 75	<100	<.1	3	< 2	1.1	< 2	2	2	< 2
	102	<100	<.1	4	< 2	1.1	< 2	2	3	2
	170	<100	<.1	3	< 2	1.1	< 2	2	2	< 2
	247	<100	<.1	3	< 2	1.1	< 2	2	2	< 2
Total No. of Measurements		10	10	10	10	10	10	10	10	10
Range		<100-140	<.1	3-18	< 2	1.1-8.6	<2-4	2-9	2-22	<2-12
Median		<100	<.1	9.5	< 2	2.95	< 2	4.5	7	4.5

Table 3-2b. Average abundance (ppm) of element in the earth's crust (Krauskopf 1967).

Ba	Cd	Cr	Cu	Fe*	Ni	Pb	V	Zn
425	0.2	100	55	5.7	75	13	135	70

---

*Multiply by 10^4

Hydraulically damped gravity cores undoubtedly give the most accurate trends in near-surface sediments because these samples are collected with minimum disturbance. Of the 10 hydraulically damped gravity cores analyzed, 4 showed higher concentrations of Zn and 2 showed higher concentrations of Cr in the surface 1 cm than at greater depth in the core, but the magnitude of increase was less than a factor of 2. Although the upper surfaces (seafloor) of the vibracores are probably disturbed, samples of the tops of 4 out of 10 vibracores show an increase in Zn of a similar magnitude.

In the remaining cores, the surface concentrations are similar to or lower than values measured at greater depth in the cores. Cr and Cu show similar trends although with much less resolution because concentrations are near or below the limit of detection. The two cores analyzed after total decomposition showed no metal enrichments in the surface sediments. The few cases in which surface sediments show higher concentrations of Zn do not provide evidence for recent accumulation of anthropogenic metals in Georges Bank sediments. Textural data for cores showing this increase indicate that the surface sediments also contain a higher percentage of fine-grained sediments (silt and clay) than found deeper in the core. The correlation coefficients (Table 3-3) suggest that much of the variability in trace metals is due to natural variations in grain size and organic carbon content. The highest values of Cr, Cu, and Zn are found in fine-grained sediments 142 cm deep at station 4506D in sediments having a ^{14}C age of 20,000 years. This lends strong support to the conclusion that the observed increases in metal content in some surface sediments are natural rather than man-induced.

Table 3-3. Correlation coefficients (r^2).

	Mud	Organic C
Zn*	0.81	0.607
Cr*	0.62	0.51
Cu*	0.54	0.46
Mud**		0.43

*Partial leach technique

**Silt plus clay

Radiocarbon

Radiocarbon dating was carried out on 25 subsamples from the vibracores. Samples of sufficient size to permit determinations of organic carbon were taken where possible, although individual shells or shell hash were also analyzed.

Perhaps the most significant finding from the radiocarbon data is that sediments may be actively accumulating in the area of anomalously fine-grained sediment south of Nantucket and Martha's Vineyard (see Figure 3-3). This contrasts with a number of previous studies (Schlee, 1973) which have concluded that this "mud patch" is a relict deposit.

Cores 4507C and 4508B east of the "mud patch" center (Figure 3-3) have ages of less than 2,000 years in the surface interval (Table 3-4). This age is somewhat old because it represents the average over the long depth interval required for sufficient datable material. However, surface values are typically nonzero in marine sediments due to biological mixing, the incorporation of detrital old carbon, and slow exchange between atmospheric and oceanic ^{14}C. Nozaki et al. (1977) measured 2,400 years for the surface few cm on the Mid-Atlantic Ridge and Erlenkeuser et al. (1974) reported an age of 850 years for surficial Black Sea sediments.

Interval accumulation rates calculated for core 4508 vary between 43 and 78 cm/1,000 years and average 58 cm/1,000 years. Somewhat slower rates (29-48 cm/1,000 years average 36 cm/1,000 years) were found for core 4507, which is farther east of the "mud patch" center. The fact that these rates are relatively fast and constant within a factor of 2 suggests that these sediments have been continuously accumulating since the last sea level transgression about 10,000 years ago (Milliman and Emery, 1968).

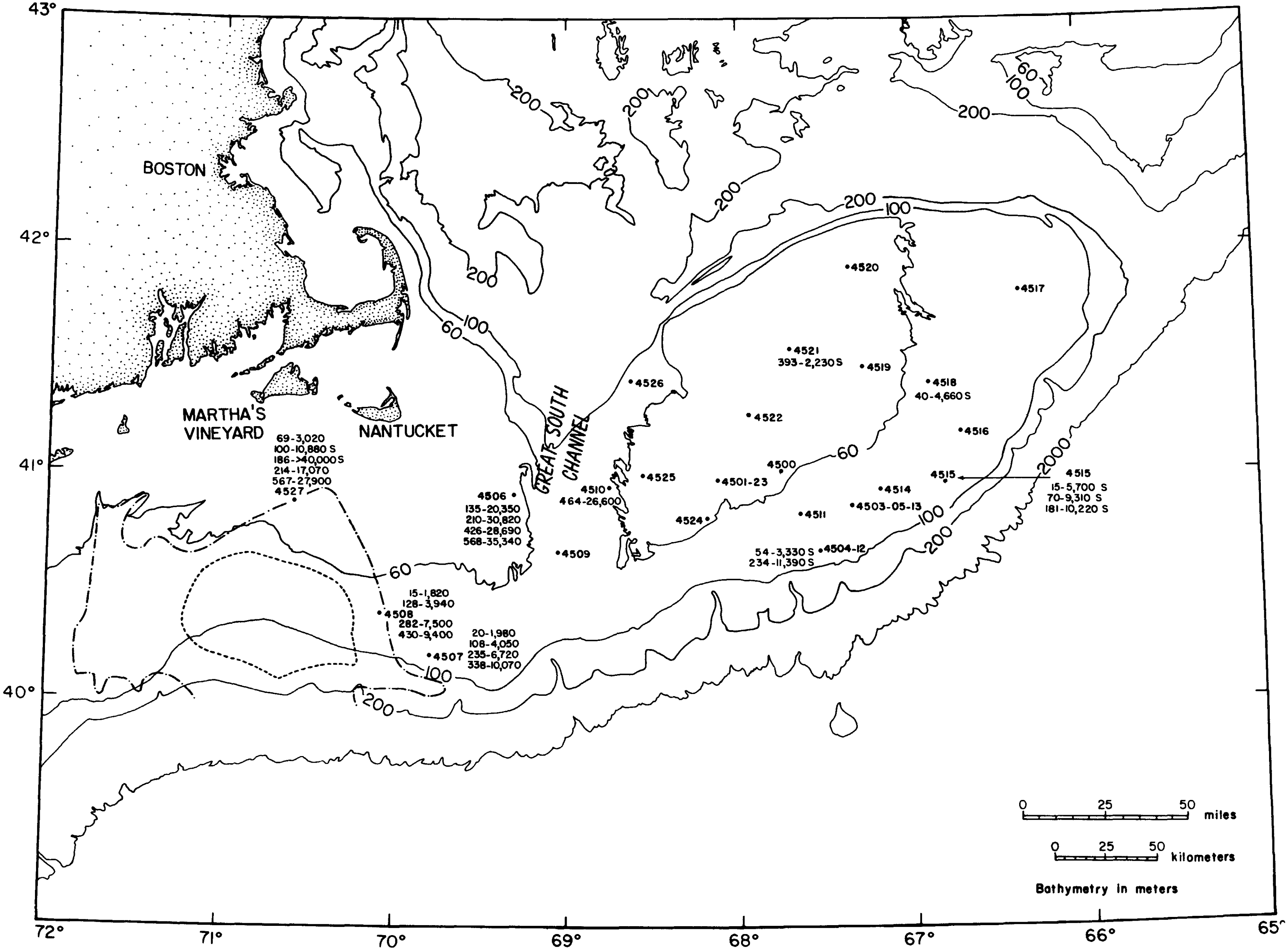

Figure 3-3. Radiocarbon ages of Georges Bank sediments. Station numbers in bold print. Left column is sediment depth in cm (middle of interval dated); right column is radiocarbon age. Dates were determined on organic carbon unless noted by "S" following date which indicates a shell material. Dashed contours south of Martha's Vineyard outline area of anomalously fine-grained sediment (Schlee, 1973): —•—° muddy sand; --- silt.

Table 3-4. Radiocarbon ages of vibracore samples from Georges Bank.

Core	Sediment Depth (cm)	Material Dated	Age
4506D	120 - 150	organic carbon	20,350 ± 600
	(138 - 141 missing)		
	195 - 225	organic carbon	30,820 ± 2,000
	413 - 438	organic carbon	28,690 ± 1,000
	553 - 583	organic carbon	35,340 ± 2,000
4507C	0 - 40	organic carbon	1,980 ± 200
	93 - 123	organic carbon	4,050 ± 300
	220 - 250	organic carbon	6,720 ± 300
	323 - 353	organic carbon	10,070 ± 300
4508B	0 - 30	organic carbon	1,820 ± 200
	113 - 143	organic carbon	3,940 ± 200
	271 - 293	organic carbon	7,500 ± 250
	419 - 440	organic carbon	9,400 ± 300
4510A	449 - 479	organic carbon	26,600 ± 700
4512C	52 - 55	Shell	3,330 ± 200
	211 - 256	Shell	11,390 ± 300
4515A	0 - 30	Shell	5,700 ± 250
	70	Shell	9,310 ± 300
	165 - 197	Shell	10,220 ± 300
4518A	25 - 55	Shell	4,660 ± 250
4521A	373 - 413	Shell	2,230 ± 200
4527C	54 - 84	organic carbon	3,020 ± 250
	90 - 110	Shell	10,880 ± 300
	173 - 198	Shell	40,000 ±
	198 - 229	organic carbon	17,070 ± 300
	549 - 574	organic carbon	27,900 ± 800

These radiocarbon data from cores on the edge of the "mud patch" provide the first evidence that this anomalous area of fine-grained sediments is a modern sediment sink. Preliminary ^{210}Pb profiles from hydraulically damped gravity cores taken at the same stations support this interpretation (M. H. Bothner and P. P. Johnson, unpublished data).

The source of sediments making up this deposit is at present uncertain. One possible source is the large area of coarse-grained sediments of Nantucket Shoals and Georges Bank. Although present in low concentration, the fine-grained material winnowed from the sands in these areas during storms and periods of maximum tidal currents would be transported to the southwest toward the "mud patch" by the net current drift (Bumpus, 1973).

Identification of the "mud patch" as a modern sediment sink is significant to questions about the fate of pollutants added to Continental Shelf waters off the northeastern United States. Because of the known association of trace metals and hydrocarbons with fine-grained sediments, this area may also be a sink for sediment related pollutants. If the sediments are found to originate in the shallow area to the northeast, then the "mud patch" may be an excellent location to study the geochemical cycling and fate of new pollutants that may be added to the Georges Bank area by hydrocarbon exploration and development.

Other noteworthy points can be made from the radiocarbon data obtained on these cores. First, the uncertainty in using shell dates rather than organic carbon in sediments is highlighted by samples from core 4527C. At a depth of 173-198 cm, the shells gave a date of >40,000 years, whereas the organic carbon from the interval immediately below yielded an age of 17,070 years. Clearly very old shells have been incorporated into these sediments.

Second, in core 4506, collected from a shoal area west of Great South Channel and texturally similar to a glacial till, the ^{14}C ages ranged from about 20,000 to 35,000 years or Late Wisconsin time. The location of this sample corresponds with the maximum extent of glacial ice as inferred from textural analysis of surface samples (Schlee and Pratt, 1970). The ages and texture of till-like material throughout the 20 feet of core penetration are consistent with the presence of ice at this location in Late Wisconsin time.

Finally, the remaining radiocarbon data on shells from the Georges Bank area are within the range of 2,000-11,000 years. Because of the problem of relict shell material, the dates obtained can only be interpreted as a maximum age. Generally, then, much of the sandy sediment on Georges Bank appears to have been deposited and reworked since the last glacial maximum.

The extent of reworking is apparent in core 4521A where a 2,200 year old shell occurs at about 4 m depth. Since modern shells precipitated in seawater may have an age of several hundred years due to the slow exchange of ^{14}C between the atmosphere and ocean, and since it is possible to bury older shells, the age of this shell material in calendar years may be considerably less than 2,200 years. Given the problems with shell dates, the calculated accumulation rate of 2 m per 1,000 years is a lower limit, yet this is the highest rate observed in this study. The area in which this sample is located, the top of Georges Bank, receives severe turbulence from storm waves and tidal currents. As a result, this accumulation as measured is likely to have occurred in a single event or a series of events rather than as steady accumulation. The occurrence of a young shell at this sediment depth gives an indication of the very strong mixing and/or migration of sand waves in this high energy area of Georges Bank.

SUMMARY

1. Size analysis of vibracores collected from the North Atlantic Outer Continental Shelf areas indicates a predominance of the sand size class at essentially all depths and at all locations. Larger concentrations of silts and clays were evident in samples taken west of Great South Channel, and more common occurrences of gravel are observed to the east. Texture and ^{14}C age of sediment in a core just west of Great South Channel suggest that these sediments are glacial till of Late Wisconsin age. Hydraulically damped gravity cores collected at the same locations as vibracores typically have uniform texture from the undisturbed surface to a depth of 20-30 cm. This uniformity may be due to effective mixing of the sediments to this depth by biological and physical processes.
2. The major clay mineral group in these sediments is illite with moderate amounts of chlorite and small amounts of kaolinite. These data are consistent with the patterns identified in surface sediments and the hypothesis (Hathaway, 1972) that the illite and chlorite are indicative of largely unweathered material that was eroded in Paleozoic and older rocks in the northern Appalachian region. During glacial periods this material was transported to the shelf edge and redistributed as sea level rose during interglacial stages.
3. The leachable concentrations of Cr, Cu, and Zn and the total concentrations of Ba, Cd, Cr, Cu, Fe, Ni, Pb, V, and Zn are low

(see Tables 3-1 and 3-2) and are characteristic of an area having uncontaminated coarse-grained sediment. For samples analyzed by both methods, the nitric acid leached about 21% of the total zinc, 27% of the total chromium, and 15% of the total copper.

Evidence for the accumulation of metals in surface sediments from present-day sources is not apparent in this study. In cores collected with a special technique to preserve the surface-most sediments, there is no apparent difference between trace-metal concentration at the surface and at deeper levels in the core. Small increases (factor of 2) in trace-metal concentrations generally correlate with higher silt plus clay and organic carbon content in the sediment.

4. Radiocarbon analyses of organic sediment south of Nantucket Island and east of the "mud patch" center indicate fairly constant accumulation of fine-grained sediment at an average rate of 36 to 58 cm/1,000 years during the past 10,000 years. This indication of a modern sediment sink is supported by some preliminary ^{210}Pb analyses. If this hypothesis is confirmed by more detailed studies presently underway, then this area of anomalous fine-grained sediments takes on new significance because it would represent the only major depositional site on the Continental Shelf off the northeastern United States (exclusive of the Gulf of Maine) for modern sediments and for sediment-related pollutants which may be introduced by offshore development activity.

Radiocarbon dates on shell material over most of Georges Bank are between 2,000 and 11,000 years B.P. These dates are upper limits because of the non-zero age of modern shells and because of the possibility of burying old shells. As there is no present-day source for the coarse-grained sediments on Georges Bank, this residual material is undoubtedly relict, having been transported by glacial proceses. The young shell dates at depth (<11,000 years) reflect reworking since the last sea level transgression.

The extent of reworking on top of the bank is evident from the occurrence of a 2,200 year shell at a depth of 4 m. Given the problems with shell dates, the calculated accumulation rate of 2 m per 1,000 years is a lower limit, yet this is the highest rate observed in this study. The location of this sample, on top of Georges Bank, receives severe turbulence from storm waves and tidal currents. As a result, the accumulation measured is likely to have occurred in a single event or a series of events rather than as steady accumulation. These data provide yet additional evidence of the high wave and current energy in this region of the Continental Shelf.

LITERATURE CITED

Biscaye, P.E. 1965. Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and the adjacent seas and oceans: Geol. Soc. Am. Bull: 76:803-832.

Bothner, M.H. 1979. Trace metals in surface sediments of the Mid-Atlantic Outer Continental Shelf: U.S. Geological Survey Open-File Report 79-843, 27 p.

Bumpus, D.F. 1973. Description of circulation on the Continental Shelf of the East Coast of the United States: Progress in Oceanogr., vol.

6, pp. 111-158.

Erlenkeuser, H., E. Suess, and H. Willkowm. 1974. Industrialization affects heavy metal and carbon isotope concentrations in recent Baltic Sea sediments: Geochim. Cosmochim. Acta., vol. 38, pp. 623-642.

Flanagan, F.J. 1969. U.S. Geological Survey Standards - II. First compilation of data for the new U.S.G.S. rocks: Geochim. Cosmochim. Acta., vol. 30, pp. 81-120.

Flanagan, F.J. 1973. 1972 Values for international geochemical reference samples: Geochim. Cosmochim. Acta., vol. 37, pp. 1189-1200.

Hathaway, J.C. 1972. Regional clay mineral facies in estuaries and continental margin of the United States East Coast: Geol. Soc. Am. Mem. 133:293-316.

Krauskopf, K. B. 1967. Introduction to Geochemistry, N.Y., McGraw-Hill Co. 721 p.

Manheim, F.T., J.C. Hathaway, F.J. Flanagan, and J.D. Fletcher. 1976. Marine mud, Mag-1, from the Gulf of Maine in F. J. Flanagan, ed., Description and analysis of eight new U.S.G.S. rock standards: U.S. Geol. Surv. Prof. Paper #840, pp. 25-28.

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

Nozaki, Y., J. Kirk Cochran, and Karl K. Turekian. 1977. Radiocarbon and ^{210}Pb distribution in submersible-taken deep-sea cores from project famous: Earth and Planetary Science Letters, vol. 34, pp. 167-173.

Schlee, J. 1966. A modified Woods Hole rapid sediment analyzer: Jour. Sed. Petrology, vol., 36, pp. 403-413.

Schlee, J. 1973. Atlantic Continental Shelf and Slope of the Eastern United States - sediment texture of the northeast part: U.S. Geol. Surv. Prof. Paper 529-L, 64 p.

Schlee, J. and R.M. Pratt. 1970. Atlantic Continental Shelf and Slope of the United States - gravels of the northeast part: U.S. Geol. Surv. Prof. Paper 529-H, 39 p.

Suess, H.E. 1954. Natural radiocarbon measurements by acetylene counting: Science, vol. 120, pp. 5-7.

CHAPTER 4

David W. Folger, Sally A. Wood, Michael H. Bothner,
and Bradford Butman

CHAPTER 4

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CHAPTER 4

SUBMERSIBLE OBSERVATIONS ON GEORGES BANK

David W. Folger, Sally A. Wood, Michael H. Bothner, and Bradford Butman

INTRODUCTION

In 1975 and 1976 the U. S. Geological Survey conducted 17 reconnaissance dives to assess, by direct observation, the microtopography, sediment texture and composition, sediment mobility, bottom water circulation, and some benthic biology of Georges Bank as part of the environmental study of the North Atlantic Outer Continental Shelf. Data reported here were collected from the submersibles and from support vessels.

SETTING AND PREVIOUS WORK

Dive sites were selected in five areas of Georges Bank (Figure 4-1). Three of these were in lease areas where previous data had been collected and where long-term observations were planned. Two were outside of any selected lease block but were useful to gain information concerning regional circulation patterns and sediment distribution. All the direct observations were intended to assist in the selection of future sampling sites and indirect geophysical observations and to aid in the interpretation of data collected from those areas. The two dive sites selected in Great South Channel (107, 4502) at the southwestern end of Georges Bank are important because Great South Channel is a conduit for much of the tidal flow from the Gulf of Maine and is floored in some areas by boulder pavement that contrasts sharply with the configuration of sand waves on the Bank top. Dive site 107 lies in water 77 m deep and dive site 4502 in water 70 m deep. One dive site (4503) on the southeastern flank of the Bank in 84 m of water was

Figure 4-1. Map showing locations of sites where dives were conducted in 1975 and 1976 to assess geologic, biologic and hydrologic characteristics of the the water column and the bottom. Bathymetry in meters.

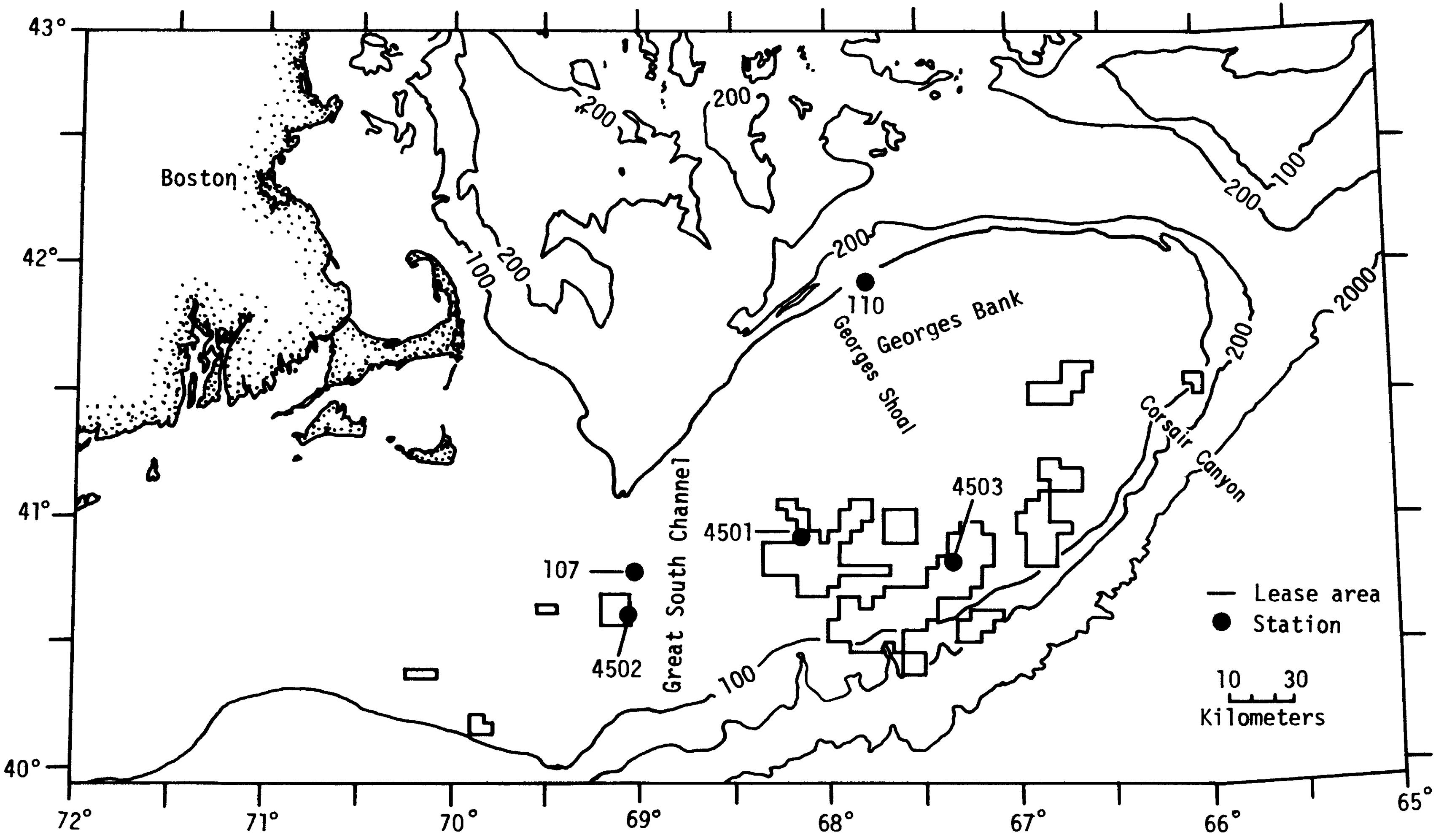

43°
42°
41°
40°
72°
71°
70°
69°
68°
67°
66°
65°
Boston
100
200
200
200
200
100
200
2000
200
100
110
Georges Bank
Georges Shoal
Corsair Canyon
Great South Channel
107
4501
4502
4503
Lease area
● Station
10 30
Kilometers

Figure 4-1

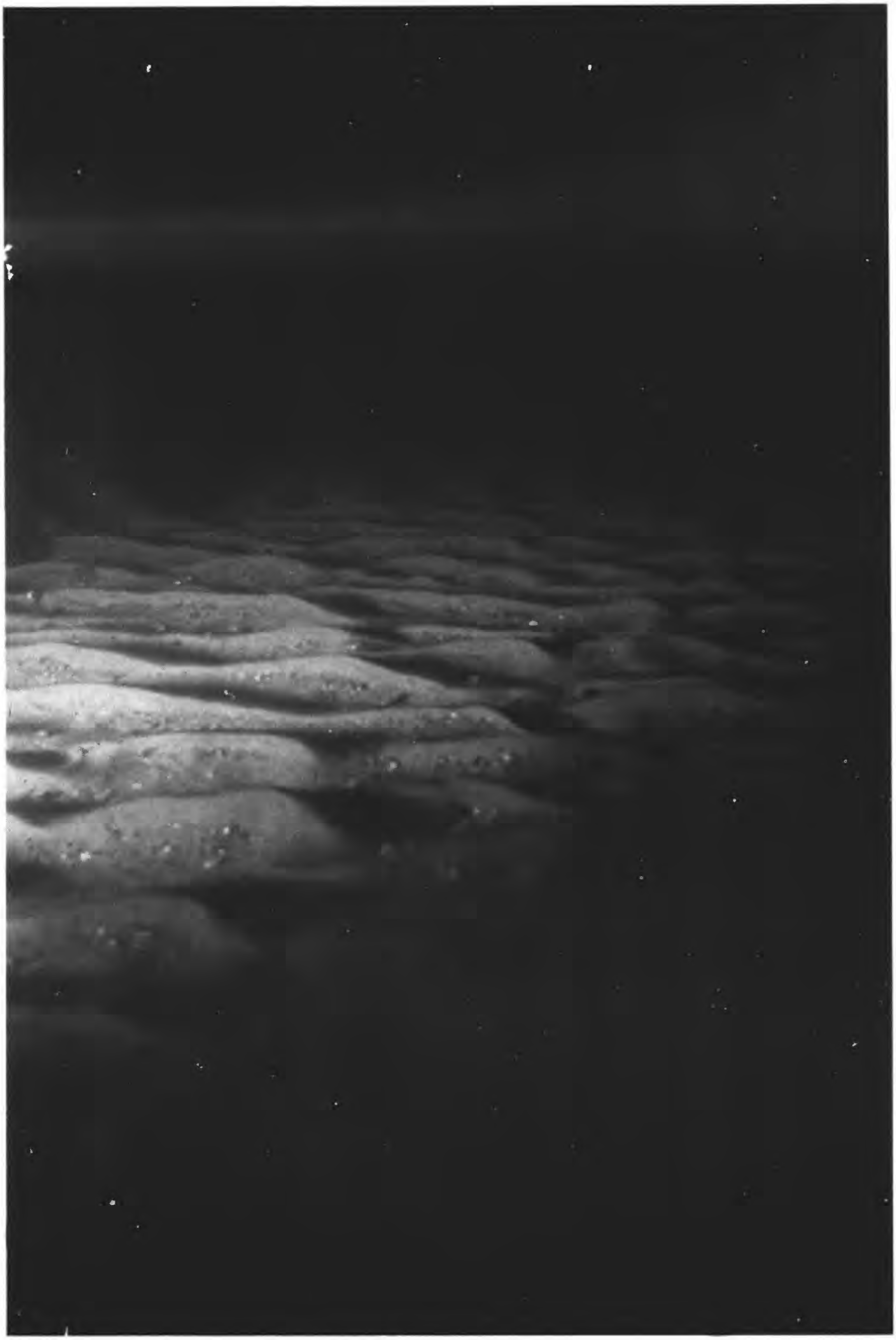
located in a main block of lease tracts where the bottom is characterized by smooth, gently dipping bathymetry (Emery and Uchupi, 1972). We considered this to be an important site for monitoring oceanographic conditions on the Bank with tripods over a period of several years. The shallowest dive selected was at Station 4501 in waters 46 m deep. This area of large shoals and troughs is overlain by linear sand waves which are constantly reworked by strong tidal currents. Sand wave crests move at an estimated rate of 12 m per year (Stewart and Jordan, 1964). Fortunately, bottom photos of the area taken prior to diving (see Figure 4-2) revealed such vigorous bottom current scour that the submersible operators considered the site hazardous and cancelled the dive in that area. The last site (110) occupied on the northwestern flank of the Bank where few data are available was selected to gain a better regional picture of bottom conditions and bottom water flow.

Previous direct observations made in the Georges Bank area prior to U. S. Geological Survey dives included those made by divers on Georges Shoal (Stewart and Jordan, 1964), aboard submersibles in the canyons on the shelf edge (Trumbull and McCamis, 1967; Ross, 1968; Ryan _et al_., 1978), and since 1973 by the National Marine Fisheries Service on the shelf and in the canyons (Corsair Canyon to Atlantis Canyon). Three of these NMFS dive sites were on Georges Bank, 2 in Great South Channel, and 28 in the canyons; the dives were mainly conducted to obtain detailed information on the abundance, distribution, and ecology of selected megafauna (Uzmann _et al_., 1977; Uzmann, personal communication).

Sedimentologic and stratigraphic studies of the area have been extensive (Schlee and Pratt, 1970; Stetson, 1937 and 1949; Wigley, 1961;

Figure 4-2 Diving was prevented due to high current speeds at Station 4501 in 1975 and 1976. Bottom photos taken from the support ship revealed sand waves with coarse detritus in the troughs. Because the camera tipped over, no estimate of the sand wave size can be made.

Figure 4-2



Uchupi, 1963 and 1968; Hulsemann, 1967; Schlee, 1968; Knott and Hoskins, 1968; Hathaway, 1971; Hathaway *et. al.*, 1976; Lewis and Sylwester, 1977). Studies were also carried out on the bottom currents and sediment mobility (Ericson *et al.*, 1952; U.S. Department of the Navy, 1954; Stewart and Jordan, 1964; Csanady, 1974). Bottom structure has been studied by Emery and Uchupi (1965), Oldale *et al.* (1974), and Lewis and Sylwester (1977). Comprehensive studies of Georges Bank have been compiled by Emery and Uchupi (1972) and the U. S. Geological Survey (1975).

METHODS

Data were collected on 9 dives during one cruise in September 1975 (DSRV NEKTON BETA and R/V ADVANCE II) and on 8 dives during another in July 1976 (DSRV NEKTON GAMMA and R/V ATLANTIC TWIN)(Tables 4-1, 4-2). Both Loran A and C were used aboard R/V ATLANTIC TWIN and R/V ADVANCE II. Photos were taken from the submersible through viewing ports with handheld 35 mm cameras and a TV camera. When the submersible was on the bottom, the photographs from the viewing port were only about 1 m away from the surface being photographed at the closest point that could be observed. There was no data window on the cameras used in the submersible, hence, the time, number, etc., are not on each photograph. Because all the photos were taken at an oblique angle, their scales vary with distance and thus cannot be noted in the photographs. Bottom water flow was estimated by simply watching the movement of particulate matter over the bottom or past the observation ports. This technique is only approximate but gives the instantaneous direction and speed of current flow, probably within 20%. Water temperature was recorded during each descent by watching the thermometer and the depth gauge. It is thus an

Station	Dive #	Date 1975	Location		Time		Min. Δ T	Water Depth (m)	Observer	Pilot	Comments
					Down	Up					
4503	533	12 Sept.	40°50.7' N	67°25.4' W	1052	1300	128	82.3	Folger	Slater	Did not locate RR wheel; bottom survey.
4503	534	14 Sept.	40°51.2' N	67°25.1' W	0815	0915	60	81.7	Folger	Slater	Located RR wheel; bottom survey.
4503	535	14 Sept.	"	"	0950	1200	130	82.3	Butman	O'Donnell	Bottom survey.
4503	536	14 Sept.	"	"	1320	1500	100	81.7	Farlow	O'Donnell	Bottom survey.
4503	537	14 Sept.	"	"	1530	1620	50	80.8	Malpass	Slater	Current meter array search.
4502	538	15 Sept.	40°39.1' N	69°03.8' W	0900	1000	60	67.7	Folger	Slater	Located RR wheel; bottom survey.
4502	539	15 Sept.	"	"	1040	1150	70	67.1	Farlow	O'Donnell	Biology survey.
4502	540	15 Sept.	"	"	1225	1310	45	67.7	Butman	O'Donnell	1-1.5 knot current; bottom survey.
4502	541	15 Sept.	"	"	1340	1600	120	67.4	Folger	Slater	Bottom survey.

TABLE 4-1. Operational Summary, R/V ADVANCE II 75-6 and NEKTON BETA, 12-16 September 1975.

Sta./Dive #		Date 1976	Locations		Loran (A) (C)	Time		ΔT (min)	Water Depth (m)	Observer	Pilot	Notes
			Lat.	Long.		Down	Up					
Moor. 107	683	July 2	40°48.6 N	69°0.0 W	37541.2 70182.5 (C)	1653	1800	67	77	Folger	Zahoran	1-1.5 kn current large sand waves could not locate current meters
"	684	"	"	"	"	1824	1845	23	77	Folger	Parsons	Currents high Could not stem currents.
Sta. 4502	685	July 3	40°38.9 N	69°02.5 W	1105 3577 (A)	1314	1352	38	70	Kraeuter	Slater	Current 1-1.5 kn Conducted biology survey.
"	686	"	"	"	"	1809	1919	70	70	Folger	Parsons	Current 1-1.5 kn Conducted bottom survey.
4503 (Moor. 108)	687	July 4	40°51.2 N	67°24.0 W	16138.0 36801.1 (C)	1320	1450	90	84	Bothner	Zahoran	Pipe search and bottom survey.
4503	688	"	"	"	"	1531	1603	32	84	Folger	Slater	Located RR wheel.
4503	689	July 5	"	"	"	1850	1953	61	84	Kraeuter	Slater	Pipe search and biology survey.
110	690	July 6	41°59.0 N	67°47.0 W	36484.6 69979.5 (C)	1055	1143	48	85	Folger	Parsons	Current Meter search - bottom survey

TABLE 4-2. Operational Summary, ATLANTIC TWIN - NEKTON GAMMA, 1-7 July 1976.

approximate temperature curve. During the 1975 dives, grab samples were collected from the submersibles with small, closable PVC cylinders.

Aboard both support ships, suspended matter samples were collected in Niskin bottles and filtered through 0.45 mm Millipore filters. Temperature was profiled with XBTs (expendable bathythermographs). In 1975, some bottom photos were taken with a Benthos submersible camera from the surface. Grab samples were collected with a Shipek sampler. In 1976, turbidity was measured with a Montedoro-Whitney transmissometer-nephelometer during several lowerings.

OBSERVATIONS

To obtain the maximum amount of information at each dive site, several dives were usually carried out. Each was manned by a different observer who was a specialist in either geology, biology, or physical oceanography. In some cases, adverse conditions prevented this pattern from being followed, but at most sites, at least two of the three planned dives were conducted. The traverses conducted on the bottom were located close to locations where vibracores or hydraulically damped gravity cores and grab samples had been previously collected. At sites 4501, 4502, and 4503 railroad wheels with a 2 m pipe welded to them had been placed on the bottom to monitor changes in sediment deposition. That is, to determine if the area was being buried by moving sand waves or by rapid deposition of sand transported as sheet flow, or a similar mechanism.... or if the area was being actively scoured. In 1975, the initial observations of these wheels were to be made to serve as a reference for future observations. By 1976, vibracore pipes had been set in the bottom at the same three sites as additional reference markers. During both 1975 and 1976, the cruises encountered poor diving conditions due to either heavy seas or fog. In September of 1975, fall storms prevented diving on three of the six days allocated for the cruise. However, on the good days, as many as four dives with a duration up to two hours and twenty minutes were executed. In July of 1976, the sea conditions were most often excellent but fog was present during several hours every day. Because of it, two dives were the most conducted in any one day and these were of relatively short duration, often less than an hour. In addition, bottom currents during several dives in 1976 were too strong to conduct good surveys because the submersibles could not be stabilized in one postition.

Water Column Observations--1975 and 1976

Because of the strong tidal flow and, to a lesser extent, wave action, waters over Georges Bank are commonly well mixed and no thermocline develops, even during summer months. This mixing of cold deeper water with the surface water is the main cause of the fog that commonly blankets Georges Bank during the summer months. During the submersible observations, this mixing was obvious in the temperature measurements recorded during the dives. Surface waters, for example, ranged only from 13^{o} to 14^{o} C and declined to only 8^{o} to 10^{o} C at the bottom at deepest dive sites (Figure 4-3). Additional XBT data collected from R/V ADVANCE II and from USCG Buoy Tender SPAR (USGS hydrographic cruises) corroborate the submersible measurements (Figure 4-4a through 4-4d).

Turbidity observed from the submersible was often high throughout most of the water column, but on some dives it cleared up at the bottom where the visibility ranged from 5 to 10 m. Much of the material in suspension appeared to be organic and probably relates to the high productivity in the water column that is, in part, due to the mixing of

Figure 4-3 Temperature measurements were recorded by the observer in the submersible. Because temperature and depth gauges had to be watched simultaneously, the profiles should be viewed as approximate.

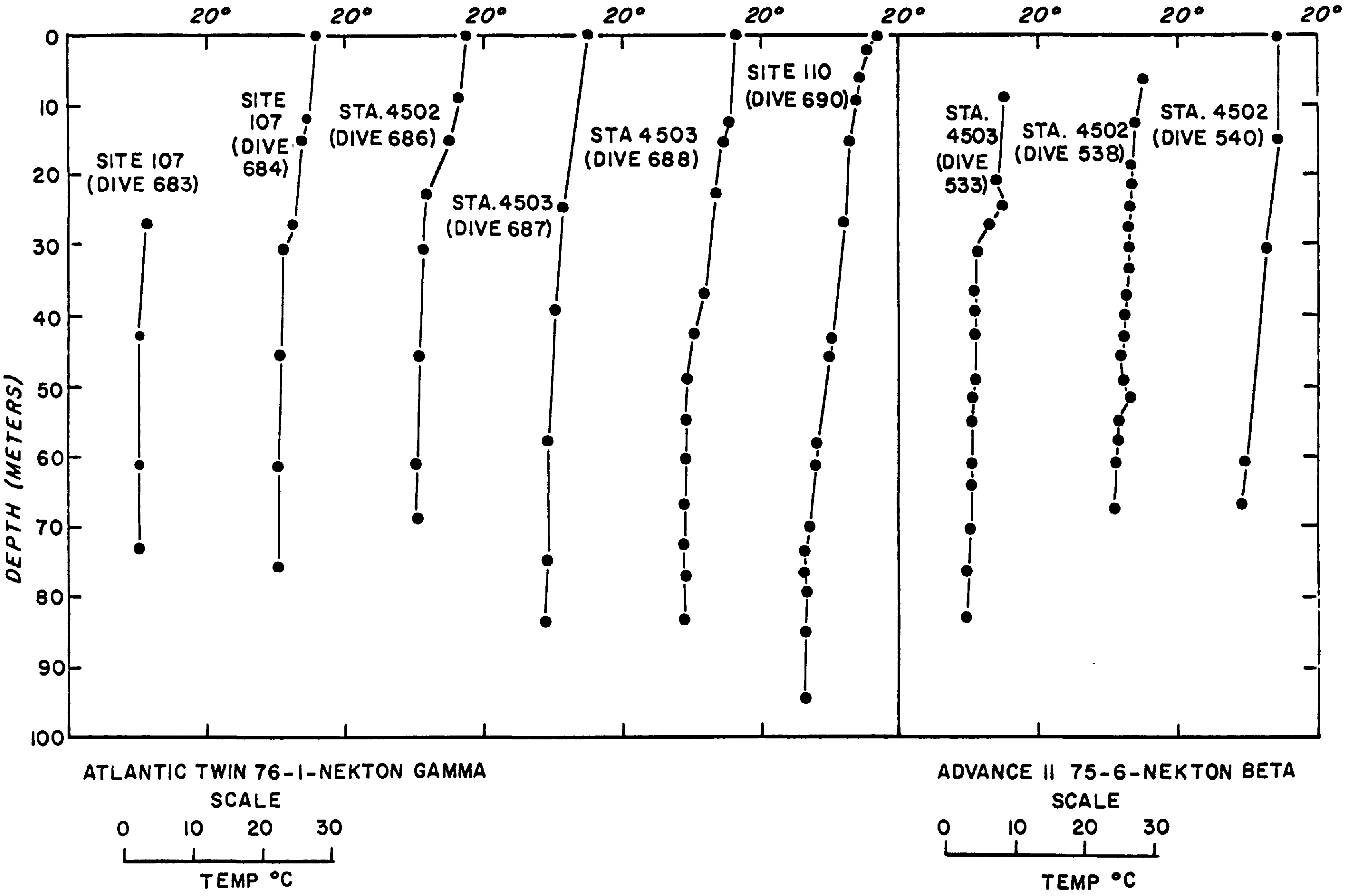

20°
20°
20°
20°
20°
20°
20°
20°
20°
20°
0
10
20
30
40
50
60
70
80
90
100
DEPTH (METERS)
SITE 107
(DIVE 683)
SITE
107
(DIVE
684)
STA.4502
(DIVE 686)
STA.4503
(DIVE 687)
STA 4503
(DIVE 688)
SITE 110
(DIVE 690)
STA.
4503
(DIVE
533)
STA. 4502
(DIVE 538)
STA. 4502
(DIVE 540)
ATLANTIC TWIN 76-1-NEKTON GAMMA
SCALE
0
10
20
30
TEMP °C
ADVANCE II 75-6-NEKTON BETA
SCALE
0
10
20
30
TEMP °C

Figure 4-3

Figure 4-4 Water column temperatures were recorded in the North Atlantic from the R/V ADVANCE II in September 1975 and from the USCG Buoy Tender SPAR in August 1975.

a and b Show station locations.

c and d Show the temperature sections.

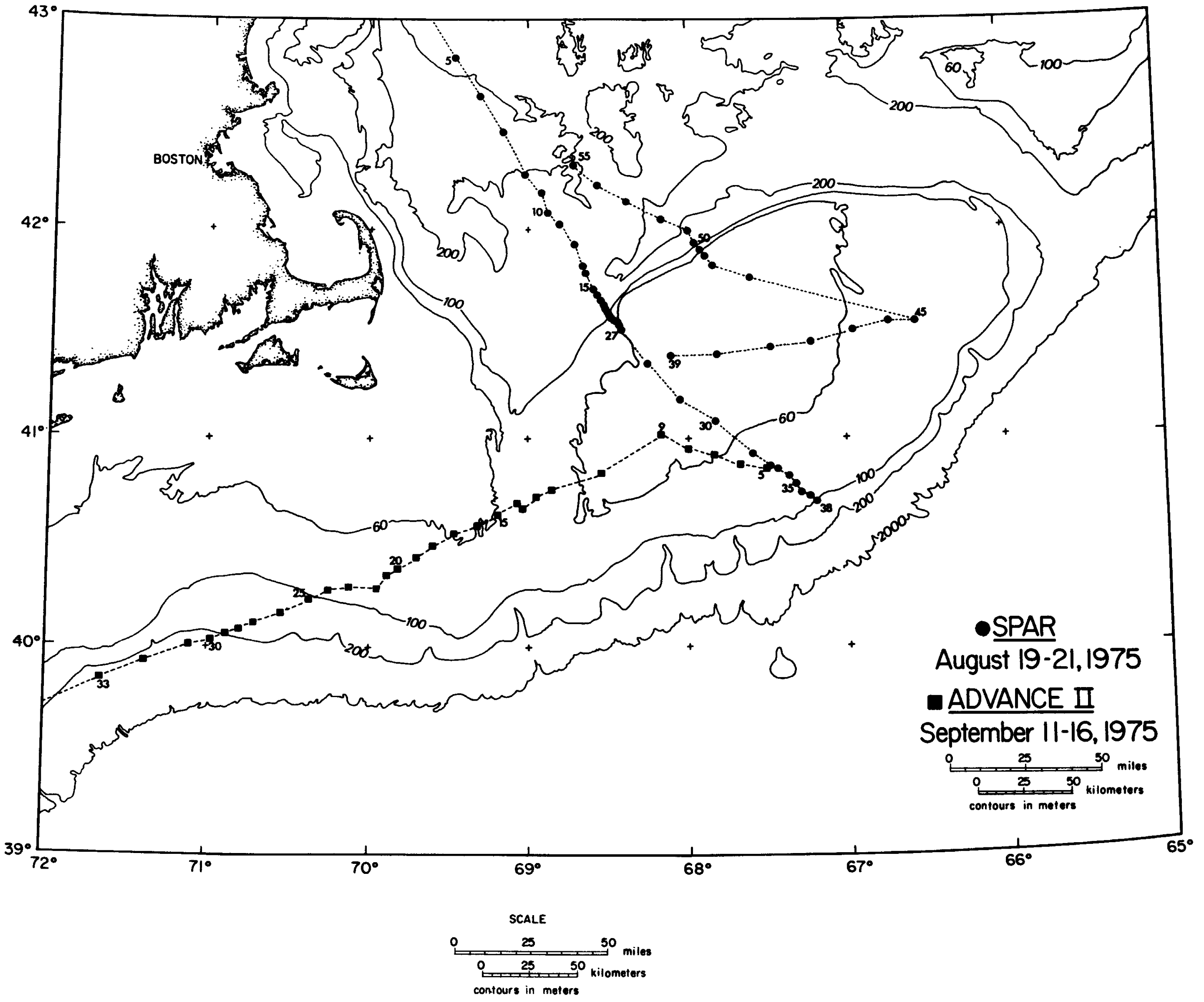

●SPAR
August 19-21, 1975
■ADVANCE II
September 11-16, 1975
0 25 50 miles
0 25 50 kilometers
contours in meters
SCALE
BOSTON
43°
42°
41°
40°
39°
72°
71°
70°
69°
68°
67°
66°
65°
60
100
200
2000
5
10
15
20
25
27
30
33
35
38
39
45
50
55

Figure 4-4a

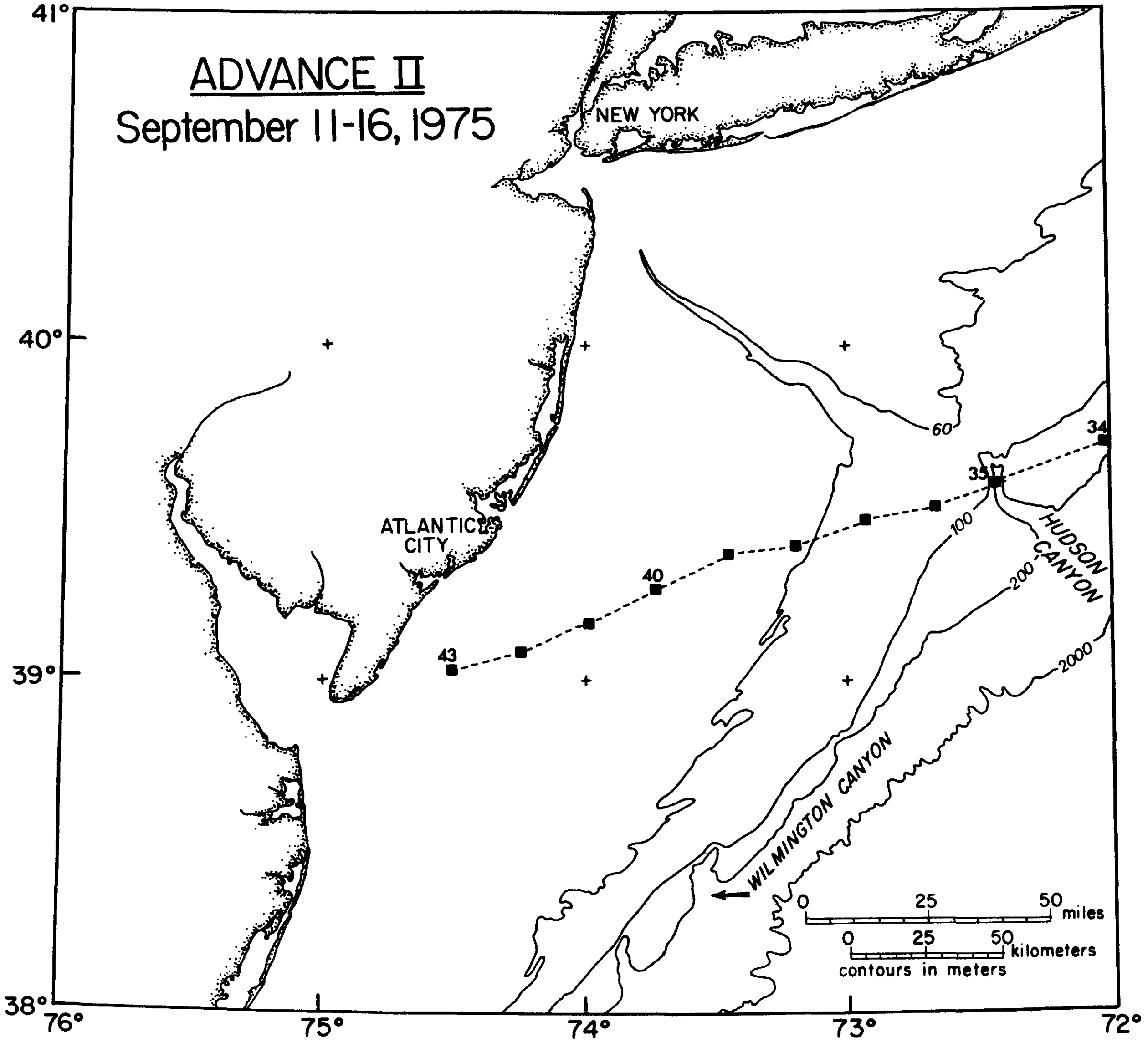

ADVANCE II
September 11-16, 1975
NEW YORK
ATLANTIC CITY
HUDSON CANYON
WILMINGTON CANYON
34
35
40
43
60
100
200
2000
0 25 50 miles
0 25 50 kilometers
contours in meters
41°
40°
39°
38°
76°
75°
74°
73°
72°

Figure 4-4b

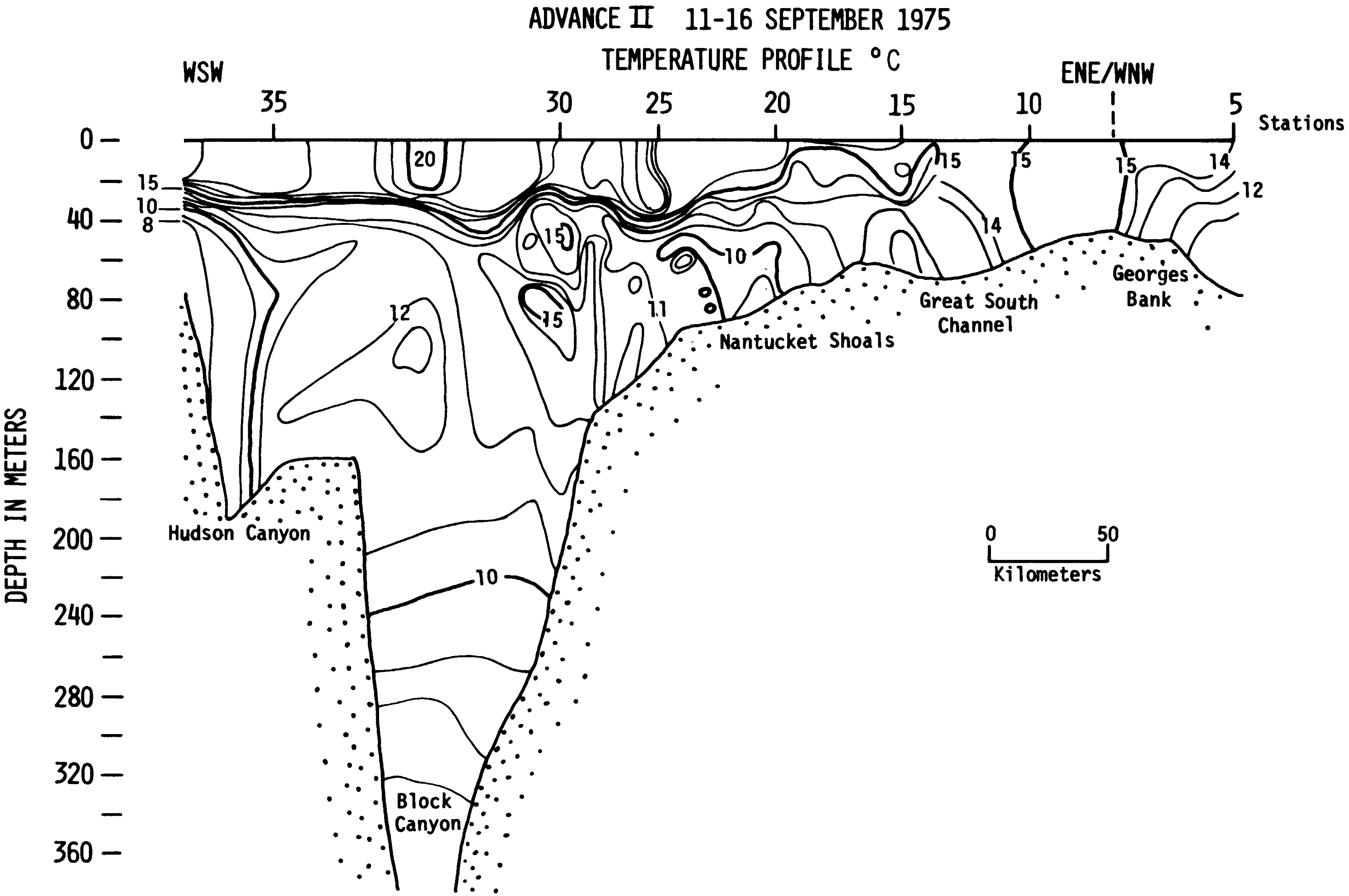
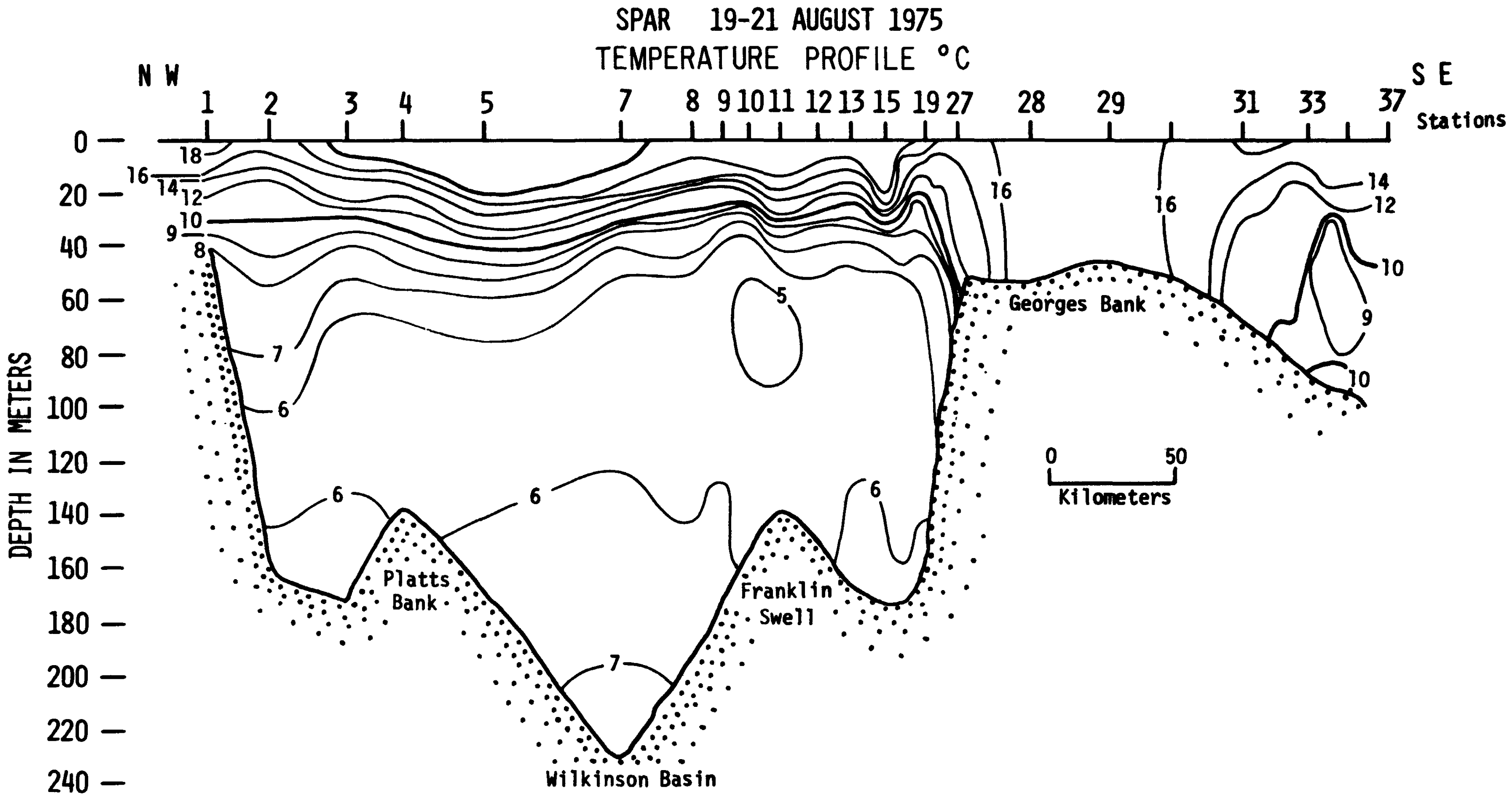

ADVANCE II 11-16 SEPTEMBER 1975
TEMPERATURE PROFILE °C

Figure 4-4c



SPAR 19-21 AUGUST 1975
TEMPERATURE PROFILE °C

Figure 4-4d

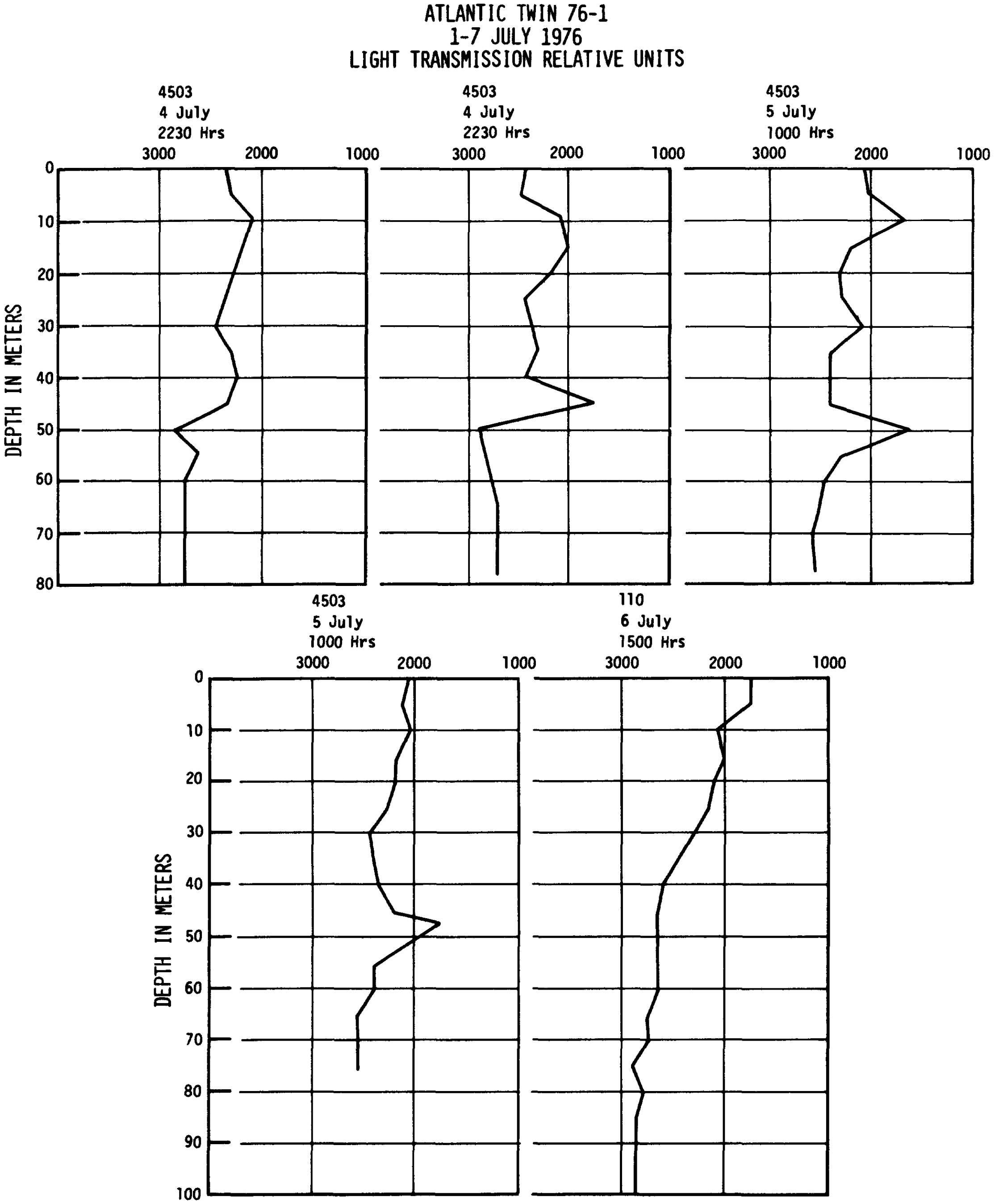
nutrient-rich deep waters in relatively shallow waters over the Bank.

Observations of water turbidity made from the support ships with the transmissometer-nephelometer in July of 1976 showed highly variable measurements but with the turbidity often declining toward the bottom. A prominent nepheloid layer (a layer with high turbidity) between 40 and 55 m deep on the south flank of the Bank at station 4503 (Figure 4-5) contained 38% combustible organic matter and only 2% skeletal and mineral matter. Thus this nepheloid layer was primarily organic in nature and probably formed along a density boundary in the water column. In contrast, on the northwestern side of the Bank at site 110, high turbidity at the surface declined rapidly between 20 and 40 m and remained low all the way to the bottom (Figure 4-5).

Suspended matter was filtered from water samples collected at the same sites where the transmissometer-nephelometer was lowered. Recovered suspended matter ranged from a high of 3.0 mg/l to a low of 0.2 mg/l. The highest values occurred in the nepheloid layer noted above. Most samples collected near surface contained about 1 mg/l, whereas those collected near bottom contained less than 0.3 mg/l (Table 4-3). The combustible organic matter fraction was most often more abundant than the noncombustible fraction. In September 1975, suspended matter recovery in water samples appeared to contain uniform total concentrations (Table 4-4). However, no transmissometer-nephelometer was available on the cruise to identify nepheloid layers for sampling. Thus, the apparent homogeneity of suspended matter concentrations may be fortuitous. Bottom currents on the Bank are mainly tidal (Bumpus, 1976). Hence, the direction and speed of water flow observed aboard the submersible at the bottom were related mostly to the phase of the tidal cycle at the time the dive took

Figure 4-5 In 1976 light transmission in the water column was recorded. At stations 4503 and 110 transmissivity showed decreasing turbidity toward the bottom with a prominent nepheloid layer at 40-55 m.

Figure 4-5


ATLANTIC TWIN 76-1
1-7 JULY 1976
LIGHT TRANSMISSION RELATIVE UNITS
4503
4 July
2230 Hrs
4503
4 July
2230 Hrs
4503
5 July
1000 Hrs
4503
5 July
1000 Hrs
110
6 July
1500 Hrs
3000
2000
1000
DEPTH IN METERS
0
10
20
30
40
50
60
70
80
90
100

Date	Time	Sta.	Latitude	Longitude	Water Depth (m)	Sample Depth (m)	Filter #	Filt. Type	Water Volume (L)	Combust. Fraction (%)	Non-Combust. Fraction (%)	Conc. Total Suspended Matter mg/l
3 July 76	1700	4502	40°38.9'N	69°02.5'W	70	83.5	V238	N	2.06	92.9	7.1	0.20
"	"	"	"	"	"	"	V459	M	1.96	70.0	30.0	0.36
"	"	"	"	"	"	"	283	*	22.5	-	-	0.69
"	"	"	"	"	"	35	V258	N	1.78	-	-	0.29
"	"	"	"	"	"	"	V474	M	2.84	53	47	0.33
"	"	"	"	"	"	"	282	*	20.5	-	-	0.46
"	"	"	"	"	"	1.5	V278	N	1.86	-	-	0.18
"	"	"	"	"	"	"	V449	M	2.76	94	6	0.94
"	"	"	"	"	"	"	281	*	22	-	-	1.29
4 July 76	2000	4503	40°51.2'N	69°24.0'W	84	10	V438	M	5.75	95	5	1.35
"	"	"	"	"	"	75	V446	M	7.75	32	68	0.24
"	"	"	"	"	"	43	V447	M	8.5	-	-	2.09
5 July 76	1300	4503	"	"	"	75	V448	M	11.4	67	33	0.31
"	"	"	"	"	"	48	V458	M	8.75	98	2	3.02
"	"	"	"	"	"	13.5	V468	M	5	95.7	4.3	1.18
"	2030	"	"	"	"	1.5	V464	M	4.5	96.2	3.8	1.78
"	"	"	"	"	"	48	V444	M	7.0	98	2	2.01
"	"	"	"	"	"	75	V473	M	5.25	-	-	0.23
6 July 76	1400	110	41°59.0'N	67°47.0'W	85	2	V478	M	5	94.7	5.3	1.50
"	"	"	"	"	"	31	V484	M	10.5	-	-	0.42
"	"	"	"	"	"	83.5	V493	M	9.5	-	-	0.27

N = Nuclepore® Filter

M = Millipore® Filter

* Inappropriate for Gravimetric Analysis

TABLE 4-3. Suspended sediment concentration in water samples collected from R/V ATLANTIC TWIN.

Station #	Date/ Time 1975	Latitude	Longitude	Sample Depth (m)	Water Depth (m)	Filter Type (Nuclepore or Millipore)	Filter #	Water Vol. (L)	Total SM mg/l
4503	9/14 1235	40°52.0'N	67°20.0'W	84	88	N	1852	0.600	0.26
4503	9/14 1235	40°58.5'N	68°08.6'W	84	88	M	4230	0.775	0.27
4503 Site 13	9/14 1235	40°52.0'N	67°20.0'W	1	88	N	1853	1.025	0.57
4501 Site 8	9/14 2138	40°58.5'N	68°08.6'W	1	46	N	1854	1.350	0.26
4501 Site 8	9/14 2138	40°58.5'N	68°08.6'W	1	46	M	4231	1.350	0.31
4501 Site 8	9/14 2138	40°52.0'N	67°20.0'W	40	46	N	1855	1.175	0.41
4502	9/15 1810	40°39.1'N	69°03.0'W	1	70	N	1856	0.775	0.52
4502	9/15 1810	40°39.1'N	69°03.0'W	26	70	N	1857	1.6	0.20

TABLE 4-4. Suspended sediment concentrations in water samples collected from R/V ADVANCE II, 1975.

place. In September 1975, on the south flank of the Bank at station 4503, bottom current speeds were often low and ranged only from 3 to 4 cm/sec; however, in July of 1976, speeds ranged from 5 to 50 cm/sec. Flow direction at that site was either to the north or south. In contrast, in Great South Channel at station 4502, current speeds ranged from 25 to 150 cm/sec during both dives conducted there. Water flow was parallel to the axis of the Channel and moved either to the north or to the south.

Bottom Observations 1975

In fall 1975, nine dives were conducted at two sites. The first (4503) on the southern side of the Bank within the major lease blocks and the other (4502) in Great South Channel in a lease block where conditions contrasted sharply with those at the first site. The third site selected for diving as noted above was not occupied because currents were judged to be too extreme for safe diving. At each of the two sites occupied, the plan was to locate the railroad wheel that had been emplaced on the bottom and then conduct the surveys from that location. At each site, one or two geological bottom surveys were conducted, one biological survey, and one survey concerned mainly with the transport of sediment by currents. Water depths at site 4503 on the south side of the Bank were close to 80 m, and those in Great South Channel at site 4502 were close to 70 m.

At site 4503--the bottom was covered by small (20 cm wave length, 2-3 cm wave height) asymmetric ripples. Wave crests were oriented between 220° to 240° true with the steep side of the ripples to the southeast (Figure 4-6). The sediment covering the bottom ranged from very fine sand to gravel (Table 4-5) and many areas of flocky material covered the underlying sediment. The nature of this flocky material is

Figure 4-6 In October 1975 at Station 4503 (∿80 m water depth), the bottom was covered by small asymmetric sand ripples with wave lengths of about 20 cm and wave heights of 2-3 cm. Wave crests were oriented at 220° - 240° T. Photo taken with a handheld 35 mm camera.

Figure 4-6

ADVANCE II 75-6
SIZE ANALYSIS

SAMPLE SIZE DISTRIBUTION

										Percentage by Wt.			Sand Fraction (%)				
Station	Date 1975	Latitude	Longitude	Water Depth (m)	Med. Size ϕ	Mean Size ϕ	S.D. ϕ	Skewness ϕ	Kurtosis ϕ	Gravel	Sand	Mud	Very Coarse Sand	Coarse Sand	Med. Sand	Fine Sand	Very Fine Sand
4501	9/14	40°58.5'N	68°08.1'W	46	0.98	0.98	0.79	-.16	3.11	3.0	96.5	0.5	0.0	49.0	47.0	4.0	0.0
4502	9/15	40°39.1'N	69°03.8'W	75	0.40	0.34	1.04	0.16	2.19	11.8	87.2	1.0	17.0	65.0	14.1	4.0	0.0
4502	9/15	40°39.1'N	69°03.8'W	75	0.67	0.58	1.14	-.03	1.03	12.0	87.1	1.0	11.3	49.0	35.7	3.0	1.0
4502	9/15	40°39.1'N	69°03.8'W	75	0.34	0.32	1.08	0.35	2.60	10.5	88.0	1.5	24.0	58.0	14.0	4.0	0.0
4503	9/12	40°51.2'N	67°25.1'W	86	0.54	0.51	1.16	0.06	0.74	12.5	86.7	0.8	13.1	56.0	21.9	8.0	1.0

TABLE 4-5. Results of sediment size analyses conducted on grab samples recovered from the ship and submersible.

unknown but it probably consists mainly of organic and fine terrigenous particulate matter. Organisms observed at the bottom that were most common included hake (*Urophycis chuss*), sand dollars (*Echinarachnius parma*), clams, quahogs (*Arctica islandica*), scallops (*Pecten* sp.), cod (*Gadus callarias*), flounder, sculpin (*Myxocephalus octodecimspinosus*), eel pout (*Macrozoarces americanus*), and hermit crabs (*Pagurus* sp.). In some areas, worm tubes often covered about 10% of the bottom as estimated by visual observations. The bottom was also commonly hummocky, with small pits and mounds that were 1-2 cm in diameter.

Though the small asymmetric ripples indicate that the bottom sediment is in motion, the railroad wheel which had been emplaced for approximately ten days showed no evidence of significant scour around it or of any deposited sediment on it.

The small ripples contrasted with the large sand waves observed at station 4501 in bottom photos taken from the support ship (Figure 4-2). There, in the shallower water (46 m), large sand waves and strong currents (estimated at the surface at 3-4 kn) show that much greater volumes of sediment are continuously in motion near the Bank crest than farther down the flank at station 4503.

At station 4502, there were no small sand ripples observed. The topography, however, was commonly hummocky with mounds and pits of 20-30 cm diameter and 5-6 cm high or deep. Bottom sediments were most commonly composed of medium-to-coarse sand and gravel with common shell debris scattered throughout. The most common organisms observed close to the bottom were hake (*Urophycis chuss*), scallops (*Pecten* sp.), flounder, hermit crabs (*Pagurus acadianus*), starfish (*Asterias vulgaris*, *Henricia sanguinolenta*), clams, and quahogs (*Arctica islandica*). Over much of the area, a layer of pea-sized gelatinous spherules covered the bottom. This gelatinous material was sampled and later identified by Richard Haedrich of the Woods Hole Oceanographic Institution as tunicates (Figure 4-7). The layer appears to be sufficiently coherent to bind the grains in the surface sediments and may have prevented the development of small sand waves or ripples that were observed at site 4503.

Though the ripples were not observed, the railroad wheel did show evidence of scour around it and hence the effect of strong bottom currents.

Bottom Observations 1976

In 1976 at station 4503--the small ripple marks observed in 1975 were not present at this site, despite 25 cm/sec currents measured on one dive. In some areas, the flat bottom was pock-marked by small mounds and depressions that may have been caused mainly by scallops (*Pecten* sp.). More fine material appeared to be present overlying coarse-grained sand in some areas.

The railroad wheel did not show any evidence of scour around it or deposition upon it (Figure 4-8). The main change was the abundance of organic activity, including both weeds and organisms that surrounded it. Eel pout (*Macrozoarces americanus*), goosefish (*Lophius americanus*), lobsters (*Homarus americanus*), and other organisms were using the railroad wheel as a habitat and probably nullified the effects that scour or deposition might have had. The organisms observed in the area appeared to be as rich and diverse as the year before.

Station 4502--In Great South Channel, the currents were extremely strong and observations difficult. Current speeds were estimated as exceeding 75 cm/sec. No ripples were observed during the two dives; ripples may not have developed due to the high current speeds and

Figure 4-7. Bottom sediments at Station 4502 were composed of sand and gravel overlain by gelatinous spherules. The spherules were sampled and identified as tunicates.

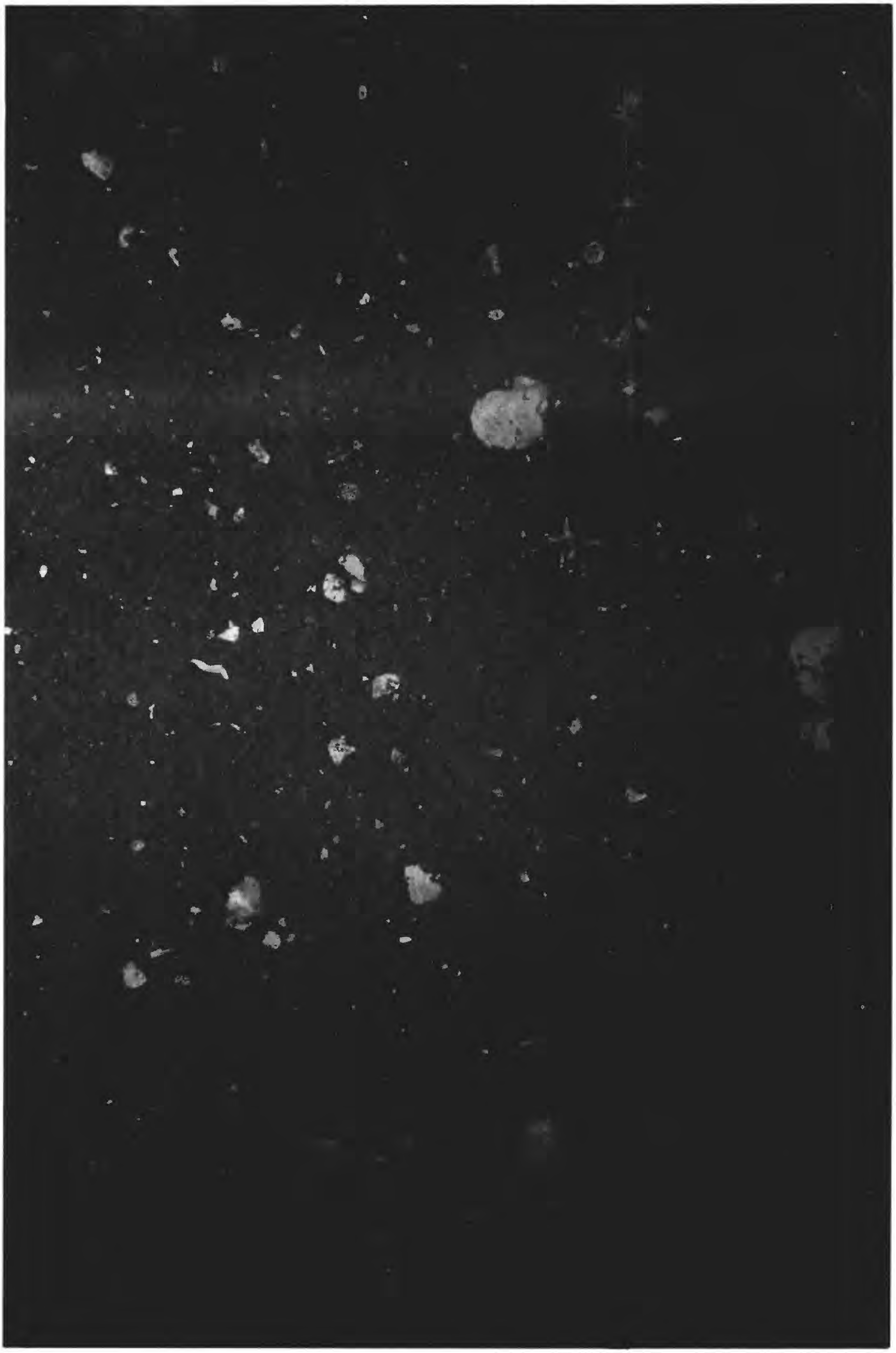


Figure 4-7

Figure 4-8. Bottom photos at Station 4503 reveal little scour or deposition around the railroad wheel between October 1975 (top) and July 1976 (bottom). Growth had accumulated on the wheel during the year.

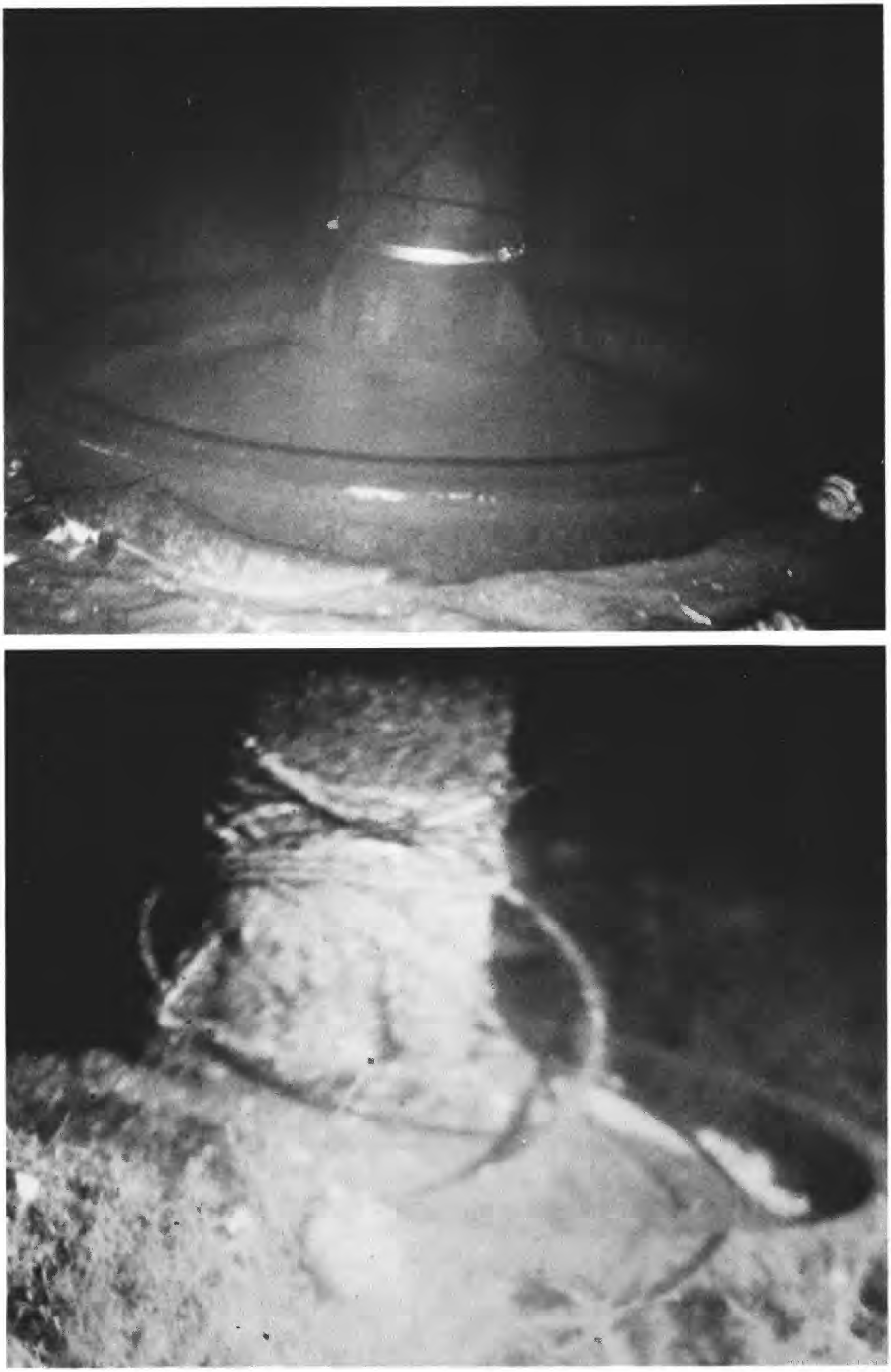


Figure 4-8

resulting sheet flow. Coarse sand and gravel were most common on the bottom; some of the finer material was actually being transported with the current, along with such organisms as starfish. Because of these high current speeds, the submersible could not be maneuvered adequately to conduct an effective search for the railroad wheel and the pipe that had been set there the previous year. Observation of the distribution of organisms on the bottom was not possible because everything was in motion.

Station 107--Two dives conducted nearby at mooring site 107 revealed a significantly different bottom, though water depth was only about 8 meters shallower (77 meters). Large asymmetric sand waves with wave lengths of 1 to 3 m and wave heights of 6-7 m lay with crests oriented in an east-west direction. Some of these were actually isolated waves or small dunes that lay on a gravel boulder pavement. The tide had apparently just changed before one dive took place because the sand was being transported up the south-facing steep slope, reversing the asymmetry of the bedform. The organisms at or near the bottom were varied and included hake (Urophycis chuss), skate (Raja ocellata and R. erinacea), cod (Gadus callarias), rays, eel pout (Macrozoarces americanus), sand dollars (Echinarachnius parma), fiddler crabs (Uca sp.), and shrimp (Crangonidae, Pandalidae). Most of the white shell debris that was observed consisted of clam shell fragments. Because of the high current speeds, some of the smaller shells were being rolled along by the current.

Station 110--One short (48 minute) dive was carried out to assess the bottom conditions along the north flank of the Bank in 85 m of water. There, the bottom was devoid of ripple marks and was composed of hard-packed medium-grained sand that was covered almost everywhere by brittle stars (Ophiuroidea)(Figure 4-9). A 1,000-kg mooring anchor for the buoy that had been set several months before to locate the station had barely sunk into the sand and showed no evidence of scour around it. This was consistent with the observations of the bottom current speeds which were between only 0 and about 10 cm/sec. The organisms observed here, aside from the ubiquitous brittle stars, were eel pout (Macrozoarces americanus), hake (Urophycis chuss), crabs (Cancer borealis), flounder, and scallops (Pecten sp.). The dive was terminated due to fog.

RESULTS

The 17 dives and associated observations from the surface on these two short cruises have served two useful purposes. (1) The dives have allowed us to characterize the geological and biological conditions on the bottom and their interrelationships that would have been otherwise impossible to acquire from the surface alone. (2) The understanding gained of the actual bottom conditions has allowed us to design the tripods and other sampling equipment to gain the maximum information possible from both in situ and surface observations.

Clearly, the maximum current speeds and associated bottom sediment movement took place in waters less than 50 m deep on the Bank top and in Great South Channel which serves as a conduit for flow from the Gulf of Maine. In these areas, then, stability problems due to scour will be greatest, and excavation problems, where large lag gravel and boulder deposits occur, will be most difficult. The submersible could only acquire information under relatively calm conditions, and thus scour associated with high sea states can only be gained by indirect in situ observations.

Figure 4-9. In 1976 at Station 110, the bottom was composed of hard sand partially covered by brittle stars (Ophiuroidea).

Figure 4-9

The suspended matter observed in the water column can influence the distribution of pollutants. Presumably, the material observed during the dives represents minimum concentrations because conditions during dives were relatively quiet. However, the largely organic layer that was observed in the water column in the south flank of the Bank in 1976 could interact with any pollutant settling into it; it might either retard or enhance settling, depending on the nature of the material.

The mobility of the sediment on the bottom, particularly in shallow areas and in Great South Channel, clearly influences the distribution and character of the ubiquitous organisms in the area. Any pollutants introduced into these areas obviously can be distributed rapidly over large distances by the high current speeds and mixed into the mobile substrate. Thus, the rich organic benthic and epibenthic life could be affected over a wide area in a short period of time. Conversely, the widespread mixing of the water column and the sediment movement could also dilute pollutants rapidly, perhaps to levels that would not affect organisms seriously. These problems can only be resolved over a period of time with detailed future observations.

ACKNOWLEDGEMENTS

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included R. Slater, J. O'Donnell, R. Zahoran, and C. Parsons.

LITERATURE CITED

Bumpus, D.F. 1976. Review of the physical oceanography of Georges Bank, International Commission of Northwestern Atlantic Fisheries Research Bulletin, v. 12, Dartmouth, Nova Scotia, Canada.

Csanady, G.T. 1974. Barotropic currents over the continental shelf: J. Phys. Oceanogr.: v. 4, no. 3, p. 357-371.

Emery, K.O. and Elazar Uchupi. 1965. Structure of Georges Bank: Marine Geology, v. 3, no. 6, p. 349-358.

Emery, K.O. and Elazar Uchupi. 1972. Western North Atlantic Ocean, topography, rocks, structure, water, life, and sediments: Am. Assoc. Petroleum Geol. Mem. 17, 532 p.

Ericson, D.B., Maurice Ewing and B.C. Heezen. 1952. Turbidity currents and sediments in North Atlantic: Am. Assoc. Petroleum Geol. Bull., v. 36, no. 3, p. 489-511.

Hathaway, J.C. 1971. Data file Continental Margin Program Atlantic Coast of the United States. v. 2 of Sample collection and analytical data: Woods Hole Oceanographic Institution Reference No. 71-15, 496 p.

Hathaway, J.C., J.S. Schlee, C.W. Poag, P.C. Valentine, E.G.A. Weed, M.H. Bothner, F.A. Kohout, F.T. Manheim, R. Schoen, R.E. Miller, and D.M. Schultz. 1976. Preliminary summary of the 1976 Atlantic Margin Coring Project of the U.S. Geological Survey: U.S. Geological Survey Open File Report 76-884, 217 p.

Hulsemann, J. 1967. The continental margin off the Atlantic coast of the United States-carbonate in sediments, Nova Scotia to Hudson Canyon: Sedimentology v. 8, no. 2, p. 121-145.

in the structure off the continental shelf off northeastern United States: Marine Geology, v. 6, p. 5-43.

Lewis, R.S. and R.E. Sylwester. 1977. Shallow sedimentary framework of Georges Bank, U. S. Geological Survey Open-File Report 76-874.

Oldale, R.W., J.C. Hathaway, W.P. Dillon, J.D. Hendricks, and J.M. Robb. 1974. Geophysical observations on northern part of Georges Bank and adjacent basins of Gulf of Maine: Am. Assoc. Petroleum Geol. Bull., v. 58, no. 12, p. 2411-2427.

Ross, D.A. 1968. Geological observations from ALVIN: Woods Hole Oceanographic Institution Reference No. 69-13, p. 71-72.

Ryan, W.B.F., M.B. Cita, E.L. Miller, D. Hanselman, W.D. Nesteroff, B. Hecker, M. Nibbelink. 1978. Bedrock geology in New England submarine canyons. Oceanologica Acta. vol. 1. No. 2. p. 233-254.

Schlee, John. 1968. Sand and gravel on the continental shelf of the northeastern United States: U.S. Geological Survey Circular 602, 9 p.

______, and R.M. Pratt. 1970. Atlantic continental shelf and slope of the United States-gravels of the northeastern part: U.S. Geological Survey Professional Paper 529H, 39 p.

______, R.E. Mattick, D.J. Taylor, O.W. Girard, J.A. Grow, E.C. Rhodehamel, W.J. Perry, Jr., K.C. Bayer, M. Furbush, C.P. Clifford, and J.A. Lees. 1975. Sediments, structural framework, petroleum potential, environmental conditions, and operational considerations of the United States North Atlantic Outer Continental Shelf: U. S. Geological Survey Open-File Report 75-353, 179 p.

Stetson, H.C. 1937. Current measurements in the Georges Bank canyons:

Am. Geophys. Union Trans. 18th Annual Meeting, July 1937. p. 216-219.

______. 1949. The sediments and stratigraphy of the east coast continental margin. Georges Bank to Norfolk Canyon: Mass. Inst. of Technology and Woods Hole Oceanographic Inst. Papers in Physics, Oceanography and Meteorology, v. 11, no. 2, p. 1-60.

Stewart, H.B., Jr., and G.F. Jordan. 1964. Underwater sand ridges on Georges Shoal in Miller, R.L. ed., Papers in Marine Geology, F.P. Shepard Commemorative Volume: New York, MacMillan Co. p. 102-114.

Trumbull, J.V.A. and M.J. McCamis. 1967. Geologic exploration in an east coast submarine canyon from a research submersible: Science v. 158, p. 370-372.

Uchupi, Elazar. 1963. Sediments on the continental margin off eastern United States in Geological Survey Research 1963: U. S. Geological Survey Professional Paper 475-C, p. C132-C137.

______. 1968. The Atlantic continental shelf and slope of the United States-Physiography: U. S. Geological Survey Professional Paper 529C, 30 p.

Uzmann, J.R., R.A. Cooper, R.B. Theroux and R.L. Wigley. 1977. Synoptic Comparison of three sampling techniques for estimating abundance and distribution of selected megafauna: Submersible V.S. Camera Sled V.S. other Trawl. MFR Paper 1273 Marine Fisheries Review, vol. 39. no. 12.

U. S. Department of the Navy. 1954. Feasibility Report on Texas Towers Part 1, 62 p.

Wigley, R.L. 1961. Bottom sediments of Georges Bank: Journal of Sed. Petrology, v. 31, no. 2, p. 165-188.

CHAPTER 5

SHALLOW SEDIMENTARY FRAMEWORK AND RELATED POTENTIAL GEOLOGIC HAZARDS OF THE GEORGES BANK AREA

Ralph S. Lewis, Richard E. Sylwester, John M. Aaron,
David C. Twichell, and Kathryn M. Scanlon

CHAPTER 5

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ABSTRACT

Two thousand nine hundred kilometers of minisparker data were collected on Georges Bank by the U. S. Geological Survey during October 1975. Several sedimentary features were observed in the data. Georges Bank is a compound feature resulting from erosion of Tertiary coastal plain strata followed by deposition of an extensive wedge of sediment on the western flank of the cuesta. Marine planation (probably late Pleistocene) produced an erosion surface roughly paralleling the present seafloor. The truncated bank surface was blanketed by a veneer of late Pleistocene drift which masks underlying features and which is being reworked by modern processes; thus, present bank morphology is inferred to be recent.

This reconnaissance survey provides a framework for evaluation of more detailed seismic data and a guide for collection of cores for geotechnical analysis, both of which are essential for a second level assessment of geologic hazards in the area.

INTRODUCTION

During fall 1975, the U. S. Geological Survey conducted a reconnaissance geophysical survey of Georges Bank. The work included high-resolution (minisparker) coverage carried out in conjunction with seismic and magnetic studies of deeper structure. This is a report of the analysis of minisparker data collected during the study. The data represent the most complete seismic coverage of Georges Bank undertaken to date, and the analysis has led to a broadening of our understanding of the stratigraphy and structure of the upper 350 m of the bank. Minisparker data are also instrumental in the assessment of geologic hazards, which must concern those who wish to initiate drilling programs or consider placement of bottom supported structures on Georges Bank. It is our purpose to discuss several features recognizable in the data, provide a plausible explanation for the relationships observed, and briefly discuss their environmental significance. The high-resolution data were acquired for and funded by the Bureau of Land Management under Memorandum of Understanding AA550-MU6-29.

METHODS

Our findings are based on 22 high-resolution seismic lines obtained during the third U. S. Geological Survey cruise aboard the R/V FAY, between 2 October and 17 October 1975. Approximately 2,900 km of the bank was surveyed using a Del Norte 800 joule sparker and a 200 element hydrophone (Figure 5-1). Northwest-southeast trending track lines were spaced about 25 km apart, and the east-west lines about 50 km apart. Navigation was based on 15 minute Loran C fixes supplemented by Loran A. Reflected seismic signals were filtered between 200 and 1,000 Hz and displayed on a dry paper graphic recorder. Ship speed averaged 5 knots during the cruise.

INTERPRETATION OF RECORDS

Tracings of reflectors observed on the seismic records were reduced to interpretive line drawings (distance vs depth), assuming sound velocities of 1.5 km/sec in seawater and 1.7 km/sec in bank sediment (L. McGinnis, Northern Illinois University, oral communication, 1976).

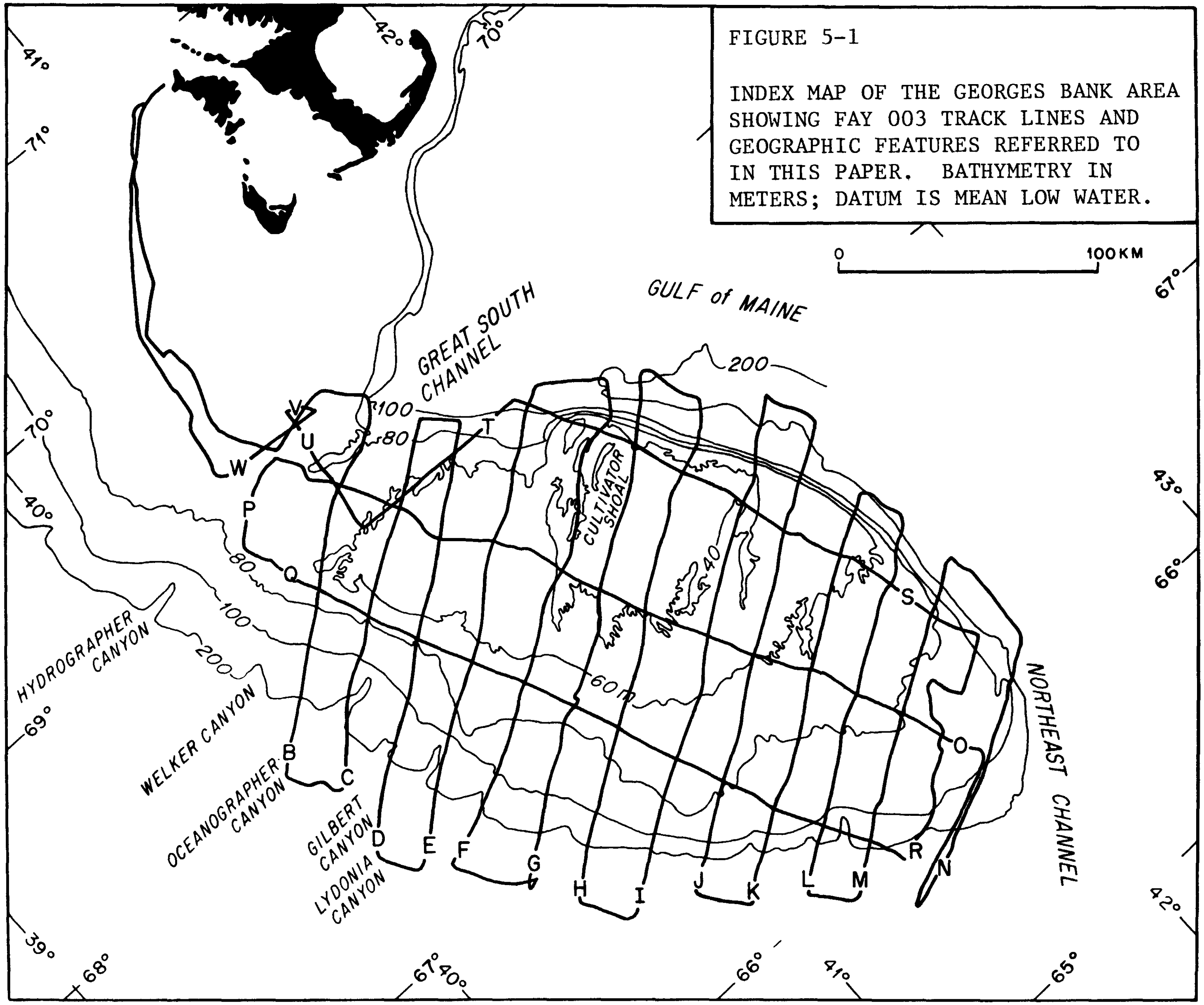


FIGURE 5-1

INDEX MAP OF THE GEORGES BANK AREA SHOWING FAY 003 TRACK LINES AND GEOGRAPHIC FEATURES REFERRED TO IN THIS PAPER. BATHYMETRY IN METERS; DATUM IS MEAN LOW WATER.

Interpretive sections were also corrected for variations in ship speed. Vertical exaggeration is approximately 40X on line drawings.

DISCUSSION OF DATA

The deepest acoustical reflector visible on the records, reflector C, lies at or near the limit of minisparker penetration and is observed on a limited number of track lines (Plate 5-2, line J; in pocket). Where reflector C is visible it appears to dip slightly to the south, deepening from about 275 m to about 325 m below sea level, southward across the bank.

Reflector C is unconformably overlain by a series of sub-parallel southeast dipping reflectors herein termed the "T" sequence. Track line J (Plate 5-2) illustrates this angular relationship and reveals a southeastward thickening of the sequence, as evidenced by the southeastward divergence of several major internal reflectors (identified by a T on the record). Analysis of the northern 10-20 km of lines J, K, and L indicates that the sequence is terminated at an erosional scarp along the northern edge of Georges Bank.

West of track line I and east of track line J the "T" reflectors are unconformably overlain by sediment wedges which thicken southeastward and southwestward from the mid-bank region. Figure 5-2 presents an idealized east-west section illustrating this relationship, and Figure 5-3 shows the inferred areal extent of these "eastern" and "western" wedges.

Sediments composing the western wedge thicken southward along lines C, D, and E (Plate 5-1, in pocket) and westward along lines O, Q, and S (Plate 5-4, in pocket). As previously mentioned, the underlying "T" sequence dips southeastward along line S, deepening from about 150 m

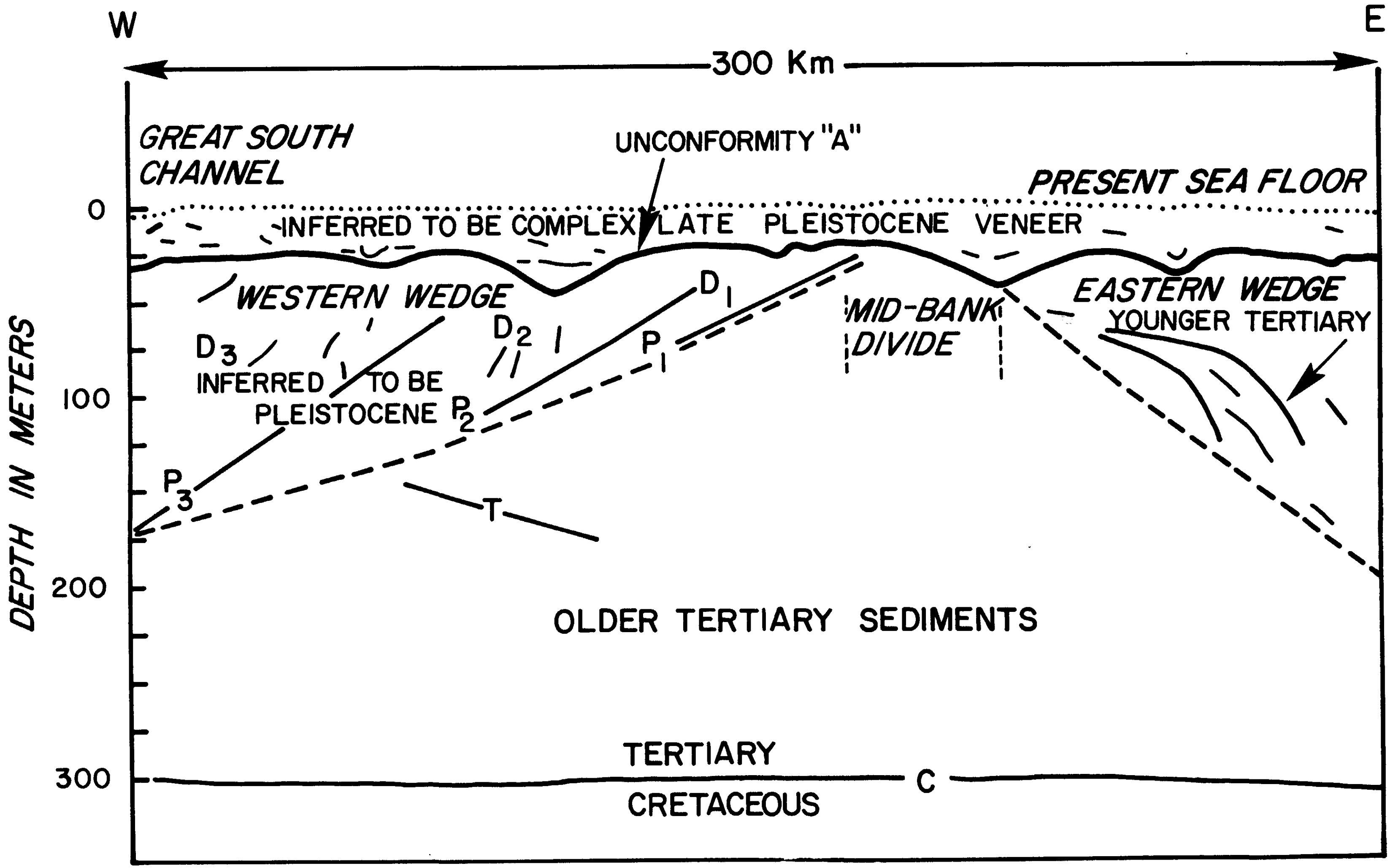


Figure 5-2. Idealized east-west cross section of Georges Bank, showing principal stratigraphic relationships inferred from seismic reflection data. Not to scale. P_1, P_2 and P_3 represent erosional events (unconformities); D_1, D_2 and D_3 are intervals of sediment deposition with irregular discontinuous seismic reflectors. The dashed lines bounding the older Tertiary sediments are major unconformities. The relative dip of the older Tertiary sediments is indicated by the line at the letter T.

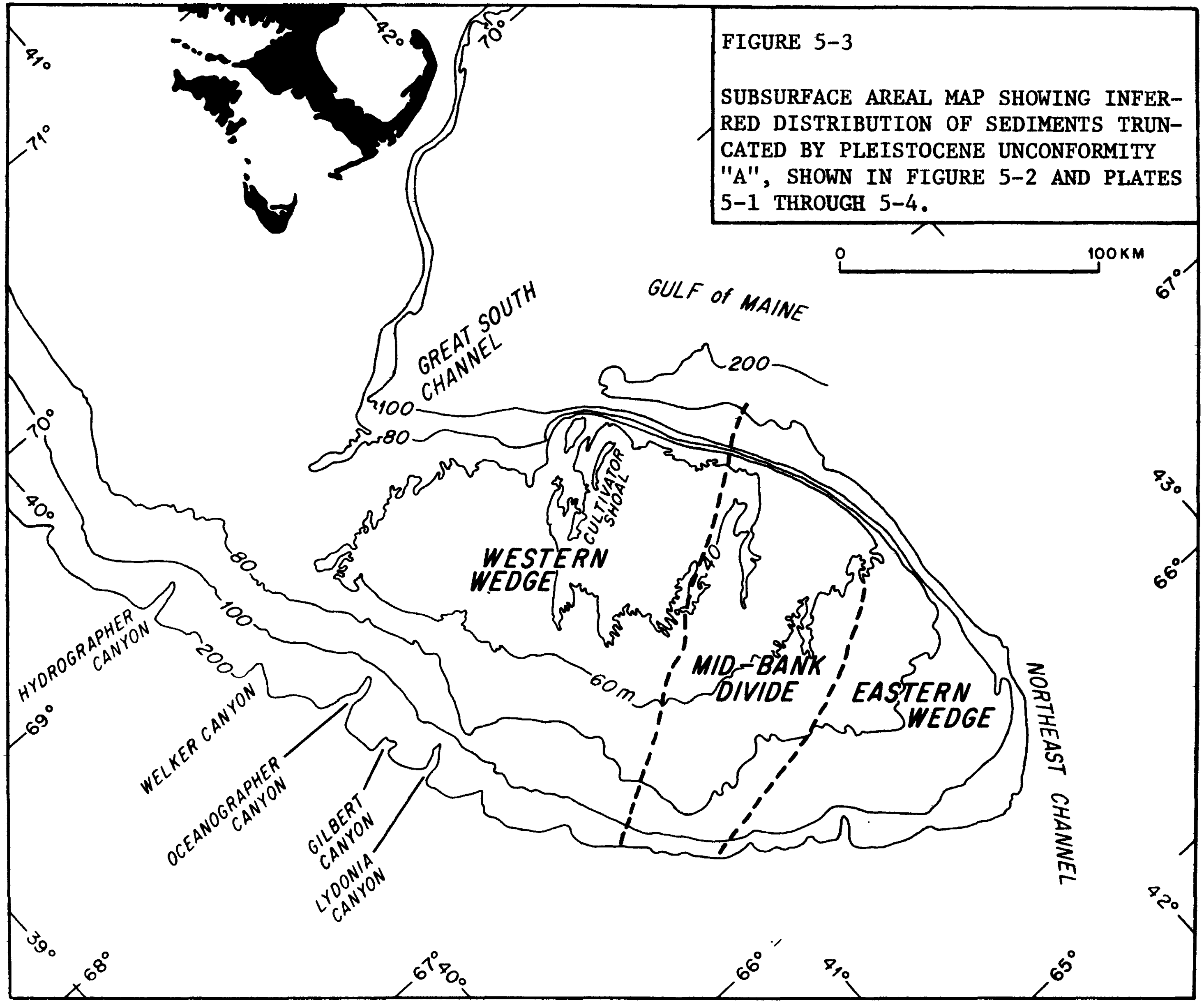


FIGURE 5-3

SUBSURFACE AREAL MAP SHOWING INFERRED DISTRIBUTION OF SEDIMENTS TRUNCATED BY PLEISTOCENE UNCONFORMITY "A", SHOWN IN FIGURE 5-2 AND PLATES 5-1 THROUGH 5-4.

below sea level in the west to about 350 m below sea level in the east. Wedge sediments can be differentiated from this underlying material because they exhibit a reversal of dip relative to the "T" sequence. A three-dimensional view of the wedge can be constructed by viewing the intersection of track lines C, D, E, and F (Plate 5-1) with line Q (Plate 5-4). Throughout the area west of track line I sediments overlying the "T" sequence dip southwestward into the present Great South Channel.

Detailed analysis of the western wedge (line Q, Plate 5-4) reveals structures resembling foreset bedding. These structures, designated D_1, D_2, and D_3 on Figure 5-4, are sandwiched between more continuous southwest dipping reflectors, P_1, P_2, and P_3. The section depicted by Figure 5-4 represents a shingling of progressively younger sediments westward along line Q. The foreset-like structures are truncated by more gently dipping erosion surfaces which are, in turn, overlain by still younger structures, a relationship suggestive of cyclic periods of erosion followed by deposition. Three such cycles of erosion and deposition are shown in Figure 5-4. A similar sequence of events is noted southward along track lines C, D, E, and F (Plate 5-1).

Eastern wedge sediments do not resemble those to the west and are, in fact, separated from them by a narrow north-trending zone termed the "Mid-Bank Divide" (Figure 5-3). Sedimentary structures of the eastern wedge rest unconformably on older "T" sequence material and resemble a southeastward prograded delta complex. They can be differentiated from the underlying "T" sequence by numerous discontinuous internal reflectors which form an angular relationship to the older, more gently dipping, sediments below. The eastern wedge thickens southeastward from the Mid-Bank region. Structures composing this wedge are massive

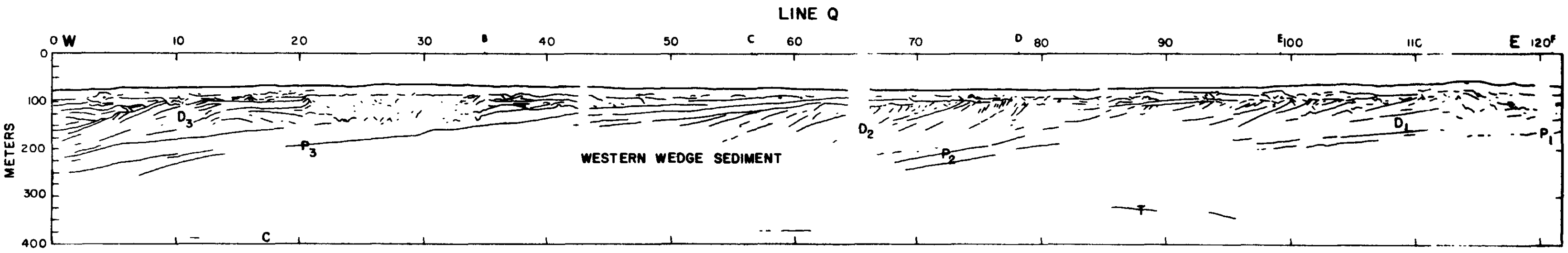


FIGURE 5-4. LINE DRAWING OF THE WESTERN END OF PROFILE LINE Q SHOWING WESTWARD SHINGLING OF REFLECTORS. P_1, P_2, AND P_3 DEPICT EROSIONAL EVENTS (UNCONFORMITIES); D_1, D_2, AND D_3, ARE PERIODS OF SEDIMENT DEPOSITION. B, C, D, E, AND F SHOW POSITION OF CROSS LINES. SCALE ACROSS TOP IS IN KILOMETERS.

features that show no evidence of the cyclic events noted in the western third of Georges Bank. Track line L (Plate 5-2) provides a good illustration of the eastern wedge and its relationship to underlying horizons. The mid-bank divide area is composed of "T" sequence material, which is truncated 20 to 80 m below the present seafloor by an ubiquitous unconformity, reflector "A," that truncates all pre-existing bank structures and results in the separation of eastern and western wedge sediments (Figure 5-3). Unconformity A is identified on several of the records presented in Plates 5-1 to 5-4.

The shallow unconformity deepens southward, averaging 60-80 m below sea level under the northern bank and 90-120 m below sea level to the south. Unconformity A is incised by many channels (lines J, K, and L, Plate 5-2) to depths of 20-40 m. Cross-sections of several of these channels are asymmetric, having long, gentle south facing walls and short, steeply-sloping north facing walls (line K, Plate 5-2). Many of the channels have a complex cut-and-fill history, appearing to have been rechannelled and subsequently filled with younger material. In some places more recent channelling has incised older channels, further deepening unconformity A.

The sediment cover blanketing unconformity A is fairly uniform (20-50 m) except in areas of localized channel filling or shoaling where the cover may thicken to 80 m. Large areas of the sediment blanket are devoid of internal reflectors but occasionally it contains discontinuous, flat-lying reflectors.

Modern processes are reworking the sediment veneer to form sand waves and dune-like features that are concentrated in the northern portion of the bank (Plate 5-5, in pocket). The data suggest that these large features, such as Cultivator Shoal (line S, Plate 5-4) are migrating over former seafloor surfaces, which appear as flat-lying reflectors underlying the reworked material.

SUMMARY OF MAJOR SHALLOW FEATURES

A deep, nearly flat-lying reflector (C) is overlain by a sequence of sub-parallel, continuous, southeast-dipping reflectors ("T" sequence). These sediments are thickest in the mid-bank divide region. West of the Mid-Bank area the "T" sequence is overlain by an extensive wedge of southwest dipping sediment. The wedge thickens westward from the mid-bank divide region and southward across the bank. The northern half of the wedge is thinner than its southern extension, dips more gently to the southwest, and lacks the cyclic repetition of structures that are observed to the south.

In the eastern third of the bank the "T" sequence is overlain by massive, prograded, delta-like structures. These features thicken southeastward from the mid-bank divide region and do not contact the western wedge material.

The bank has been truncated by an erosion surface 20-80 m below the present seafloor. This ubiquitous unconformity is a complex surface incised by stream channels. Sediments above the unconformity form a nearly uniform blanket of sediment. Numerous episodes of cutting and filling are indicated by reflectors within the sediment blanket. The present seafloor nearly parallels the shallow unconformable surface, except where modern processes are reworking surficial deposits.

GEOLOGIC SIGNIFICANCE

Georges Bank has long been recognized as a remnant of the coastal plain, nearly isolated from the surrounding continental shelf by erosion of the Gulf of Maine, Great South Channel, and Northeast Channel

(Garrison, 1970; Ballard and Uchupi, 1974; Emery and Uchupi, 1965; Knott and Hoskins, 1968). Bank morphology generally is attributed to late Tertiary erosion and to the effects of glaciation. Estimates of the extent of Pleistocene deposition on Georges Bank vary from a few meters to the 100 m of glacial deposition proposed by Knott and Hoskins (1968).

Reflector C has been identified as the Cretaceous-Tertiary boundary (Emery and Uchupi, 1965) and is described as a gently southward-dipping erosion surface. The thick sequence of sub-parallel, southeast-dipping Tertiary reflectors overlying the Cretaceous-Tertiary boundary, termed the "T" sequence in this discussion, is reported to be up to 270 m thick by Emery and Uchupi (1965).

Inferences drawn from minisparker data indicate that Georges Bank is a compound feature resulting from erosion of Tertiary coastal plain strata followed by deposition of an extensive sedimentary sequence on the western flank of a coastal plain divide. Oldale and others (1974, p. 2426) stated, "Toward the end of Tertiary time, during the Pliocene and possibly continuing into early Pleistocene time, a major episode of subaerial erosion took place. Streams eroded the inner part of the coastal plain sedimentary wedge to form an interior lowland, the Gulf of Maine, and a large cuesta, Georges Bank. Northeast and Great South Channels were the water gaps for streams draining the interior lowland." The mid-bank divide region is inferred to be the southern extension of the divide recognized in the Gulf of Maine by Oldale and Uchupi (1970).

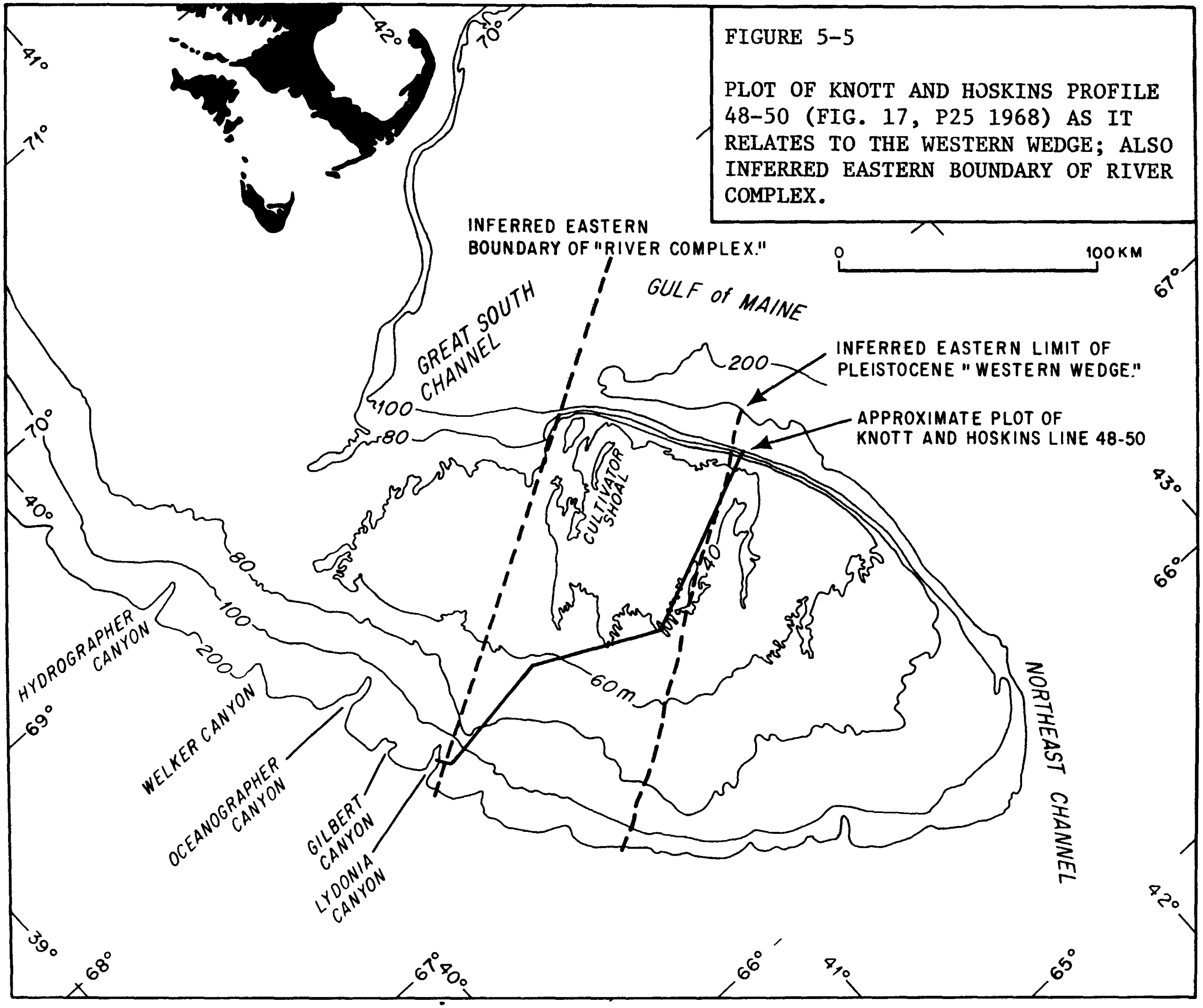
Late Tertiary to Quaternary erosion modified the coastal plain in the Georges Bank area much more than previously has been recognized, and removed much of the Tertiary section west of the divide. The western lowland is presently choked with an extensive sedimentary sequence that has filled the water gap and has buried the cuesta remnant on the western flank of the divide. Filling occurred during several (at least 3) episodes of erosion (P_1, P_2, P_3) followed by deposition (D_1, D_2, D_3). The sequence of 5 Pleistocene events described by Knott and Hoskins (1968) is, in fact, the sedimentary sequence filling Great South Channel (note plot of Knott and Hoskins line on Figure 5-5). It is important to recognize that much of the western half of Georges Bank is composed of material which post-dates the formation of the western lowland.

The eastern boundary of the old Great South Channel water gap may be indicated by an abrupt change in topography along the northern flank of the modern bank. Slightly west of Cultivator Shoal, the character of the bank edge changes from a distinct break in slope to a ramp-like feature (Figure 5-5). To the south, Lydonia, Gilbert, Oceanographer, Welker, and Hydrographer Canyons probably mark major outlets of the stream complex which formed the western lowland. Schlee and others (1975, p. 9) believe the canyons were eroded in late Tertiary and Quaternary time by streams carrying copious amounts of sediment to the upper slope during glacial stages when sea level stood at the present shelf edge. Note the position of Lydonia Canyon as it relates to the north bank ramp (Figure 5-5). A line extending from the eastern edge of the ramp to Lydonia Canyon (Figure 5-5) intersects track line E mid-way between cross lines O and Q. A feature resembling a west-facing valley wall appears on the seismic record near this point (Plate 5-1). The late Tertiary to Quaternary water gap of the western lowland is inferred to have extended eastward to these features (Figure 5-5).

The genesis of the eastern delta complex is not clear because no structural reversal occurs at the base of the complex. Southeast-dipping Tertiary material in the mid-bank region becomes younger to the southeast, and overlying deltaic sediments could

FIGURE 5-5

PLOT OF KNOTT AND HOSKINS PROFILE 48-50 (FIG. 17, P25 1968) AS IT RELATES TO THE WESTERN WEDGE; ALSO INFERRED EASTERN BOUNDARY OF RIVER COMPLEX.



represent an episode of Tertiary progradation. Outbuilding is believed to be important in the construction of the continental shelf west of Georges Bank (Garrison, 1970). If the deltaic sediment does indeed represent progradation during the formation of the coastal plain, the eastern half of Georges Bank is simply a remnant of the coastal plain cuesta truncated in a manner which exposes progressively younger parts of the Tertiary section eastward across the bank. In this instance, streams draining the interior lowland east of the divide simply breeched the cuesta in the area of the modern Northeast Channel and did not form a wide lowland east of the mid-bank region.

If one is inclined to insist on similar histories for both water gaps, the deltaic sequence must represent filling in a wide eastern lowland cut in Tertiary material by streams flowing east of the divide.

Certain inferences can be drawn from the seismic data in the absence of positive age dates for the sedimentary units of Georges Bank. Late Tertiary events in the bank region involved two drainage systems which flowed from an interior lowland, breeched the cuesta, and removed Tertiary material from the bank area. The two drainage systems are inferred to have differing histories because the genesis of the eastern delta complex seems dissimilar to that of the western fill sequence. Sediments choking the western lowland appear to represent cyclic upbuilding, interrupted by erosion, whereas those of the eastern complex are massive prograded structures, lacking evidence of cyclic events. Few outlet canyons are found along the shelf break south of Northeast Channel. This evidence supports the belief that the eastern half of Georges Bank is primarily composed of Tertiary coastal plain sediments, which include the delta complex.

Present bank morphology is a rather recent feature, having formed after the filling of the Great South Channel lowland. Marine planation truncated bank structures late in bank history creating an unconformable surface nearly parallel to the present seafloor. Pre-existing morphology was erased by this event, and sedimentation post-dating the planation has masked the underlying features. The surface of marine planation was later modified by subaerial erosion, as evidenced by the channels incising it. Post-planation sediments reveal a complex history of channel cutting and filling.

INFERRED GEOLOGIC HISTORY

During Cretaceous and most of Tertiary time the continental shelf was formed by upbuilding and outbuilding on the continental margin (Garrison, 1970). Deposition was interrupted at the beginning of the Tertiary Period by an episode of extensive erosion which is now represented by the unconformity at the top of the Upper Cretaceous coastal plain deposits (Oldale and others, 1974). The Lower Tertiary section was deposited over the unconformity as a southeastward thickening wedge. Younger Tertiary material is inferred to have prograded over the wedge, as it did south of Long Island (Garrison, 1970). Cretaceous strata were buried by at least 270 m of Tertiary sediments during shelf building (Emery and Uchupi, 1965). Some time in the late Tertiary, possibly during Pliocene time, an interior lowland formed in the Gulf of Maine area (Oldale and others, 1974).

As the Gulf of Maine deepened, a drainage divide formed, and two southward-flowing drainage systems developed on the coastal plain, east and west of the present bank (Figure 5-6 A). Further erosion in the Gulf of Maine and on the flanks of the divide removed coastal plain material surrounding the bank area and produced a cuesta cut in Tertiary strata (Figure 5-6 B). By early Pleistocene time, much of the Tertiary material composing the western flank of the cuesta is inferred to have been removed by fluvial and glacial erosion (Figure 5-6 C). Hydrographer, Welker, Oceanographer, Gilbert, and Lydonia Canyons probably formed during low stands of sea level as drainage outlets for a river complex flowing through the western lowland.

Drainage on the eastern flank of the cuesta probably removed much less of the Tertiary section. Erosion in the water gaps was confined to Tertiary coastal plain material and did not reach the Cretaceous strata.

Early Pleistocene glacial events deepened the Gulf of Maine and supplied great amounts of sediment to the Great South Channel lowland. The lowland was choked during early and middle Pleistocene time by episodic introduction of glacial material washed from the interior lowland (Figure 5-6 D). Prior to the final Pleistocene ice advance a transgression of the sea planed the bank and removed an undetermined amount of Pleistocene and Tertiary material (Figure 5-6 E). Subaerial erosion during the last glaciation modified the unconformity. Numerous stream channels incised the planation surface in the northeast corner of the bank (Figure 5-7). The channels decrease in number eastward across this area and probably represent the remains of a major late Pleistocene drainage system which flowed eastward to Northeast Channel from the Pleistocene bank surface. Subaerial exposure lasted long enough to produce the complex cut-and-fill relationships common in the late Pleistocene material blanketing the unconformity (Figure 5-6 F). Southward drainage appears to have been reestablished in Great South Channel where late Pleistocene channeling had removed older Pleistocene material.

As the last ice retreated, submergence of the bank resulted in

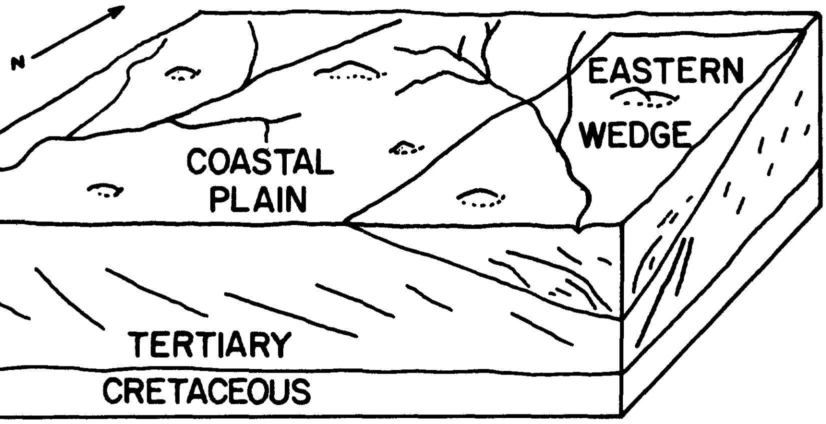

TERTIARY COASTAL PLAIN AND EARLY DRAINAGE

Figure 5-6 A

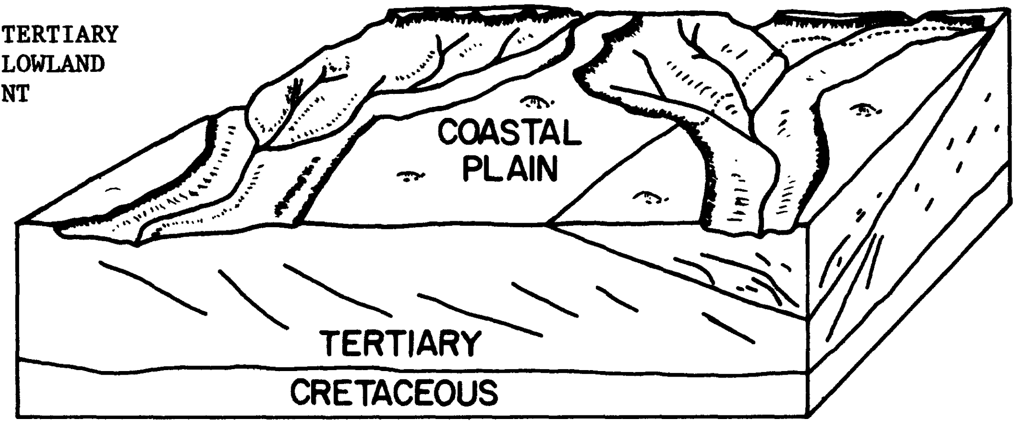

MID-LATE TERTIARY INTERIOR LOWLAND DEVELOPMENT

Figure 5-6 B

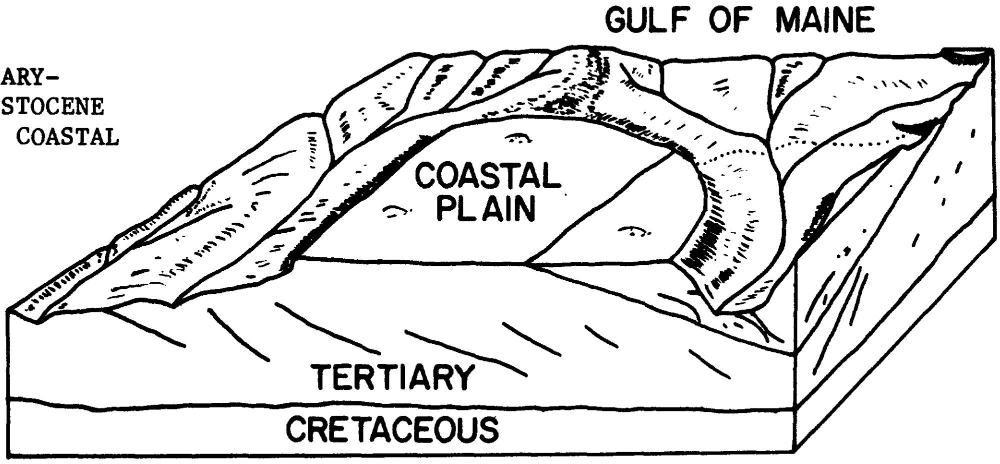

LATE TERTIARY-EARLY PLEISTOCENE EROSION OF COASTAL PLAIN

Figure 5-6 C

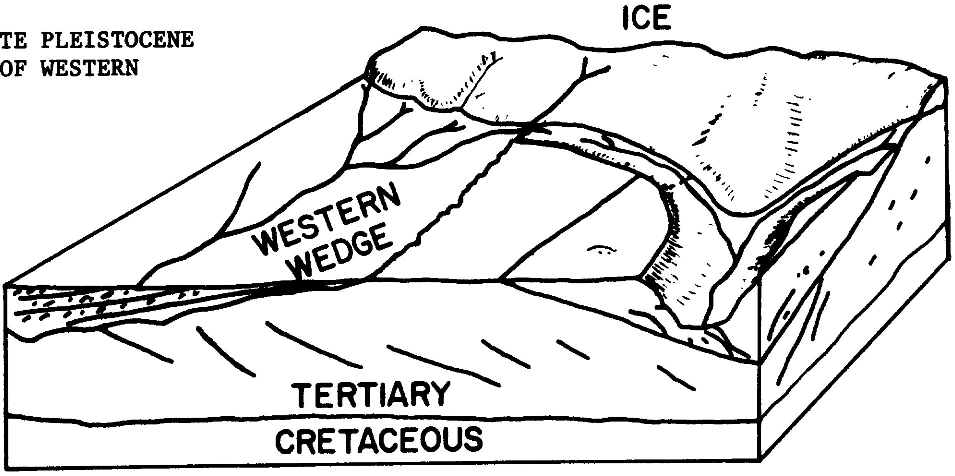

EARLY-LATE PLEISTOCENE FILLING OF WESTERN LOWLAND

Figure 5-6 D

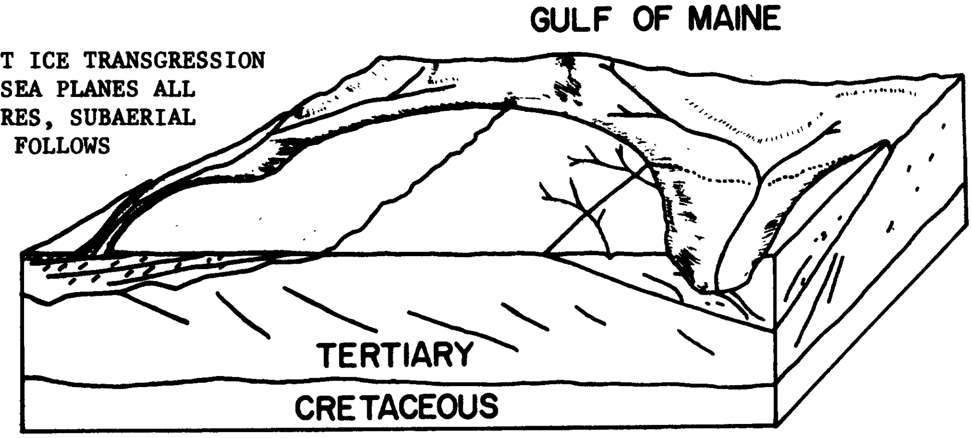

PRE-LAST ICE TRANSGRESSION OF THE SEA PLANES ALL STRUCTURES, SUBAERIAL EROSION FOLLOWS

Figure 5-6 E

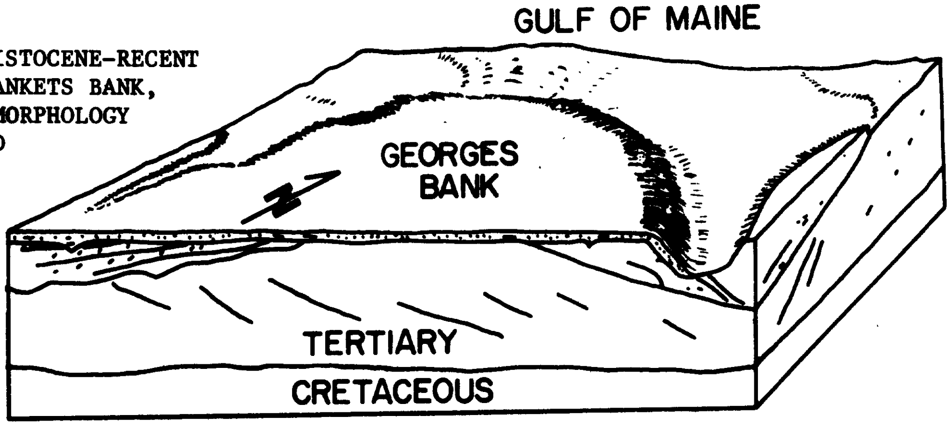

LATE PLEISTOCENE-RECENT DRIFT BLANKETS BANK, PRESENT MORPHOLOGY IS FORMED

Figure 5-6 F

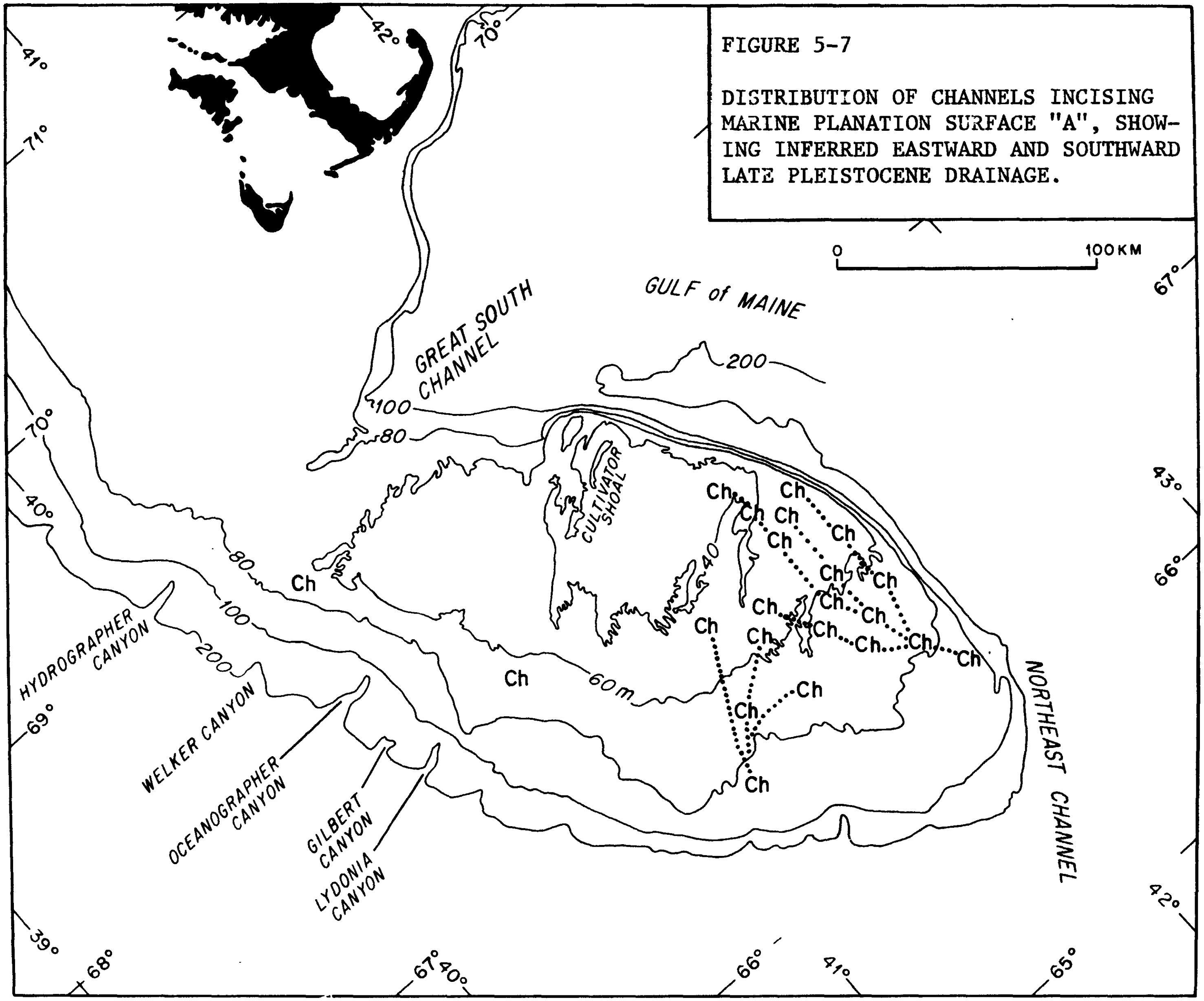


FIGURE 5-7

DISTRIBUTION OF CHANNELS INCISING MARINE PLANATION SURFACE "A", SHOWING INFERRED EASTWARD AND SOUTHWARD LATE PLEISTOCENE DRAINAGE.

reworking of the thin late Pleistocene blanket. Modern shoaling is a continuation of the submarine reworking process. The minisparker data do not reveal evidence of ice override or deformation along the north slope of the bank. The north bank edge appears to be an erosional feature, blanketed by younger material. Ice contact features may have been removed from the areas surveyed in this study by late Pleistocene marine planation, or ice may never have reached the bank. Seismic records covering the Great South Channel area also lack evidence of ice occupation. Sediments inferred to be of Pleistocene age in this report appear to have been deposited as outwash south of the ice sheets.

POTENTIAL GEOLOGIC HAZARDS

The seismic reflection techniques upon which this study is based suggest that several types of geologic hazards exist within the area of Georges Bank. However, as there is no established relationship between the acoustic and geotechnical properties of a sediment body, these seismic data do not provide specific geotechnical parameters on which to base engineering decisions. Such data are derived only from sampling and appropriate geotechnical analysis. The following can be considered potential hazards deserving further detailed study and analysis.

Mobile Sediment

The seafloor on Georges Bank is characterized in many places by large sand waves (Figure 5-8 and Plate 5-5). Sand waves are wave-like geometric configurations of the water-sediment interface that are formed by fluid flow over an erodible granular bed. Their presence indicates that fluid velocities are, or were, sufficient to erode and transport surficial sediment. Sand waves and similar bedforms are migratory features; their size, geometry, and speed and direction of movement are

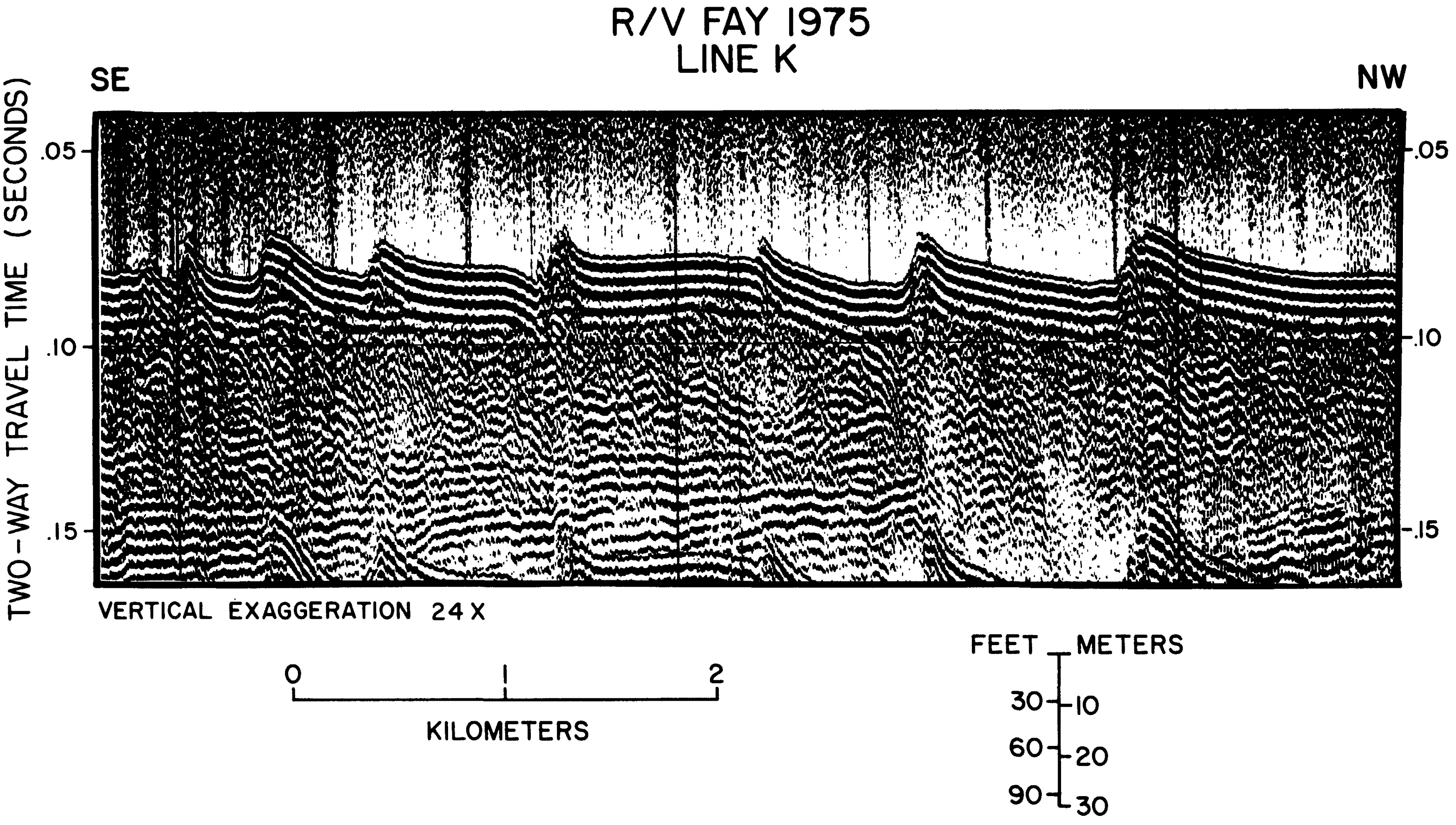


Figure 5-8. Seismic reflection profile showing sand waves on Georges Bank.

related to the grain size of sediments in the bed and to flow conditions such as water depth and current velocity.

Plate 5-5 shows the distribution of sand waves on Georges Bank, as evidenced in the 3.5 kHz and minisparker records of this survey. Sand waves are especially common in the shallower waters on top of the bank, in water depths of 60 m or less. Typically, these sand waves range in height from 5 to 15 m and in wave length from 150 to 750 m. The sharp asymmetry of the vast majority of sand waves on Georges Bank suggests that they are active, though very little is known about their migration rate. Stewart and Jordan (1964) showed that sand waves more than 8 m high on Georges Bank migrated a maximum net distance of 300 m westward over a 25 to 28 year period, in an area where current speeds ranged up to 2 kn (about 100 cm/sec).

The sediment mobility suggested by sand wave activity on Georges Bank suggests two kinds of potential hazards: (1) scour (erosion) of sediments around caissons, pipes, footings, or other bottom-supported structures could result in undermining and weakening of structures by differential settlement; and (2) deposition of excessive sediment around supporting members of structures could, in the extreme case, result in weakening of the structure by changing the resonant frequency for which it was designed (Garrison and Bea, 1977).

Unstable Shallow Sediment

Seismic reflection profiles show that the Pleistocene sediments that overlie Georges Bank are acoustically complex and contain reflectors interpreted to represent several episodes of channel cutting and filling (Figure 5-9). Some sediments are acoustically transparent and may represent reworked, disturbed, or organic-rich clays and silts. Seismic reflection data also show that the properties of the shallow

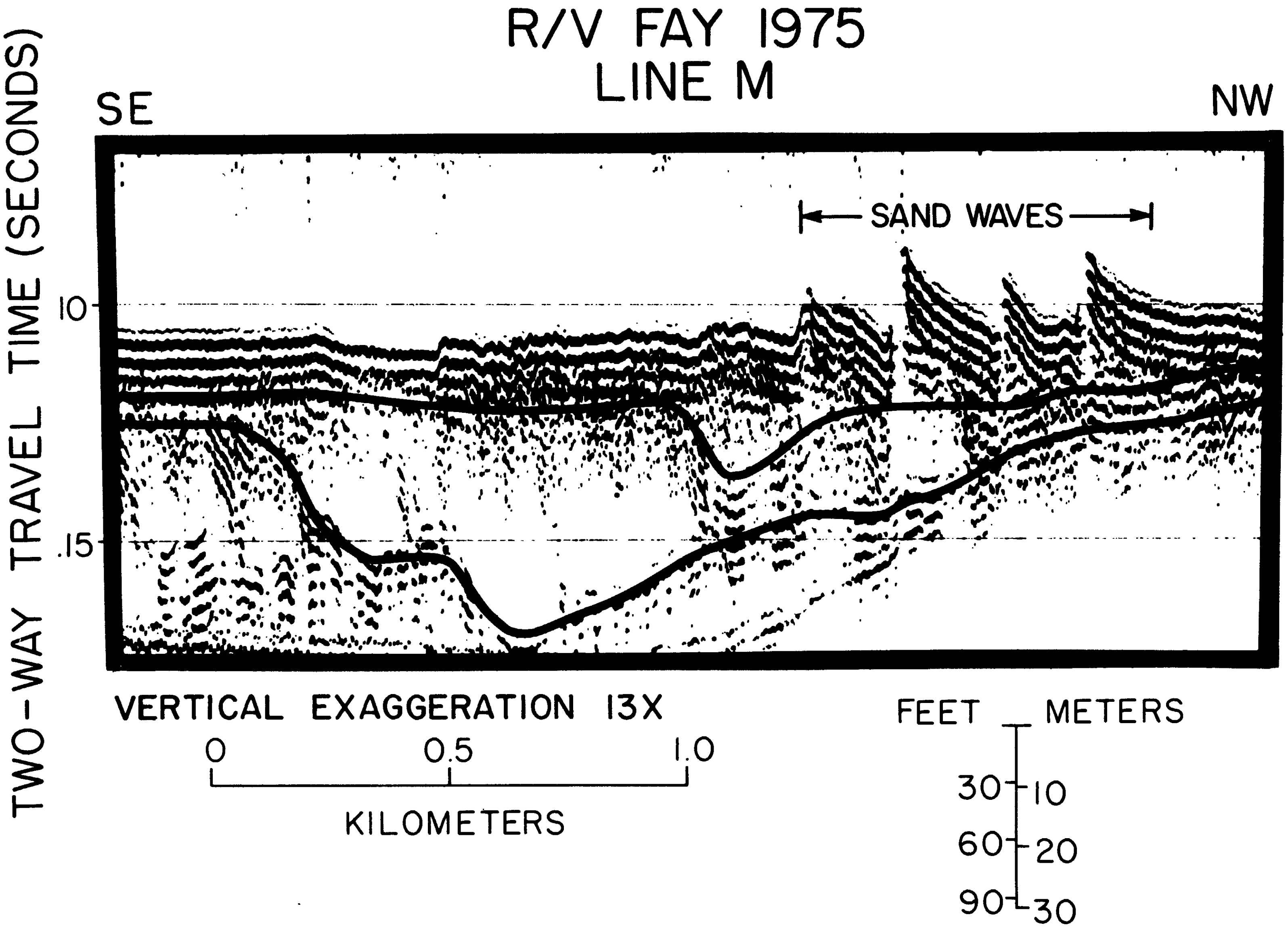


Figure 5-9. Seismic reflection profile showing buried channels on Georges Bank. Heavy lines depict two episodes of channel cutting.

sediments are quite variable and change dramatically over short distances, both laterally and vertically, especially in areas underlain by buried channels. If not recognized and appropriate mitigating action taken, sediments with such variable properties could settle differentially when loaded and thus could constitute a potential hazard to large structures erected in the area.

Plate 5-5 shows the distribution of buried channels as interpreted from the seismic reflection data gathered in this study. The wide spacing (25 km) of the track lines and the complexity of multiple episodes of channel cutting and filling do not permit a meaningful integration of data from line to line to show the ancient drainage network of Georges Bank.

Shallow Faults and Slump Features

No shallow faults or slumps were located in this study. However, these high-resolution seismic data are concentrated on the Continental Shelf. Data from the Continental Slope, where faulting and slumping are much more likely to occur on the considerably steeper slopes, are presently under study by the U. S. Geological Survey.

LITERATURE CITED

Ballard, R.D. and Uchupi, Elazar 1974. Geology of the Gulf of Maine: Am. Assoc. Petroleum Geologists Bull., vol. 58, no. 6, pp. 1156-1158.

Emery, K.O. and Uchupi, E. 1965. Structure of Georges Bank: Marine Geology, vol. 3, no. 5, pp. 349-358.

Garrison, L.E. 1970. Development of continental shelf south of New England: Am. Assoc. Petroleum Geologists Bull., vol. 54, pp. 109-124.

Garrison, L.E. and Bea, R.G. 1977. Bottom stability as a factor in platform siting and design: Offshore Technology Conference, Paper 2893, pp. 127-133.

Knott, S.T. and Hoskins, H. 1968. Evidence of Pleistocene events in the structure of the continental shelf off the northeastern United States: Marine Geology, vol. 6, no. 1, pp. 5-43.

Oldale, R.N., and Uchupi, E., 1970. The glaciated shelf off northeastern United States: U. S. Geological Survey Professional Paper 700-B, p. B167-B173.

Oldale, R.N., Hathaway, J.C., Dillon, W.P., Hendricks, J.D., and Robb, J.M. 1974. Geophysical observations on northern part of Georges Bank and adjacent basins of Gulf of Maine: Am. Assoc. Petroleum Geologists Bull., vol. 58, no. 12, pp. 2411-2427.

Schlee, J., Mattick, R.E., Taylor, D.J., Girard, O.W., Grow, J., Rhodehamel, E.C., Perry, W.J., Bayer, K.C., Furbush, M., Clifford, C.P., and Lees, J.A. 1975. Sediments, structural framework, petroleum potential, environmental conditions, and operational considerations of the United States North Atlantic outer continental shelf: U. S. Geological Survey Open File Report #75-353, 179 p.

Stewart, M.B., Jr. and Jordan, G.F. 1964. Underwater sand ridges on Georges Shoal, in R.L. Miller, ed., Paper in Marine Geology, Shepard Commemorative Volume: New York, MacMillan Co., pp. 102-114.