U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

STUDIES OF SUSPENDED MATTER ALONG THE NORTH AND MIDDLE ATLANTIC OUTER CONTINENTAL SHELF

by

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INTRODUCTION

Studies of suspended matter carried out on the North and Middle Atlantic Continental Shelf areas during 1978-1979 had the following specific objectives. The first was to evaluate the concentration and composition of suspended matter in the area of the shelf between Georges Bank and the Middle Atlantic States, an area not covered in previous work sponsored by the U.S. Bureau of Land Management. The second was to determine the variability of suspended-matter concentrations and compositions throughout the water column during a 24-hour period. The third was to utilize sediment traps at three locations on the Outer Continental Shelf to evaluate differences in the amounts and composition of resuspended bottom sediments at these three locations and to make rough estimates of the vertical flux of particulates. The final objective was to carefully document the suspended-matter regime above the area of fine-grained sediments south of Martha's Vineyard, referred to in this report as the "Mud Patch," which appears to be a modern sink for both sediments and sediment-related pollutants.

METHODS OF STUDY

Suspended-matter 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 about 1 m below the surface; one at middepth; and one 1-2 m above the bottom. Attached to the rosette sampler was a transmissometer, which continuously measured turbidity throughout the water column. Light transmission was displayed on deck; thus, an adjustment of exact sample depth to include interesting maxima or minima in light transmission was permitted. Samples were collected at the conductivity, temperature, depth (CTD) stations indicated in figure 1.

As soon as the rosette was secured on deck (usually within 15 minutes after sampling at station depths <150 m), subsamples of approximately 4 liters of water were taken from each sample bottle. Because the time between initial collection and subsampling was short, settling of larger particles (Gardner, 1977a) was minimized. The 4-liter subsamples were vacuum filtered from graduated cylinders (with bottom withdrawals) through in-line filter holders containing paired pre-weighed Millipore^R filters (nominal openings of 0.45 μm). The water was agitated periodically to avoid error due to settling of particles within the cylinder. Filters were then rinsed six to eight times with filtered distilled water (to remove salt) and frozen.

Upon return to the laboratory, the Millipore^R filters were air-dried (generally requiring 24-36 hrs) and weighed, the bottom filter being used as a control. After weighing, the filters were split, one-half being ashed at 500°C to measure the combustible fraction of the suspended material. A cut of the remaining half was immersed in optical oil and examined under a petrographic microscope to determine the constituents of the suspensate. More detailed examination of selected samples was carried out using the scanning electron microscope (SEM) with an X-ray fluorescence attachment for elemental analysis.

The dissolved nutrients: nitrate, nitrite, ammonia, phosphate, and silicate were analyzed by standard colormetric techniques. The analyses were performed by Z. Mlodzinska, Woods Hole Oceanographic Institution.

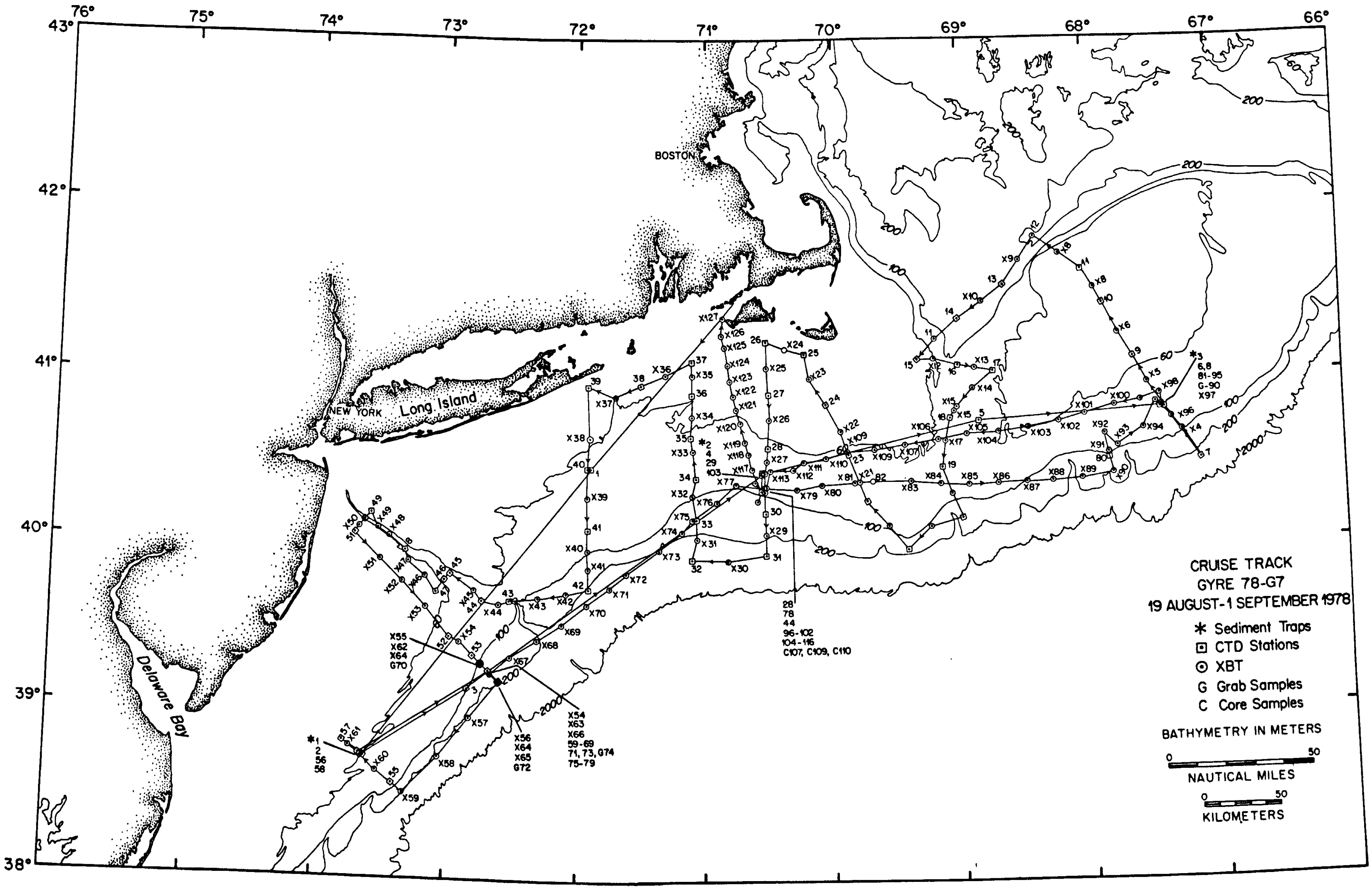


Figure 1. Underway XBT stations and stations occupied for suspended-matter and hydrographic (CTD) sampling during cruise aboard R/V GYRE August 19-September 1, 1978. Sediment-trap arrays were deployed at stations *1, *2, and *3. Twenty-four-hour stations with sample collections at approximately two-hour intervals were occupied at stations 54, 81, and 96.

Sediment traps (fig. 2) constructed by Jeffrey P. Ellis, Woods Hole Oceanographic Institution, consisted of PVC tubing 29 cm internal diameter and 76 cm long. This width/length ratio has nearly optimum trapping characteristics in currents up to 10 cm/s (Gardner, 1977b). A plastic funnel, fitted inside the trap approximately 35 cm from the top rim, directed suspended material into a wide-mouth 1 liter plastic bottle. During deployment a 2 cm mesh plastic net covered the top of the trap to prevent large nekton from entering. The closure mechanism consisted of a 35 cm diameter hollow plastic ball which was pulled into the top of the trap by surgical tubing (fig. 2) upon timed release.

To reduce bateriological decomposition of the material as it collected in the trap and to minimize resuspension of material out of the trap, a strong salinity gradient was maintained in the collection bottle. This was accomplished by evaporating a concentrated solution of reagent grade NaCl, prefiltered through a 0.45 μm Millipore filter, into the plastic jar. A layer of crystalline salt approximtely 10 cm thick conformed closely to the bottom of the jar (fig. 2).

This technique had the advantage of maintaining the salt in the trap collection vessel during the free-fall deployment of the trap array. At the time of recovery, a very strong density gradient and some remaining salt crystals were evident in each jar; which had the effect of minimizing turbulence and sediment loss from the bottles.

In most cases we found that the surgical tubing did not maintain a tight seal between the closing ball and the top of the trap at the time of recovery. Gentle surges of the trap assembly moved the ball off the trap opening and possibly added turbulence to the trap body. However, the appearance of the clear water above the sediment and the strong density discontinuity at the top of the bottle due to the saturated salt solution suggested that the samples were not resuspended and flushed out of the trap.

RESULTS

Distribution

The distribution and composition of suspended matter in surface and bottom waters is shown in figure 3. The concentration of total suspended matter in surface water exceeds 500 μg/l at the top of Georges Bank and southwest of Nantucket Shoals, where maximum surface concentrations of 730 μg/l were observed. Concentrations between 100 and 250 μg/l occur on the outer shelf south of Narragansett Bay and across both the middle and outer shelf of Long Island.

The suspended matter in surface waters is primarily organic in nature. The combustible fraction is typically >75% over most of the area and >90% at the near-shore end of Hudson Channel where high concentrations of nutrients and chlorophyll (discussed in a later section) suggest very high primary production. Surface waters of the central shoals of Georges Bank have combustible fractions of less than 50% and the highest concentration of noncombustible particulates. This is probably due to resuspension of bottom sediments in the well-mixed water column characteristic of this area during all seasons.

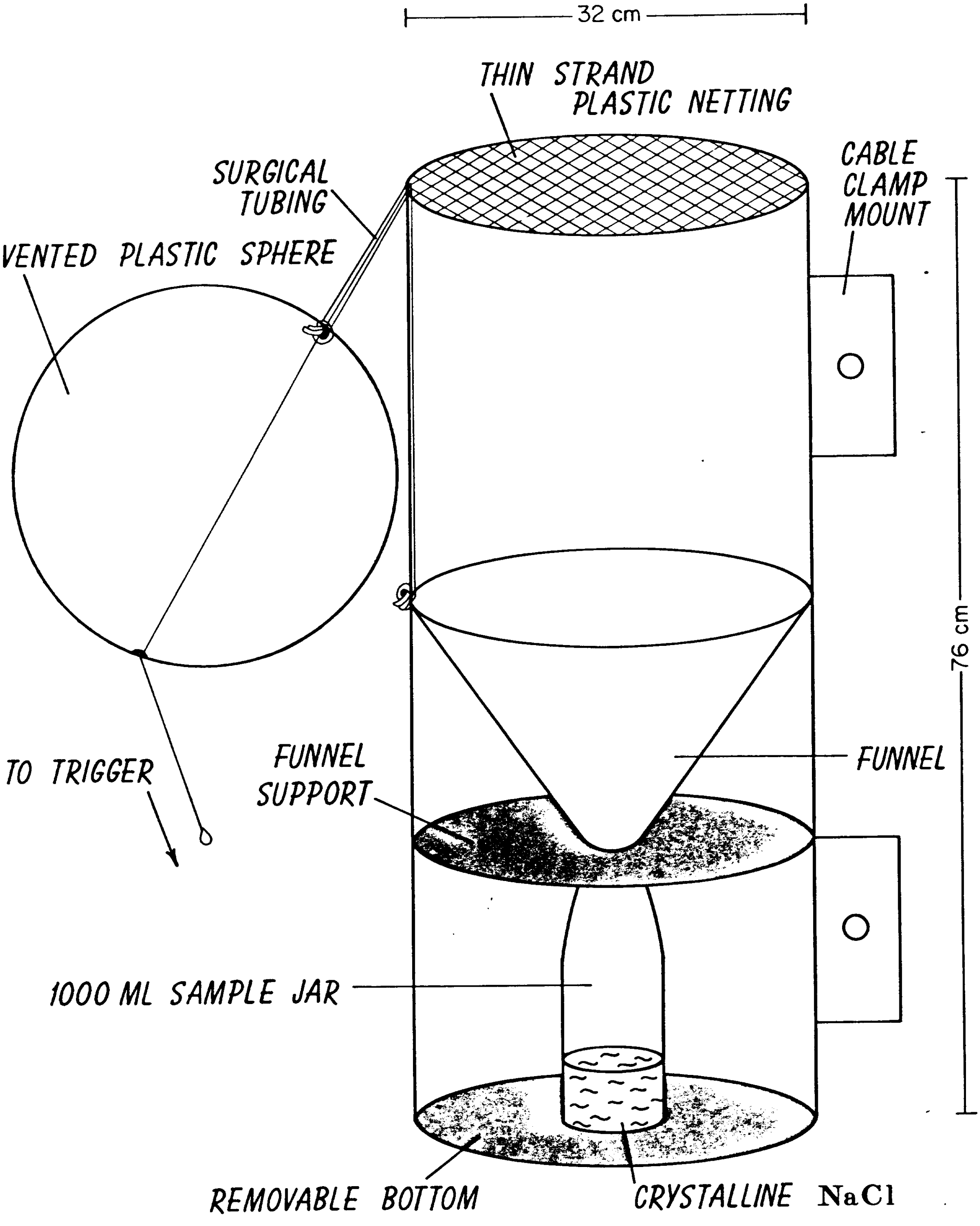
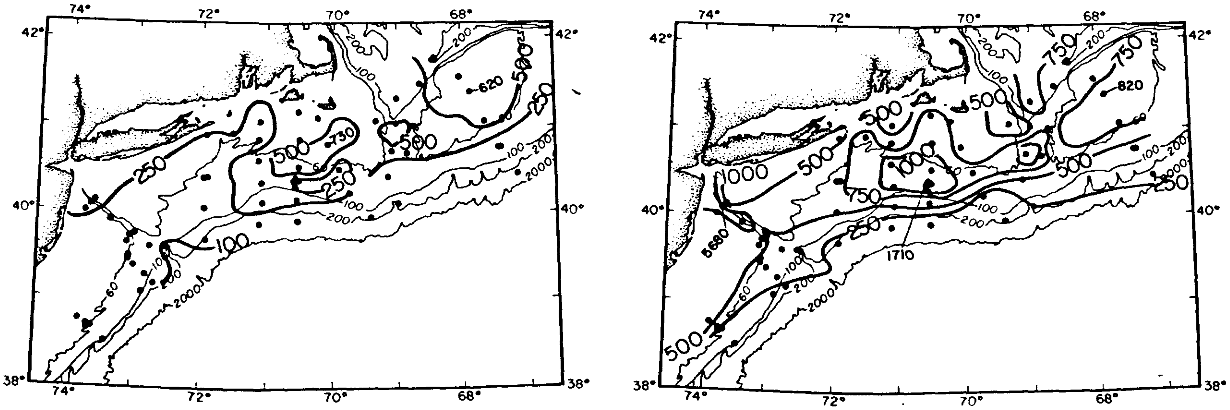
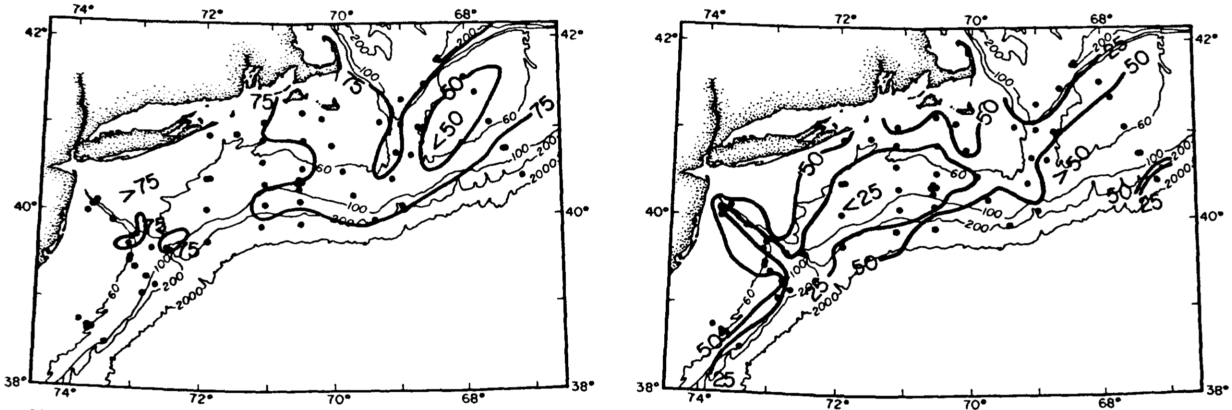


Figure 2. Schematic diagram of sediment trap. Crystalline NaCl dissolves and maintains a dense stable layer in collection bottle which minimizes flushing due to turbulence and reduces bacterial activity.



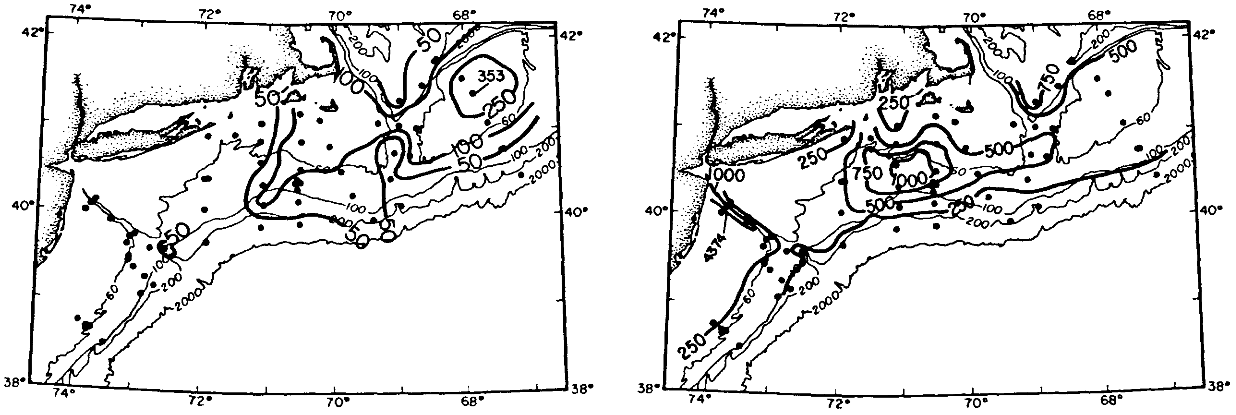
TOTAL PARTICULATES (µg/ℓ) - S

TOTAL PARTICULATES (µg/ℓ) - B



% COMBUSTIBLES - S

% COMBUSTIBLES - B



NON-COMBUSTIBLES (µg/ℓ) - S

NON-COMBUSTIBLES (µg/ℓ) - B

Figure 3. Areal distribution of suspended-particulate matter in surface (S) and near-bottom (B) water during August 19-September 1, 1978. Top illustrations show total particulate distributions; middle plots show percent combustibles; bottom plots show noncombustible concentrations. Depth contours in meters.

In bottom water, high concentrations of suspended matter are distributed in a concentric pattern over the area of fine-grained sediments south of Martha's Vineyard with maximum concentrations of 1,710 µg/l (fig. 3). In this area combustible fractions are less than 25% and locally as low as 9%, indicating a high proportion of suspended sediment.

The highest concentration of total particulates (5,680 µg/l) was measured in bottom waters of Hudson Channel closest to the New York Bight. The distribution of total particulates, percent combustibles, and concentration of noncombustibles suggests that resuspension of bottom sediment was present in and restricted to the Hudson Channel at the time of this sampling.

A transect (A-A') across Georges Bank (fig. 4) shows uniform water temperature from top to bottom (fig. 5), demonstrating strong vertical mixing in this area. Total particulate and noncombustible concentrations are also fairly uniform over the shallow region of the bank. Higher concentrations of suspended matter were found in deep water at the north end of the transect (fig. 5), typical of all seasonal data from this area (Milliman and others, 1980) and is due to resuspension of fine-grained sediments in the Gulf of Maine. The maximum nutrient concentrations were found in deep water on both sides of the bank (fig. 5).

Transect D-D' (fig. 4) through the area of fine-grained sediments south of Martha's Vineyard shows strong thermal stratification (fig. 6). A lens of colder bottom water known as the cold pool (Mayer and others, 1979) is centered at the 80-m depth contour (fig. 6). The shelf-slope front intersects the bottom at approximately 120 m. Highest concentrations of particulates and noncombustible particulates in bottom water occur in the coldest water which corresponds to the location of the finest bottom sediments. There is insufficient data to determine if the high concentration of suspended matter is due to higher turbulence in the cold pool or to the response of the finest grained sediments to tidal currents.

A subsurface maximum in total suspended matter is also present in this transect. This maximum is caused by high concentrations of phytoplankton, primarily the diatoms Rhizosolenia and Nitzchia. High phytoplankton production is also evident from the high chlorophyll concentrations (fig. 6) and higher dissolved oxygen values associated with this subsurface turbidity maximum.

Transect E-E' (fig. 4) crosses the western end of the Mud Patch. The associated profile (fig. 7) shows features similar to those diagrammed in figure 6. Transect F-F' (fig. 4) farther west crosses a sandy bottom inferred by Emery and Uchupi (1972) to be relict sediment. The highest concentrations of particulate matter are again associated with the cold pool which contains even colder water (fig. 8) than observed farther north (fig. 7).

The temperature profile through the center of Hudson Channel (fig. 9, transect Y-Y', fig. 4) shows a strong thermocline at approximately 20 m. In the deeper areas of the channel water temperatures are less than 7°C and indicate that the cold pool extends to this area. Suspended-matter concentrations reached 5.7 ppm in bottom waters at the landward station in the transect, the highest value observed during this cruise. Qualitative analyses with X-ray fluorescence show exceptionally high concentrations of Fe, Ti, and

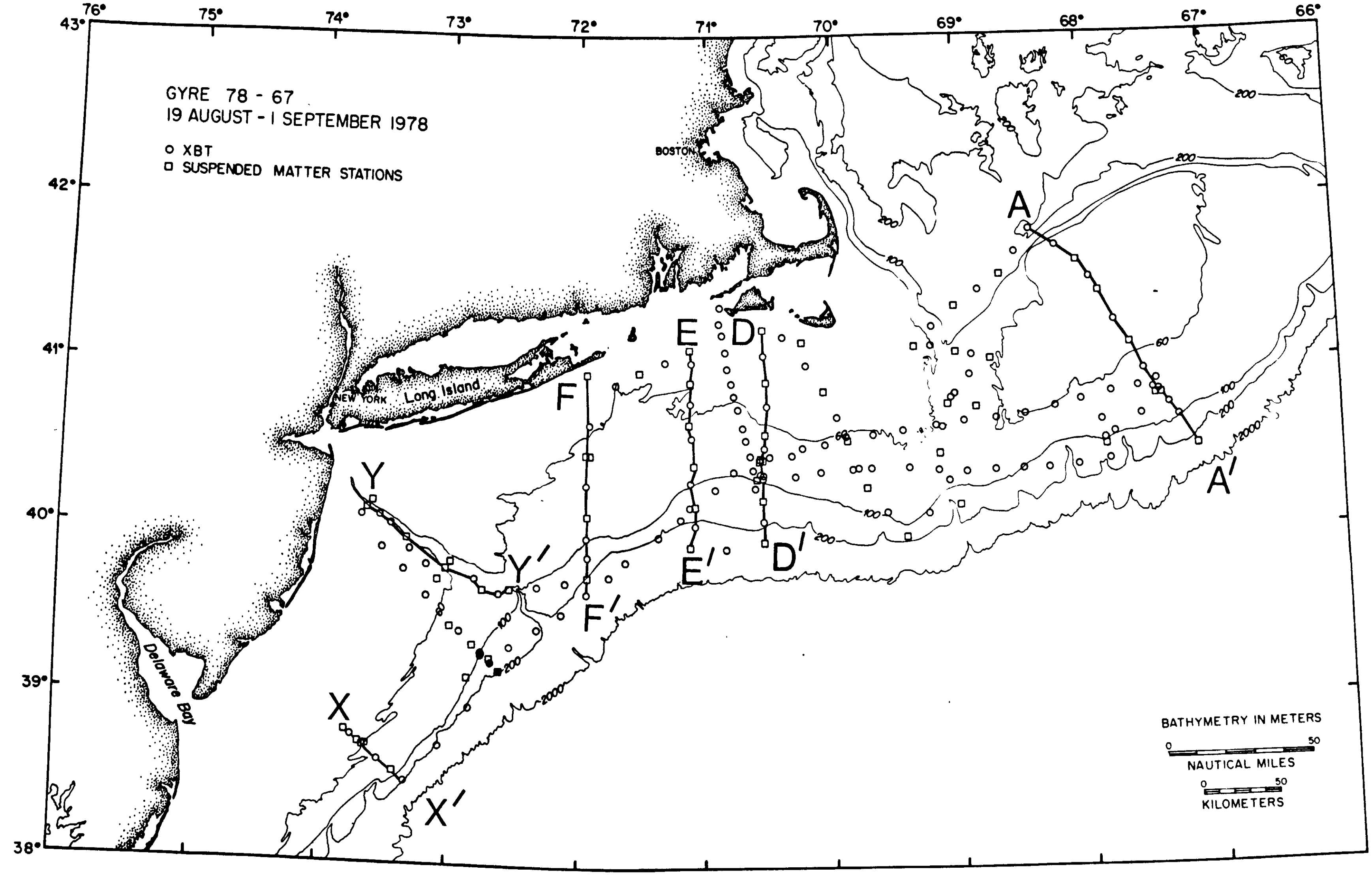


Figure 4. Locations of transects across the Continental Shelf.

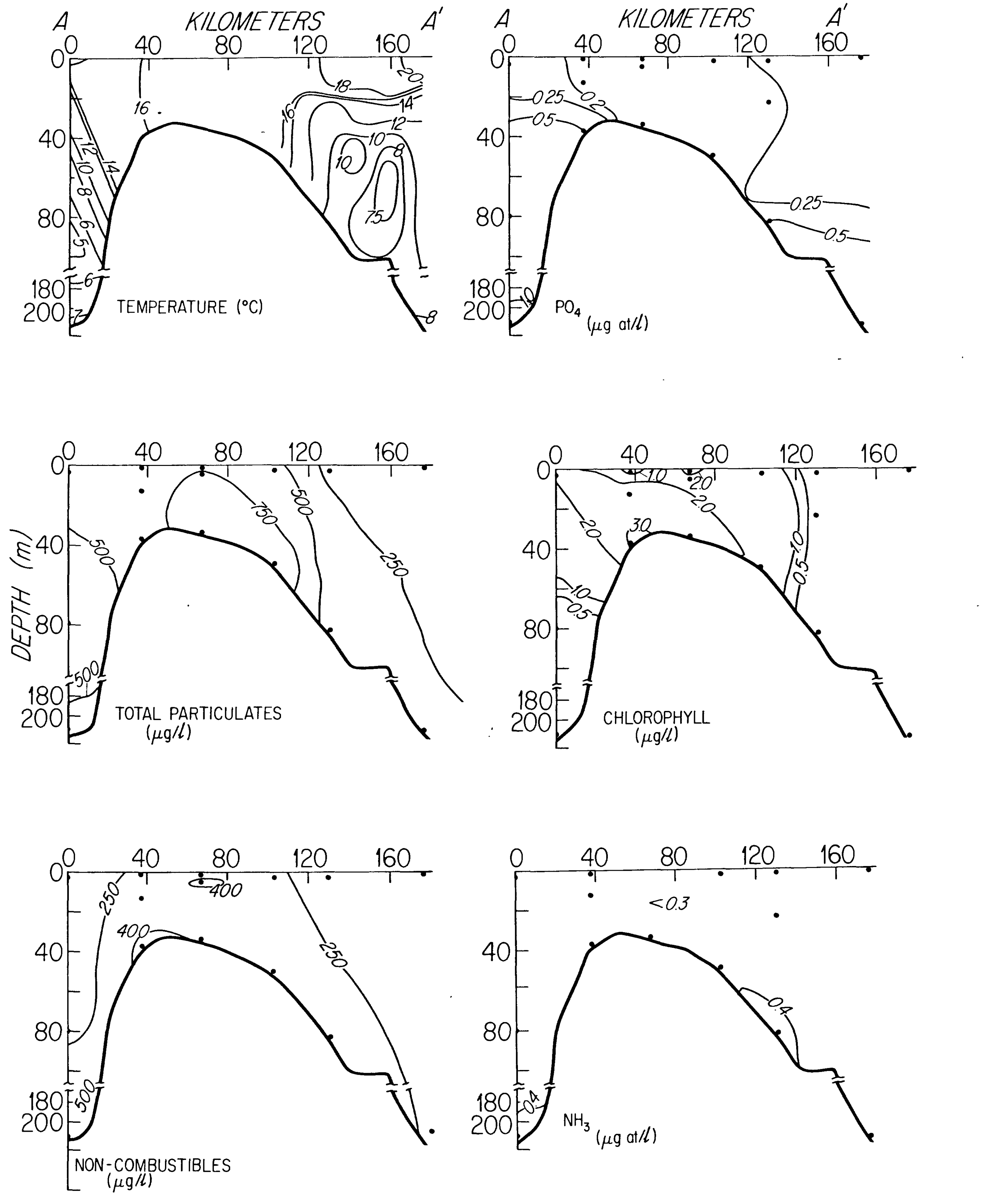


Figure 5. Vertical profiles showing water temperature, total particulates, noncombustibles, PO_4, chlorophyll A, and NH_3 along transect A-A' (see fig. 4) across Georges Bank, August 1978.

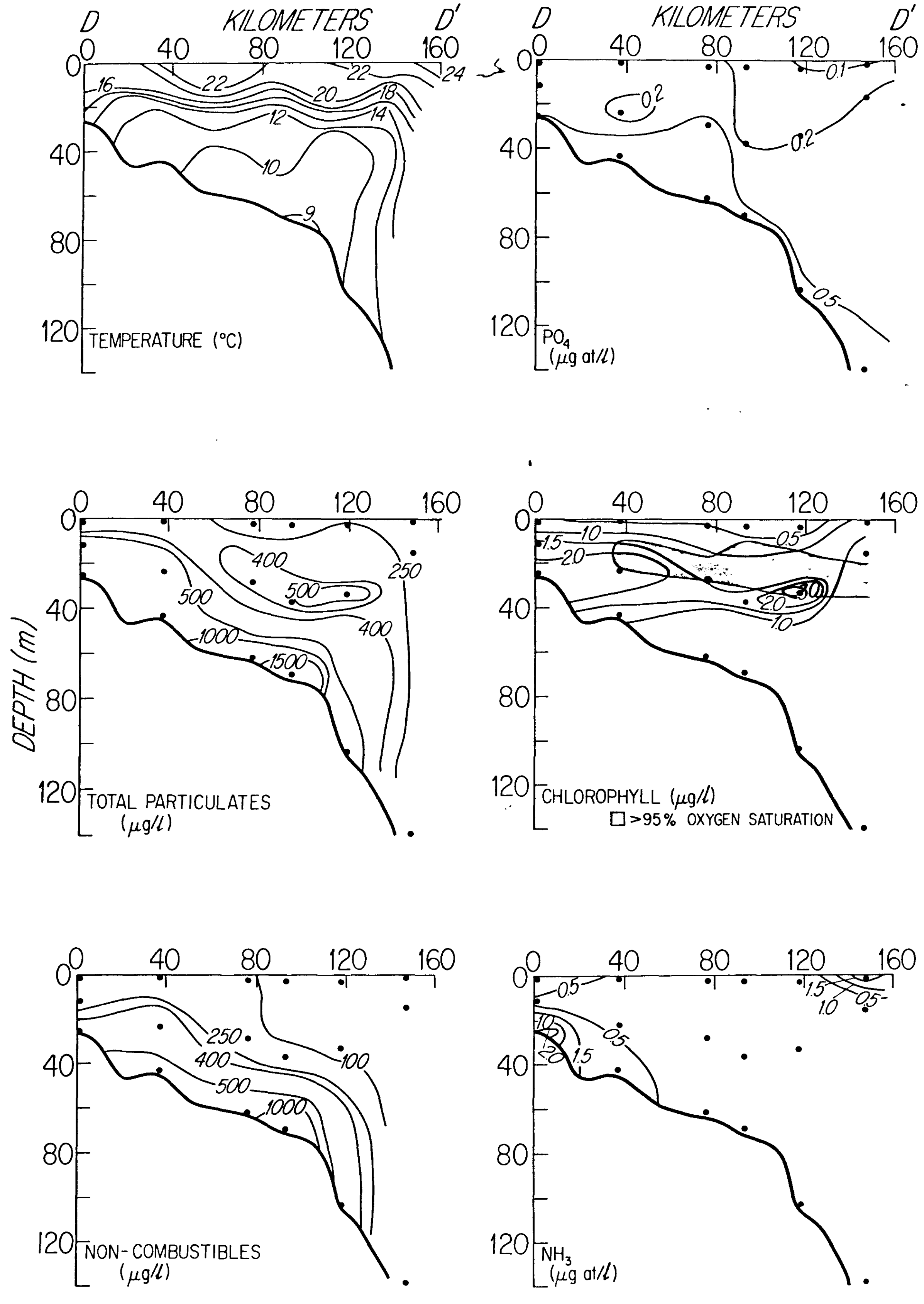


Figure 6. Vertical profiles showing water temperature, total particulates, noncombustibles, PO_4, chlorophyll A, and NH_3 along transect D-D' through the "Mud Patch", August 1978. Dissolved oxygen concentrations reflect high photosynthetic activity in the thermocline.

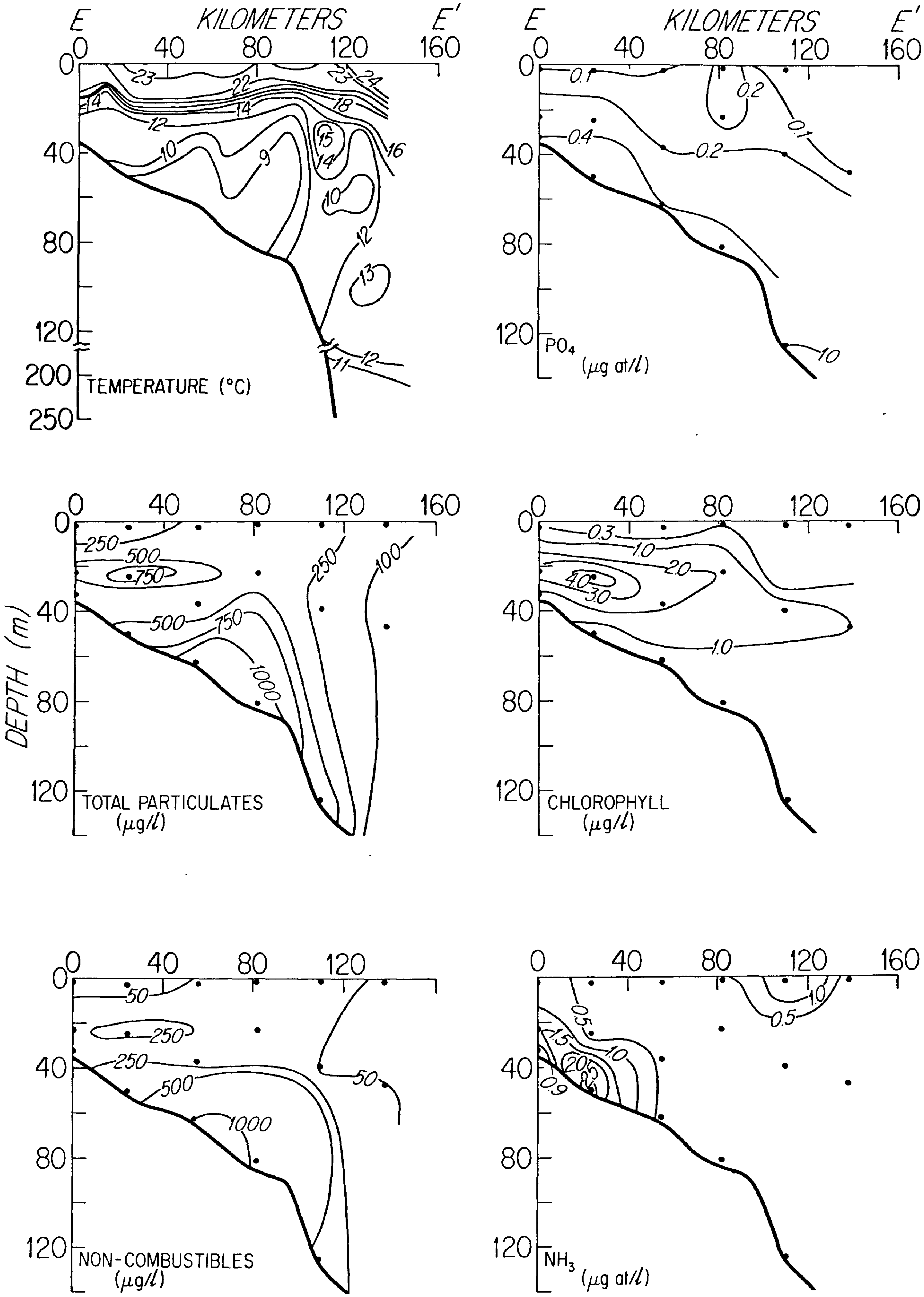


Figure 7. Vertical profiles showing water temperature, total particulates, noncombustibles, PO_4, chlorophyll A, NH_3 along transect E-E' (fig. 4) along western boundary of the Mud Patch.

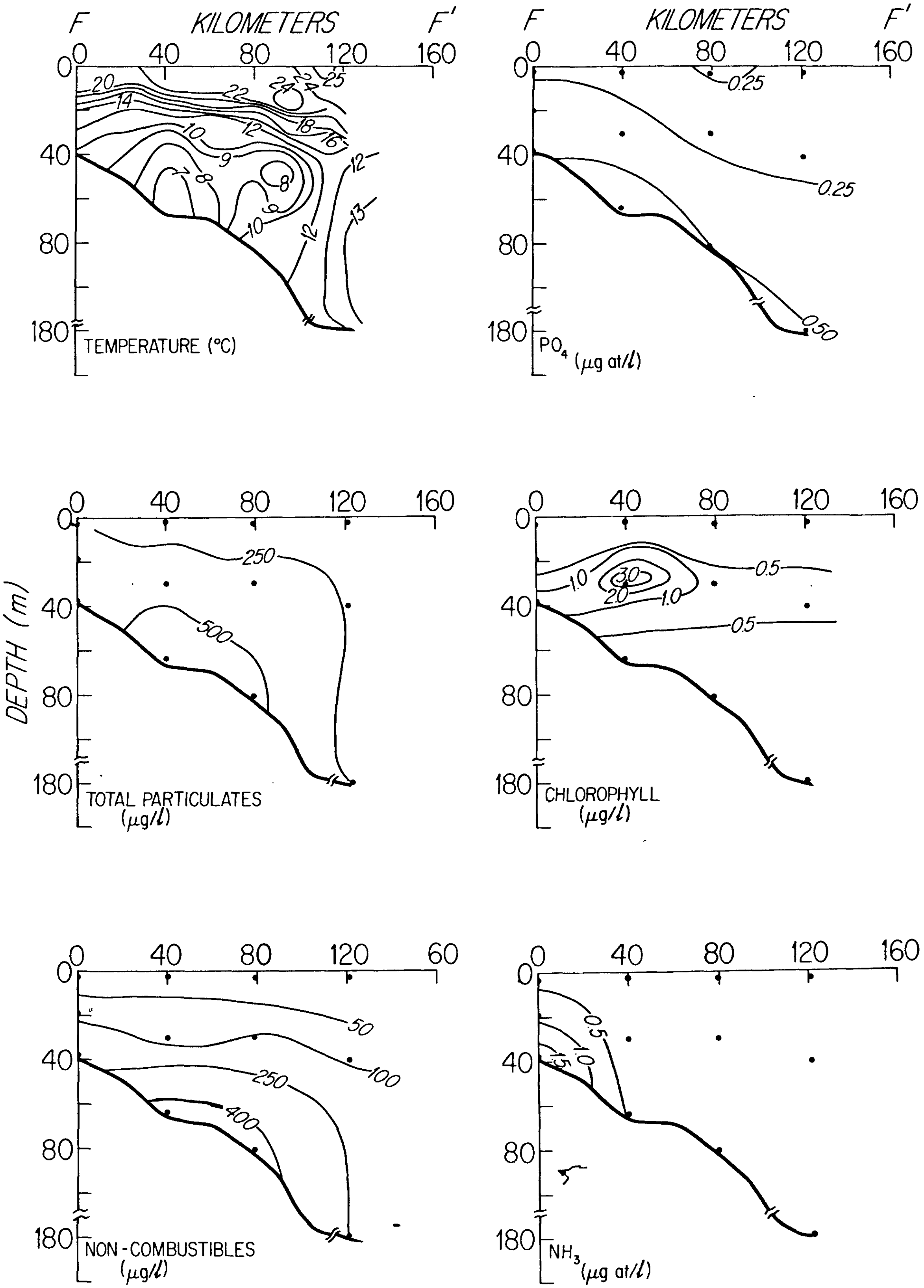


Figure 8. Vertical profiles showing water temperature, total particulates, noncombustibles, PO_4, chlorophyll A, and NH_3 along transect F-F' (fig. 4) south of eastern Long Island.

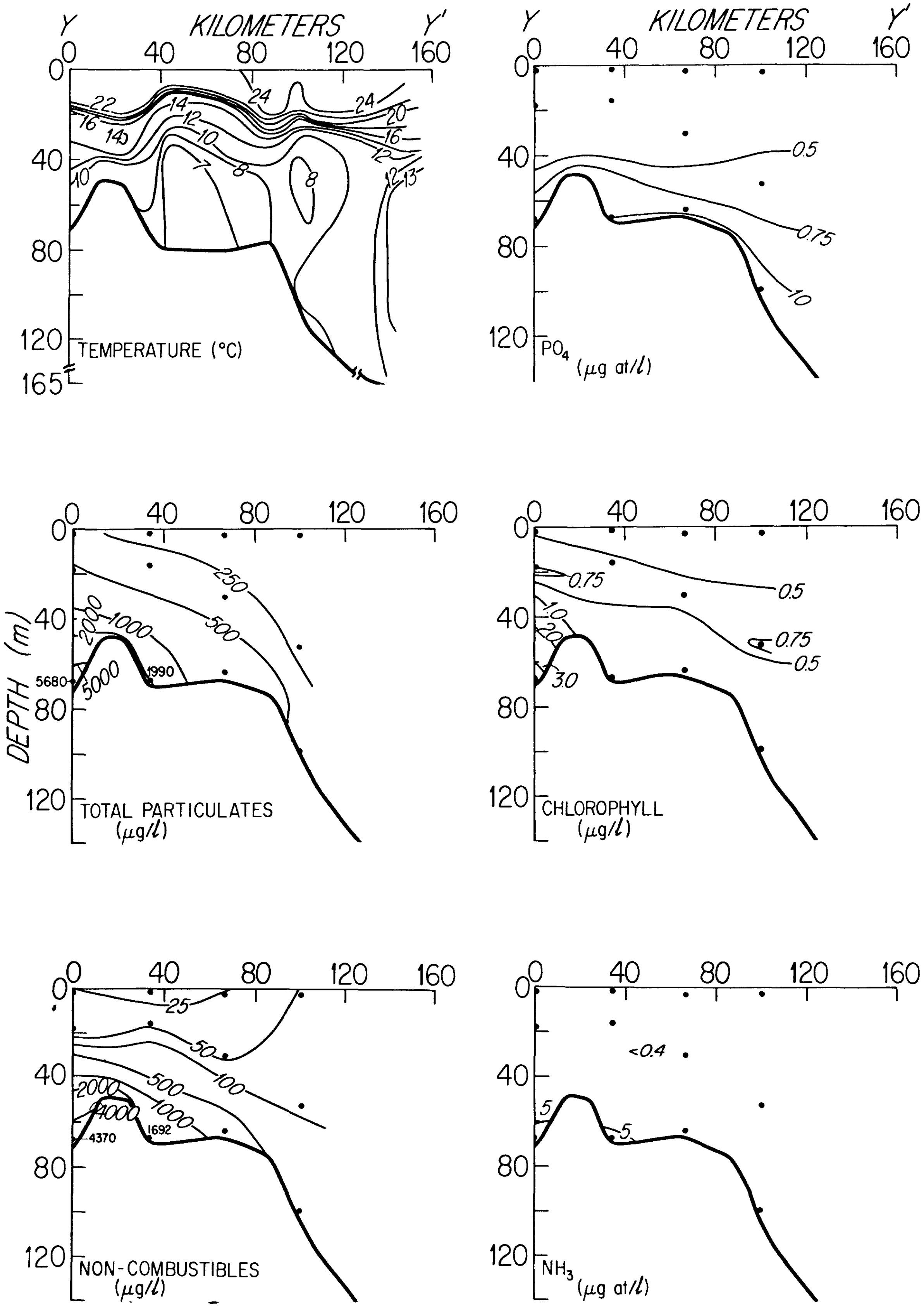


Figure 9. Vertical profiles showing water temperature, total particulates, noncombustibles, PO_4, chlorophyll A, and NH_3 along transect Y-Y' (fig. 4) along axis of Hudson Channel.

Zn, chiefly associated with amorphous organic particles from the area. These metals are undoubtedly related to waste discharge. However, it is not clear whether this material represents a plume from a recent dumping or resuspension and transport of an old waste deposit.

The profile (fig. 10) of the southernmost transect (X-X′, fig. 4) shows the coldest bottom water and within it relatively high concentrations of noncombustibles. Unfortunately, this transect was not long enough to map the landward edge of the cold pool at this latitude.

The association of high concentrations of suspended matter and cold bottom water is evident in three transects. Maps of the locations of the cold pool in May and August 1978 are shown in figure 11. Migration of the cold pool to the southwest as a discrete water mass at a rate of about 5 cm/s (Butman, unpub. data) may transport material resuspended from the Mud Patch. The material carried southward must be kept continuously in suspension because no accumulation of fine-grained material is evident in bottom surface sediment (Schlee, 1973) between the Mud Patch and Hudson Channel. The ultimate sink or the amount of material removed from the Mud Patch is not known. However, the amount removed must be smaller than the amount deposited because ^{14}C data in sediment cores from the Mud Patch suggest a modern net sediment accumulation of about 50 cm/1,000 yrs (Bothner and others, 1979).

The concentration of chlorophyll A in surface waters (fig. 12) is highest over the shoal areas of Georges Bank where it attains a maximum value of 2.3 µg/l. This area of the shelf is famous for its high primary productivity, which has been estimated at about 400 g carbon/m^2/yr (Cohen and Wright, 1978). The area around Nantucket Shoals is also characterized by high (0.5-0.8 µg/l) chlorophyll concentrations. With few exceptions, due possibly to local patchiness, the chlorophyll in surface waters over the remainder of the study area is close to 0.5 µg/l.

Chlorophyll in bottom waters (fig. 12) shows a distribution similar to that of surface waters with highest concentrations in bottom waters over Georges Bank and at stations nearest the New York Bight. As nutrients are also anomalously high in the bight (see below) it is reasonable to assume that the high chlorophyll is due to fertilization of phytoplankton from material discharged into the New York Bight. There is insufficient sample data in the southern end of the study area to evaluate the extent of chlorophyll levels in a landward direction from the southernmost transect. We observed high concentrations of the diatoms Chaetoceros and Thalassiosira, as well as the silicoflagellate Distephanus at mid and bottom depths which may have accounted for the high chlorophyll concentrations.

As seen in the profiles within the water column across the shelf, (e.g., fig. 6) the highest chlorophyll values are generally found in the samples taken in the thermocline. This chlorophyll maximum reflects the optimal environmental conditions for phytoplankton at a position which receives both some sunlight and a supply of nutrients from water below the thermocline.

Phytoplankton distribution

A variety of phytoplankton species are responsible for the chlorophyll distribution sampled during this cruise. A map of the most abundant genera is

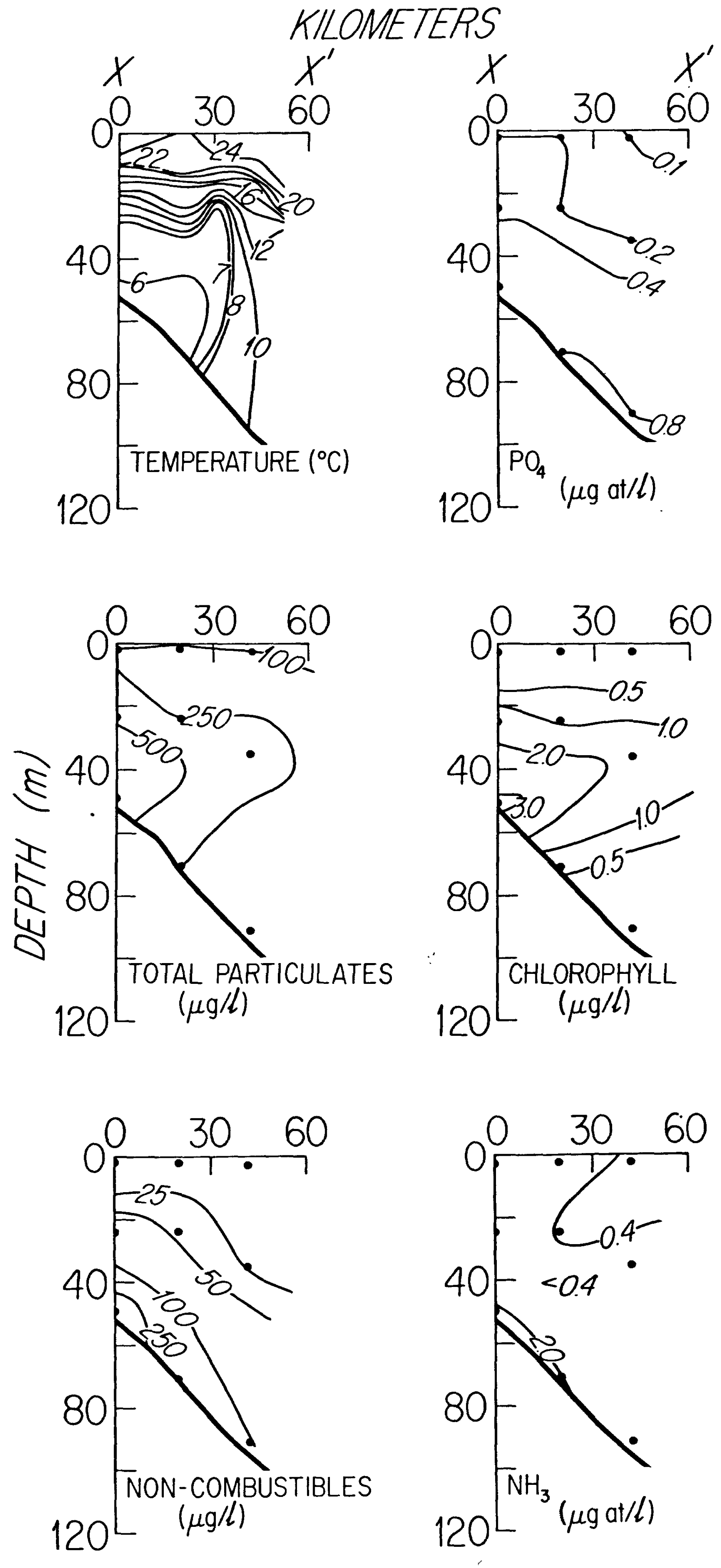
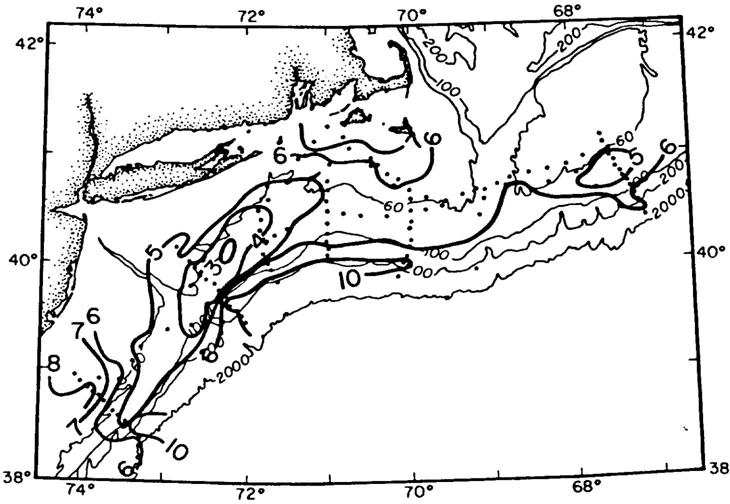


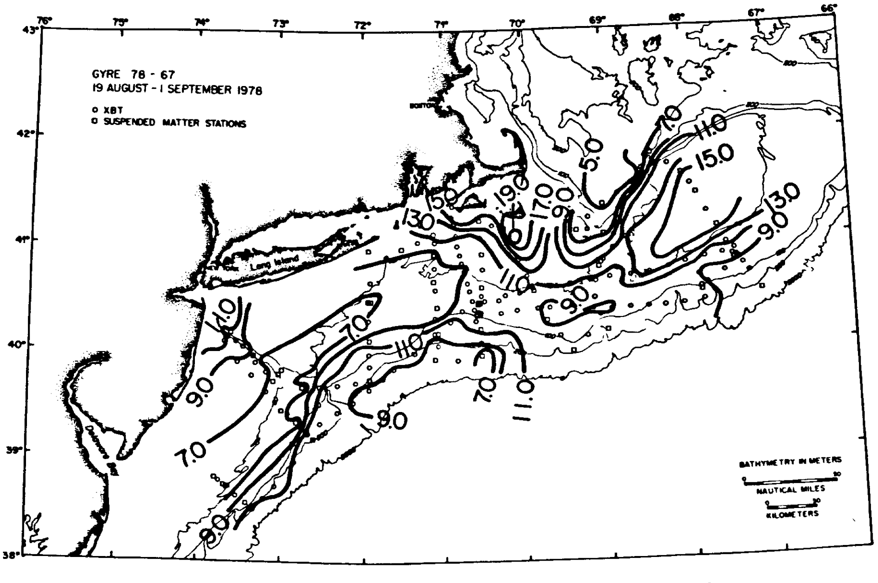
Figure 10. Vertical profiles showing water temperature, total particulates, noncombustibles, PO_4, chlorophyll A, and NH_3 along transect X-X' (fig. 4) across the Middle Atlantic Shelf, east of Delaware Bay.

A



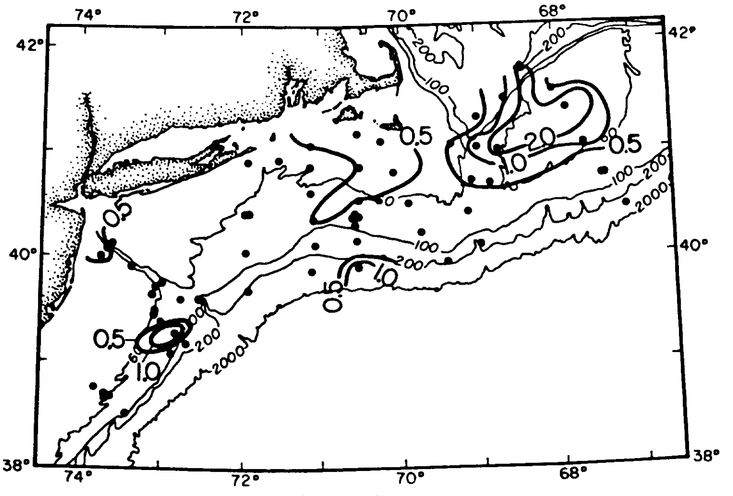
BOTTOM WATER TEMPERATURE (°C)

B

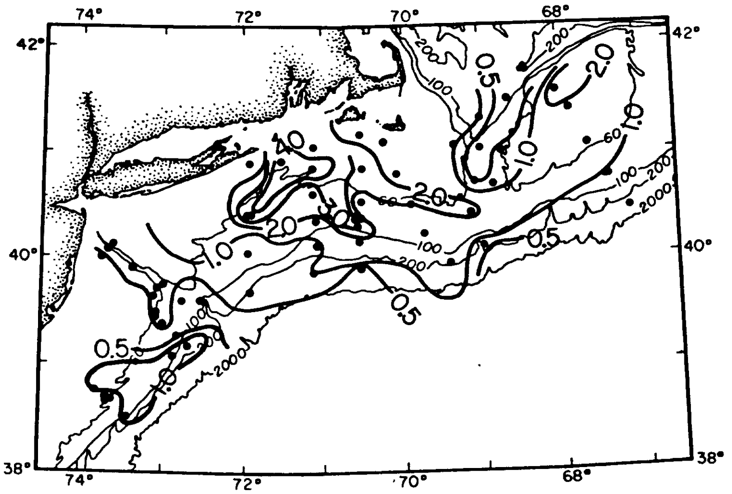


BOTTOM WATER TEMPERATURE (°C)

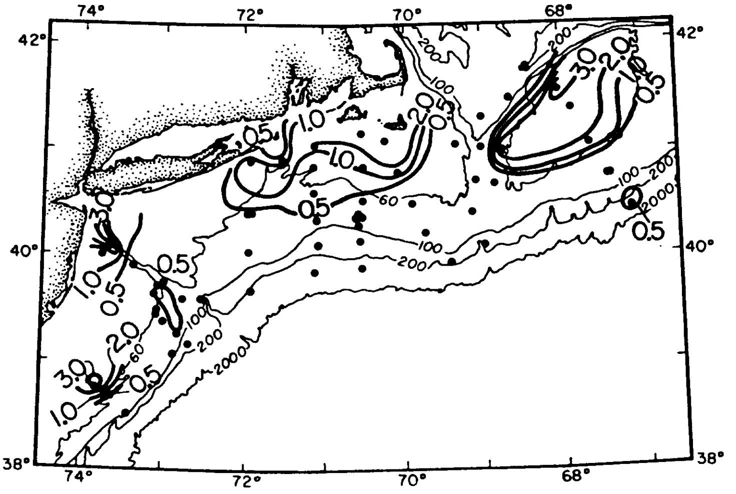
Figure 11. Bottom water temperature during cruises May 10-18, 1978 (fig. 11a) and August 19-September 1, 1978 (fig. 11b).



CHLOROPHYLL A (µg/ℓ)-S



CHLOROPHYLL A (µg/ℓ)
MID DEPTH (DEPTHS VARIABLE)



CHLOROPHYLL A (µg/ℓ)- B

Figure 12. Areal distribution of chlorophyll A measured in surface (S), middepth, and bottom (B) suspended-matter samples recovered August 19-September 1, 1978.

shown in figure 13. Over shoal areas of Georges Bank, above the 60-m contour, dominant phytoplankton are the diatoms Thalassionema and Rhizosolenia. These genera dominate throughout the well-mixed water column which is characteristic of this area. North of Georges Bank, over deeper waters of the Gulf of Maine, the dinoflagellate Ceratium is most abundant. A second assemblage consisting primarily of Rhizosolenia, Nitzchia, and Thalassiosira was observed at middepth north of the 60-m contour between Long Island and Great South Channel. In water deeper than 60 m, particularly over the Mud Patch, and over the southern flank of Georges Bank, forms of Coscinodiscus gigantea were dominant. High concentrations of phytoplankton correlate with turbidity and chlorophyll maximums observed at middepth in this area. A distinctly different assemblage dominated by dinoflagllates and silicoflagellates, characterized the middepth turbidity maximum in the Hudson Channel and the area east of Delaware Bay. Various species of diatoms were also present in lower concentrations.

The concentration of nutrients in surface water is considerably lower than in bottom waters (fig. 14) because nutrients in the upper water column have been depleted by phytoplankton production. In bottom waters, the concentrations of nitrate, silicate, and phosphate are higher at most deepwater stations, particularly in the southern Gulf of Maine and over the Continental Slope south of Rhode Island. Ammonium concentrations in bottom water are greatest at stations in Hudson Channel closest to the New York Bight and in the shallow waters between Long Island and Nantucket Island. Phosphate and silicate are also relatively concentrated in bottom waters of the Hudson Channel. Higher nutrient concentrations in bottom waters of this area are probably caused by nutrient regeneration at the sea floor (Rowe and others, 1975) and to some extent, by excretion by zooplankton.

The influence of the New York Bight environment can be clearly seen in the distributions of local suspended matter (fig. 3), chlorophyll (figs. 6-12), nutrients (fig. 14), and surface salinity (fig. 15) compared to the distributions of these measured variables in other areas sampled during this cruise.

Mineralogy

Semiquantitative X-ray diffraction techniques (modified from Biscaye, 1965) were used to determine the relative abundance of clay minerals in the samples.

We found that layered silicates, quartz, and feldspars dominate the mineralogy of the suspended load. Illite and chlorite, the most abundant layered silicates present, occur in average concentrations of $57 \pm 6\%$ (one standard deviation) and $27 \pm 4\%$, respectively (table 1). Smaller amounts of kaolinite, mixed-layered chlorite-smectite were also found.

Talc was also identified in low concentrations in a few samples from Georges Bank and the Mud Patch. Its occurrence was confirmed with additional samples collected during August 1979, when procedural blanks were run to evaluate contamination. This mineral has been identified previously as a minor constituent of suspended sediment on the Continental Shelf south of New England (Pierce and others, 1972; Meade and others, 1975) but has not been reported previously in suspended matter or in bottom sediments of Georges Bank or the Gulf of Maine. This rare and unlikely mineral may owe its presence in the water column to airborne industrial and/or agricultural contamination.

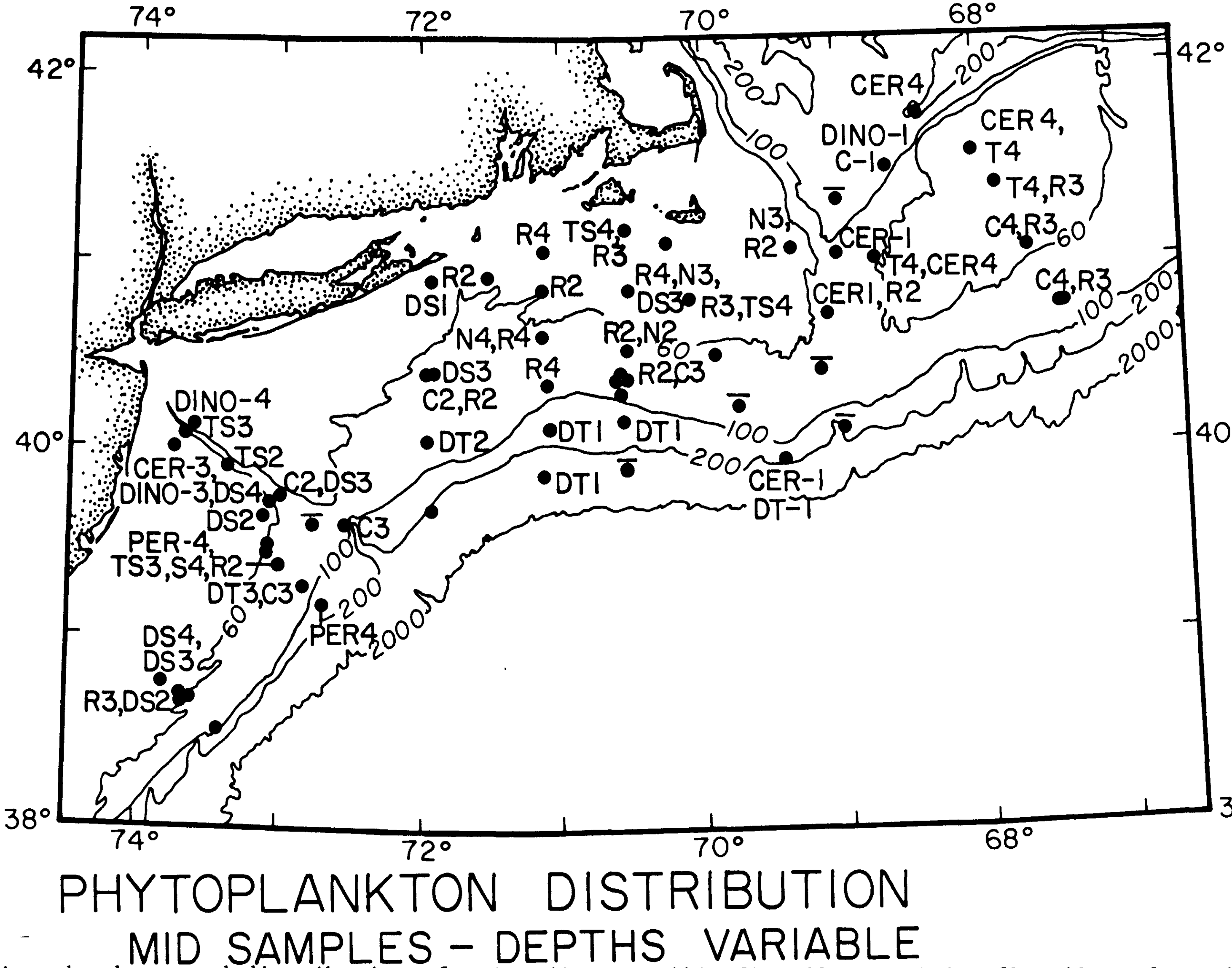
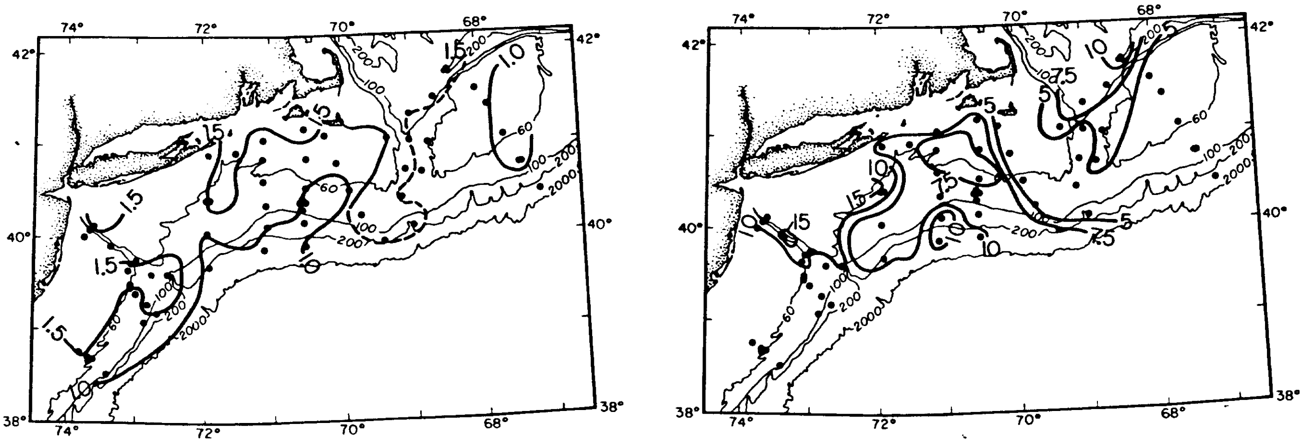
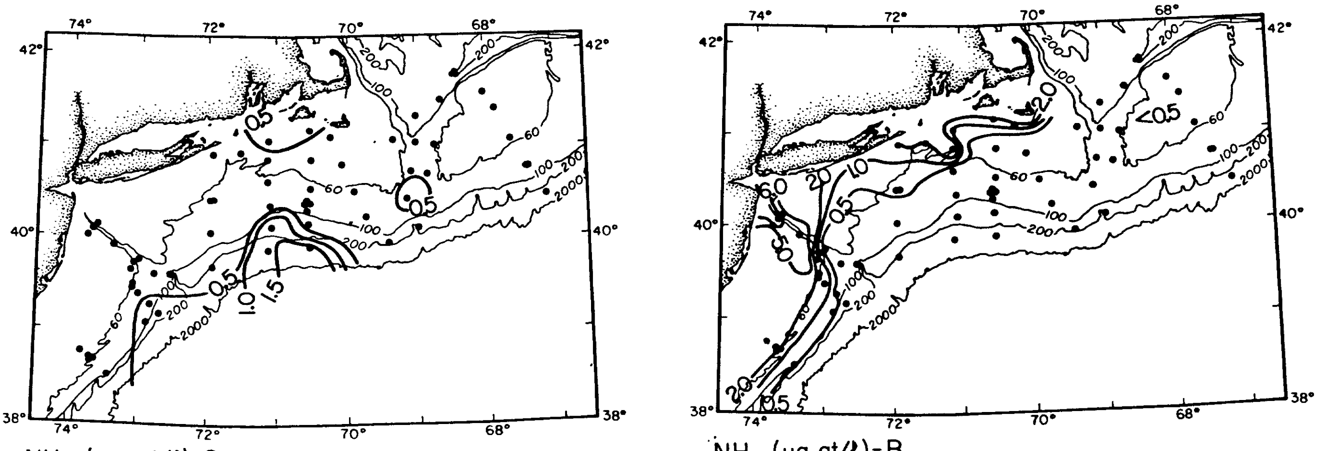


Figure 13. Relative abundance and distribution of major diatom, silicoflagellate and dinoflagellate forms based on microscopic examination of middepth suspended-matter samples. Relative abundance of phytoplankton genera indicated as follows: 4 = abundant; 3 = common; 2 = present; 1 = trace; dashes over stations where no forms were observed. Dinoflagellates: DINO = Dinophysis; CER = Ceratium; PER = Peridinium. Diatoms: TS = Thalassiothrix, Thalassionema. Silicoflagellates: DS = Distephanus; DT = Dictyocha. Depth contours in meters.



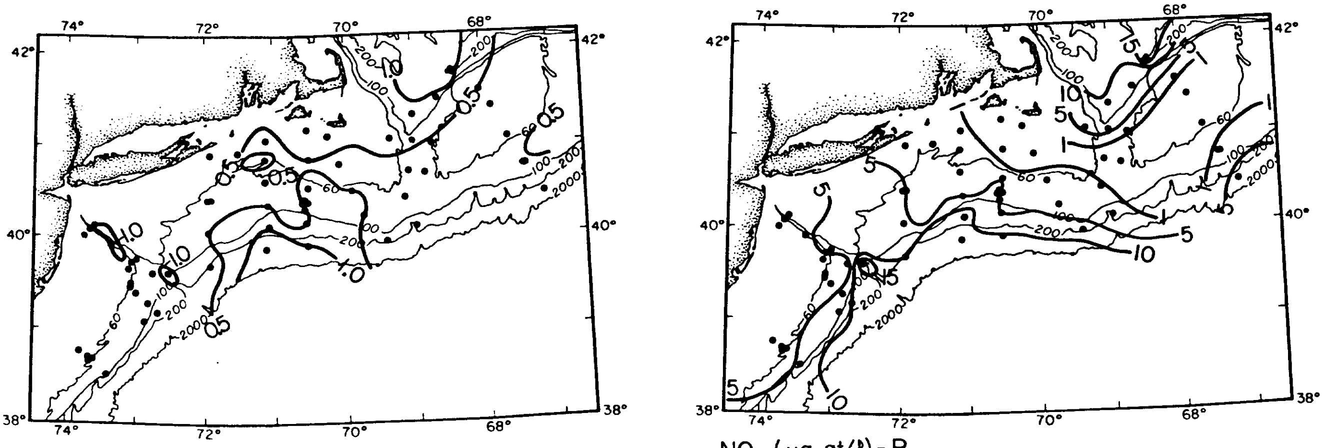
SiO_2 (μg at/ℓ)-S

SiO_2 (μg at/ℓ)-B



NH_3 (μg at/ℓ)-S

NH_3 (μg at/ℓ)-B



PO_4 (μg at/ℓ)-B

NO_3 (μg at/ℓ)-B

Figure 14. Areal distribution of SiO_2 and NH_3 in surface (S) and bottom (B) water and of PO_4 and NO_3 in bottom water for the period August 19-September 1, 1978.

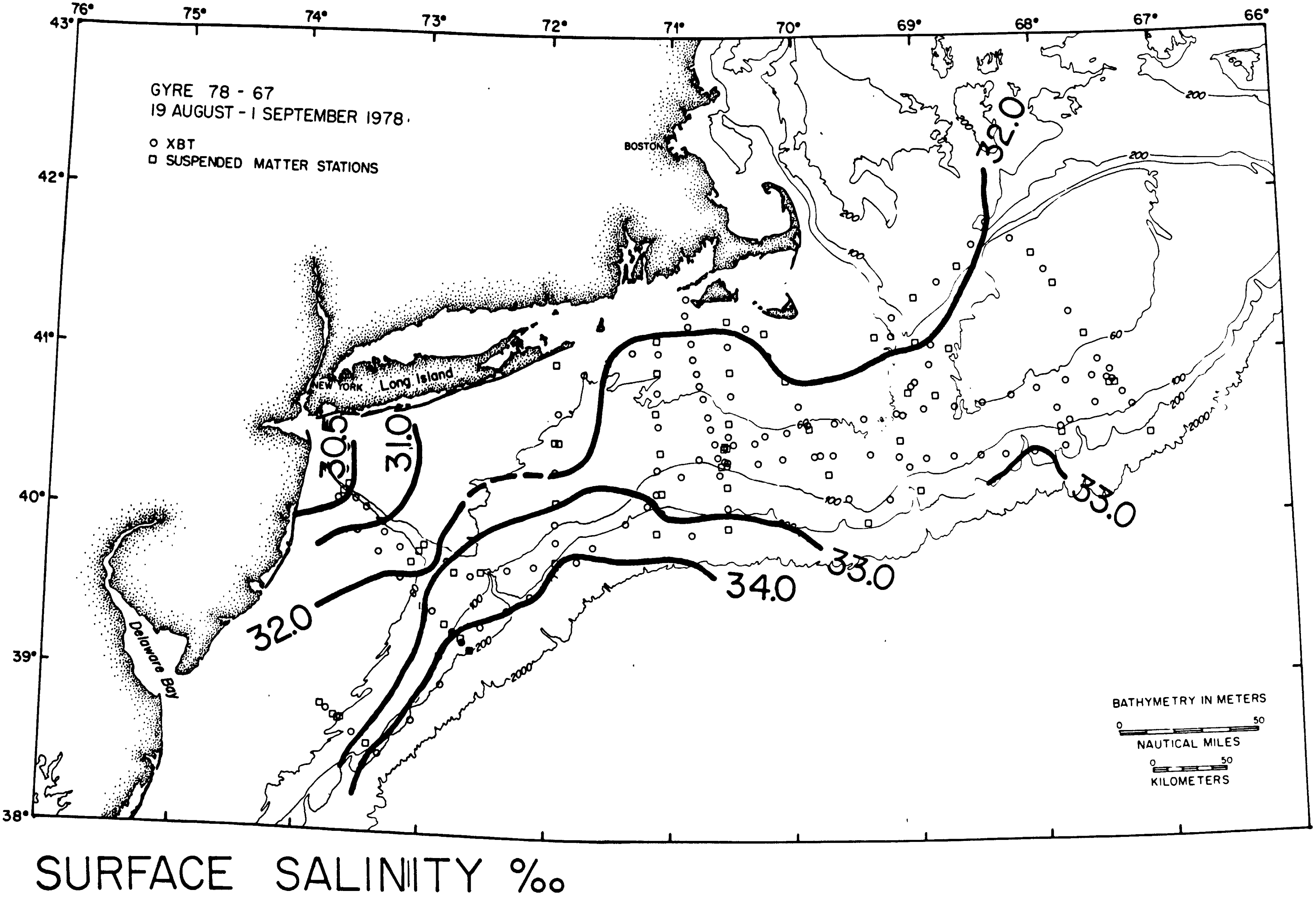


Figure 15. Salinity (0/00) of surface water collected August 19-September 1, 1978.

Table 1. Percent abundance of layered silicates as determined by X-ray diffraction. Mean values of abundant clay mineral groups.

Station	Sample depth (m)/ Water depth (m)	Mixed-layered chlorite smectite	Smectite	Chlorite	Mixed-layered illite smectite	Illite/Mica	Talc	Kaolinite	Comments
007	28/228								X
008	84/87			38	2	47		13	
009	2/52	Tr		25	7	43		25	
010	34/38	Tr?		29	6	39	9	17	
011	28/32			26	10	53		11	
012	203/205		Tr	27	2	52	4	14	
013	135/135	Tr?		28	2	56		14	
014	146/151			23	Tr	65	Tr	11	
015	48/51			24	2	60	2	12	
016	92/96		Tr	28	3	62		6	
017	51/55		Tr	32	3	53	1	11	
018	57/62								X
019	74/77		Tr	21	2	61	6	9	
020	135/138	Tr		23	3	39	Tr	34	
021	101/103			32	Tr	55		13	
022	79/81								X
023	60/63			28	1	57	1	13	
024	22/24								X
025	22/25			25	3	54		18	

TR = <1%
X = Concentration of layered silicates below limits of detection
Y = Talc is the most abundant layered silicate

Table 1. Percent abundance of layered silicates as determined by X-ray diffraction. Mean values of abundant clay mineral groups (cont.)

Station	Sample depth (m)/ Water depth (m)	Mixed-layered chlorite smectite	Smectite	Chlorite	Mixed-layered illite smectite	Illite/Mica	Talc	Kaolinite	Comments
026	26/29			28	1	57		14	
028	60/63			23	3	69	Tr	5	
029	69/72		Tr	28	Tr	57		13	
030	114/118		Tr	29	2	50		14	
031	287/421			33	3	50		13	
032	300/470								X
033	125/127			25	4	60		11	
034	81/84			31	Tr	60		8	
035	62/64		Tr	31	Tr	57		11	
036	51/51			34	1	51		14	
037	33/35								X
038	49/53		1	25	2	56		16	
039	38/40			30	Tr	61		9	
040	64/68		Tr	24	Tr	60		15	
041	81/84			18	3	69		10	
042	181/186		Tr	26	2	56		15	
043	145/156			27	2	58		13	
044	70/76			29	1	57		13	
046	78/80	Tr?		27	Tr	59		14	

Tr = <1%
X = Concentration of layered silicate below limits of detection
Y = Talc is the most abundant layered silicate

Table 1. Percent abundance of layered silicates as determined by X-ray diffraction. Mean values of abundant clay mineral groups (cont.)

Station	Sample depth (m)/ Water depth (m)	Mixed-layered chlorite smectite	Smectite	Chlorite	Mixed-layered illite smectite	Illite/Mica	Talc	Kaolinite	Comments
047	51/54			27	4	58		11	
048	67/71			33	7	50		13	
050	69/74								X
051	32/34			30	2	59		9	
052	58/61			28	3	58		11	
054	129/129		1	26	3	56		14	
055	92/95		Tr	29	1	61		9	
057	49/51								X
058	57/61			29	3	54		14	
059	127/129			32	1	59		8	
060	129/131			26	2	62		10	
061	125/129		Tr	30	2	62		15	
063	75/129			26	Tr	59		15	
064	128/129		Tr?	25	Tr	64		10	
066	126/128			29	1	56		13	
068	1/133								X
071	28/131								X
073	57/131		Tr	26	1	61		11	
077	1/128								X
078	2/128								X
079	124/128			28	1	58		13	

Tr = <1%
X = Concentration of layered silicate below limits of detection
Y = Talc is the most abundant layered silicate

Table 1. Percent abundance of layered silicates as determined by X-ray diffraction. Mean values of abundant clay mineral groups (cont.)

Station	Sample depth (m)/ Water depth (m)	Mixed-layered chlorite smectite	Smectite	Chlorite	Mixed-layered illite smectite	Illite/Mica	Talc	Kaolinite	Comments
081	12/82								X
083	82/86			28	1	61		10	
086	83/86								X, Y
087	4/86								X
091	2/86								X, Y
093	2/86								X, Y
094	3/86								X, Y
095	84/86								X
096	38/94								X, Y
097	90/94	Tr		32	4	50		13	
099	92/94		Tr	31	2	56		10	
101	59/94			26	7	50	Tr?	17	
102	91/94			30	3	56		11	
103	71/75			25	4	53		17	
104	35/93		1	27	10	48	Tr?	14	
105	90/93			26	2	60		12	
108	2/94								X
111	90/93			26	Tr	58		15	
113	93/94		Tr	27	1	59		12	
115	2/94								X
Mean values of abundant clay mineral groups ± one standard deviation				28±4		57±6		13±4	

Tr = <1%
X = Concentration of layered silicate below limits of detection
Y = Talc is the most abundant layered silicate

The relative percentages of clay minerals show very little variation within the study area, as indicated by the small standard deviations about mean values (table 1). The average illite concentrations in the clay fraction of surface sediments on Georges Bank were 59±6% (Bothner and others, 1979), very similar to the concentration found in suspension. The nearly uniform distributions of different clay minerals in bottom water indicate that mineralogy would not provide information required to trace plumes of resuspended material originating on the Continental Shelf.

Sediment traps

Information from sediment traps deployed in the deep sea has led to new estimates of the vertical flux of material to the sea floor (Spencer and others, 1978). The use of sediment traps in the Continental Shelf environment carries some added uncertainties, primarily because here higher horizontal current speeds usually exceed the settling velocity of particles. Current speeds in the areas of sediment-trap deployment were typically 20 cm/s and reached maximum speeds of 40 cm/s for short periods.

The high current speeds encountered in this environment make it difficult to predict the efficiency of the traps which have been measured in flumes with horizontal current velocities of up to 10 cm/s (Gardner, 1977b). However, flow conditions between the midwater and bottom traps were similar at each location and currents were only moderately different between locations. Therefore, we make the assumption that efficiencies among all the traps were essentially equal, and, for lack of a better estimate, that the efficiency at each location is 100%.

The gravimetric data, expressed as a flux of material collected by the traps, is presented in table 2. The rate of sediment collection in the bottom (2 m above bottom) trap is higher than the middepth (40 m below surface) trap by a factor of 2 to 60. This is an expected result because the bottom trap collects resuspended material in addition to particles traversing the water column for the first time. The biggest difference between the middepth trap and the lower trap was found in the Mud Patch where the highest turbidity in the near-bottom water was also found. This illustrates the higher degree of resuspension in the Mud Patch compared to other areas of the Continental Shelf.

The highest percentage of noncombustible material (60%) was found on Georges Bank; the high value apparently reflects the relatively high energy of this area. It is interesting that the percentage of noncombustible material in all the other traps is essentially the same - around 29%.

The relative amount of resuspension can be determined by comparing the total inventory of suspended matter in the water column with the amount of material collected in the bottom trap per day. An estimate of the suspended load (g/m^2) over the whole water column was made from the suspended-matter samples collected at discrete depths and the continuous transmissometer profiles. The average suspended load of three casts at the trap station on Georges Bank, the Mud Patch, and the Mid-Atlantic Shelf was 20, 27, and 15 g/m^2, respectively. The value over the Mud Patch is approximately two times higher than at the Mid-Atlantic station, yet the flux into the Mud Patch bottom trap is almost ten times higher. On Georges Bank, a higher flux at the

Table 2. Flux of material collected by sediment traps. Trap area, 0.646 m^2. (see fig. 1 for trap locations.)

Location	40-m trap	Bottom trap
Georges Bank deployment 8.3 days		
Total weight ($g/m^2/day$)	0.226	7.615
Noncombustibles ($g/m^2/day$)	0.072	4.612
% Noncombustibles	32.0	60.2
Mud Patch deployment 10.3 days		
Total weight ($g/m^2/day$)	0.224	14.42
Noncombustibles ($g/m^2/day$)	0.065	4.04
% Noncombustibles	28.9	28.0
Middle Atlantic deployment 6.3 days		
Total weight ($g/m^2/day$)	0.629	1.48
Noncombustibles ($g/m^2/day$)	0.186	0.440
% Noncombustibles	29.5	29.7

bottom relative to suspended load is also observed compared to the Mid-Atlantic. These differences reflect the much faster recycling of particulates in the water column over the Mud Patch and Georges Bank.

Another expression of the resuspension activity at the three sediment trap locations is the residence time of particulates in the bottom waters (Gardner, 1977b). The residence time is defined as:

$$t = \frac{\text{reservoir of resuspended particles in nepheloid layer (R)}}{\text{flux of particles in or out of this layer (F)}}$$

The following assumptions are necessary to make the calculation of mean residence time — which refers to the time necessary to resuspend or deposit the particles making up the nepheloid layer. First, the nepheloid layer is at steady state. Second, the distribution of particulates is uniform in the nepheloid layer due to mixing, so that the trap placed at any depth within the nepheloid layer would receive the same flux. On the basis of most transmissometer profiles, this assumption is good for the Mud Patch and Georges Bank and only fair in the Mid-Atlantic. A third assumption is that the particles collected in the trap were resuspended from the immediate vicinity. This is probably a poor assumption, particularly in the area of the Mud Patch which is considered to be a sink for particulates from shoal areas to the northeast (Bothner and others, 1979). The contribution of this advected material makes the estimate of the residence time of locally resuspended particles too low.

The thickness of the layer into which bottom sediment is resuspended (table 3) was estimated from transmissometer profiles and δ_t water-density profiles at the trap stations. The resuspended load was estimated by subtracting the concentration of suspended matter in the clearest water in the profile from the concentration in the bottom layer. The residence time (table 3) ranged from five hours on Georges Bank to two days on the Middle Atlantic Shelf. These values are low compared to estimates of one to three months for the nepheloid layer in the deep sea (Gardner, 1977b) and emphasize the much more rapid exchange of particles between the sea floor and the water column in the shelf environment.

These values of residence time on the Continental Shelf should be taken as first order approximations. A serious uncertainty lies in the possibility that the sediment traps may be overtrapping in currents which reach 40 cm/s, although no experiments have been conducted to confirm or deny this possibility (Gardner, 1977b). If overtrapping has occurred, our estimates of residence time are too low.

A number of observations can be made from the data shown in figures 16 and 17. A general identification of the sediment-trap components is summarized in figure 17. First, the distribution of mass with size is generally uniform for the traps at 40 m depth. Zooplankton make up a considerable fraction of the material. In most cases, the highest percentage of noncombustibles is present in the finest fraction of material of the 40-m traps. This may reflect a higher proportion of resuspended sediment in this size class.

Table 3. Estimates of residence time of suspended sediment in bottom nepheloid layer.

Trap location	Suspended sed. in water column	Thickness of nepheloid layer	Resuspended sediment in nepheloid layer	Trap collection rate	Residence time
	(g/m^2)	(m)	(g/m^2)	(g/m^{2}day)	
Georges Bank	19.5	14	1.5	7.62	4.7 hours
Mud Patch	27.2	15	19	14.4	1.3 days
Mid-Atlantic	14.8	20	3	1.48	2 days

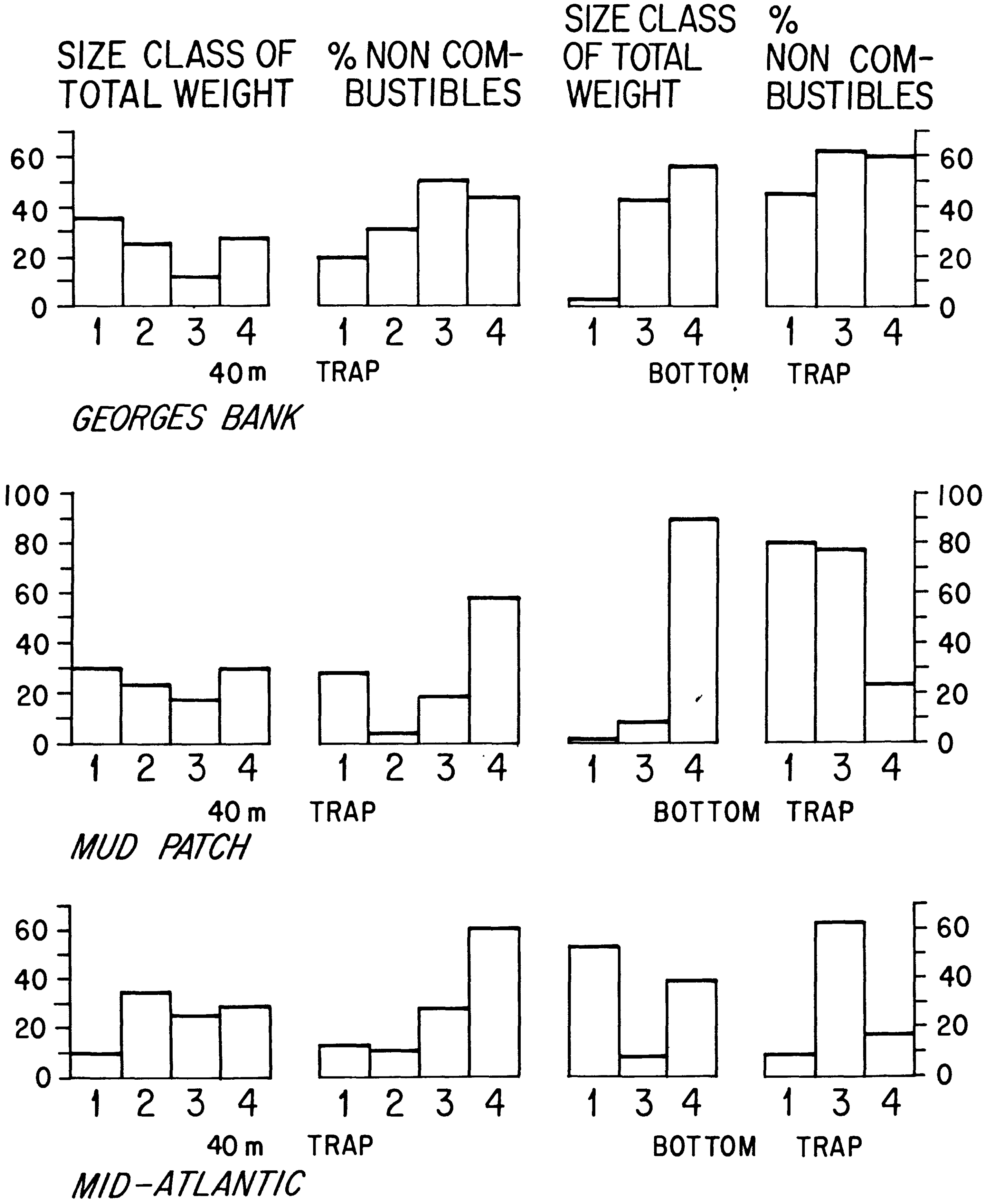


Figure 16. Weight percent and percent noncombustibles of successive size fractions in sediment recovered from mid (40 m) and near-bottom sediment trap arrays deployed for ten days or less during August 19-September 1, 1978 at Georges Bank (top row), Mud Patch (middle row), and Middle Atlantic (bottom row) sites (see fig. 1). Size classifications are as follows: 1 = >1 mm; 2 = 250 µm-1 mm; 3 = 62 µm-250 µm; 4 = 62 µm. Classification 3 for bottom traps includes size fractions between 62 µm and 1 mm.

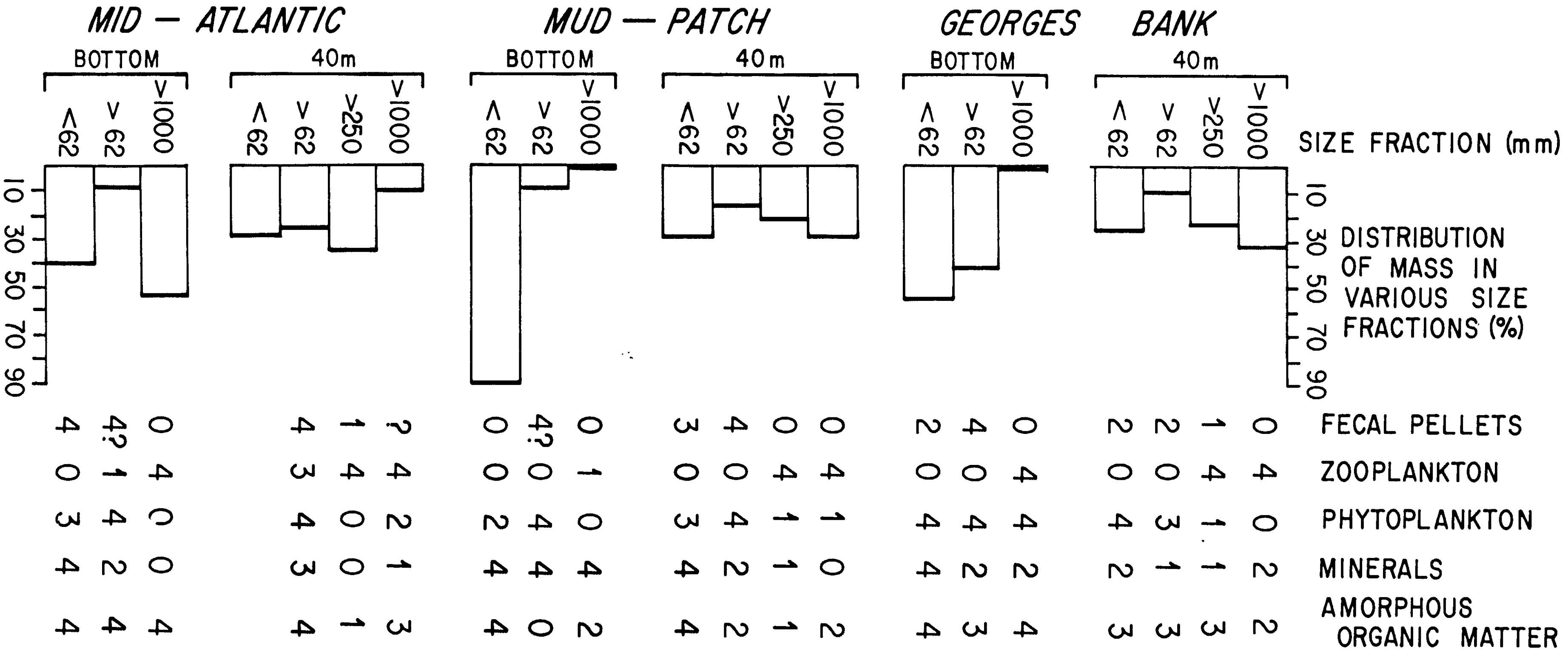
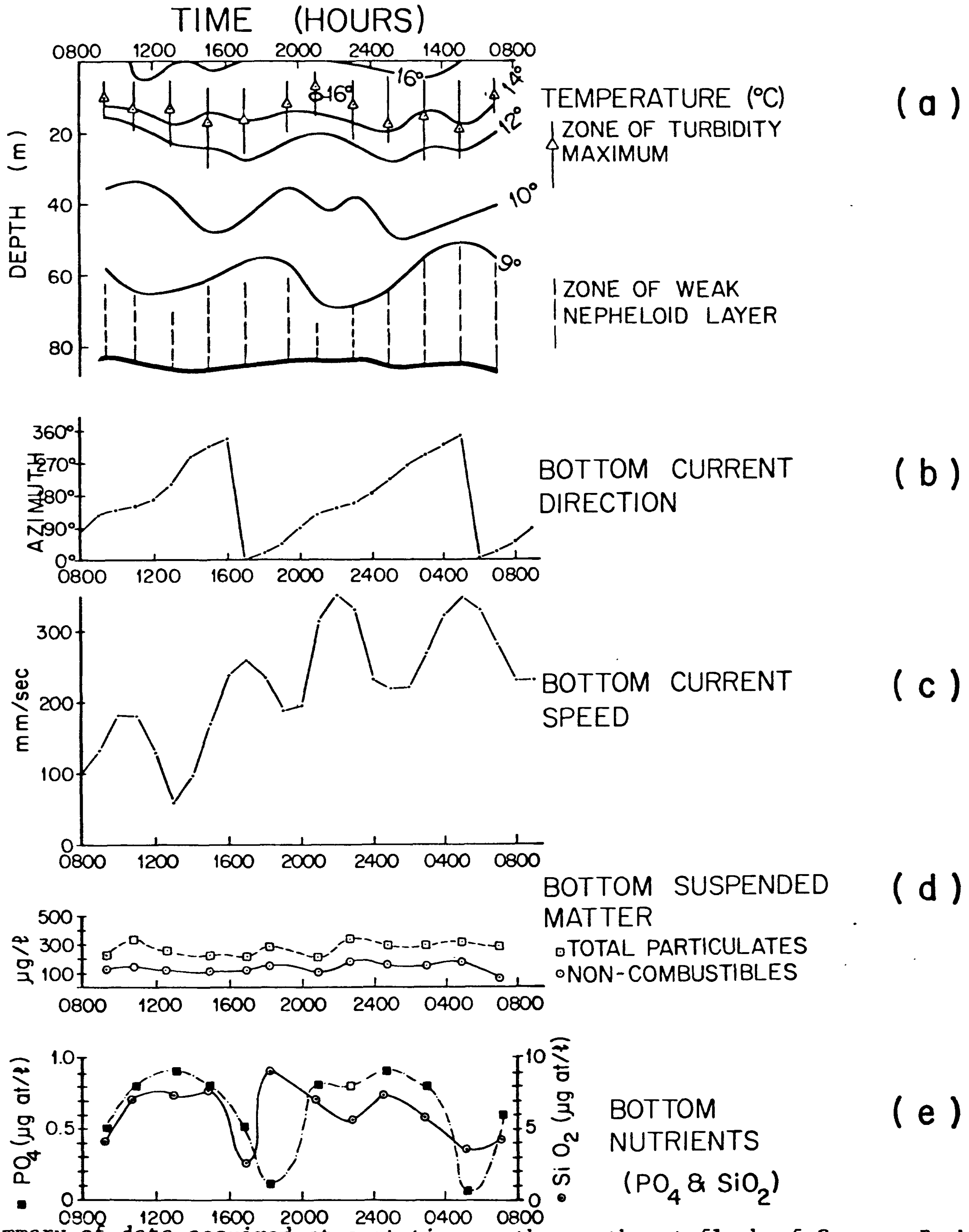


Figure 17. Histograms illustrating the distribution by weight % of successive size fractions of sediment-trap samples recovered during August 1978 at locations indicated in figure 1. Numbers listed to the right of the histograms indicate relative abundance of the major constituents of each size fraction based on microscopic examination. 4 = abundant; 3 = common; 2 = present; 1 = trace; 0 = none observed.



igure 18. Summary of data acquired at a station on the southeast flank of Georges Bank occupied during 24 hours beginning 0800 on August 29, 1978 (see fig. 1). Time is indicated along the horizontal axis. Plot (a) shows location of temperature isotherms, zones of turbidity maxima at middepth (vertical bar and triangle), and zone of bottom-water nepheloid layer (vertical dashed lines) based on transmissometer profiles. Bottom-current direction and speed are shown in middle plots (b) and (c), respectively. Plot (d) shows concentrations of total particulates and noncombustibles measured in bottom water (1-2 m above the bottom); plot (e) shows the concentrations of PO_4 and SiO_2 measured in bottom water.

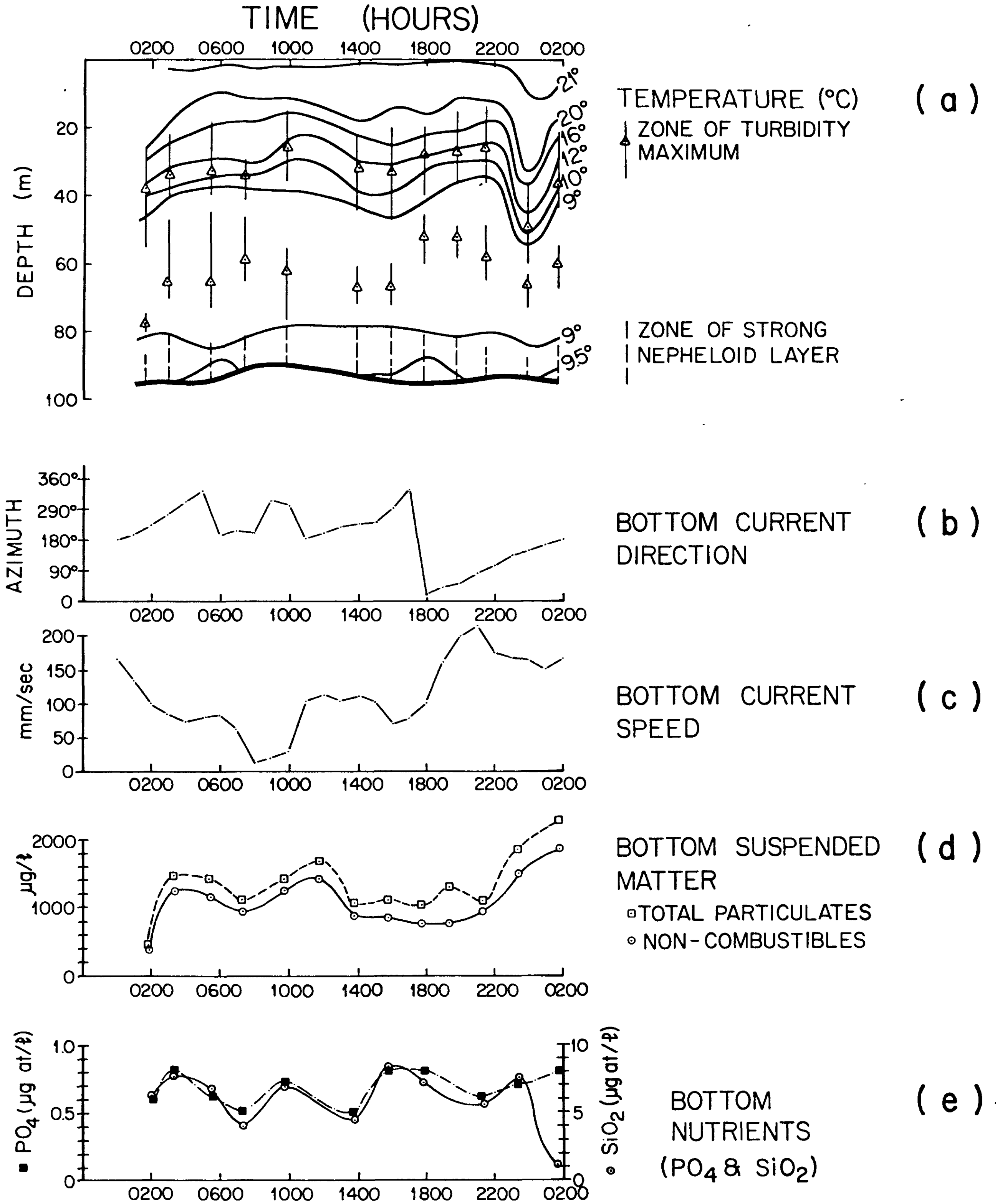


Figure 19. Summary of data acquired during 24-hour occupation of a station on the Mud Patch beginning 0130 on August 13, 1978 (see fig. 1). Each variable is plotted against time, indicated along horizontal axes. Plot (a) shows temperature isotherms and depths of turbidity maxima at middepths (vertical bars and triangles) as well as zone of strong nepheloid layer (dashed vertical line). Middle diagrams (b) and (c) show bottom-current direction and speed, respectively. Plot (d) shows concentrations of total particulates and noncombustibles measured in bottom water (1-2 m above the bottom). Concentrations of SiO_2 and PO_4 measured in bottom water are shown in plot (e).

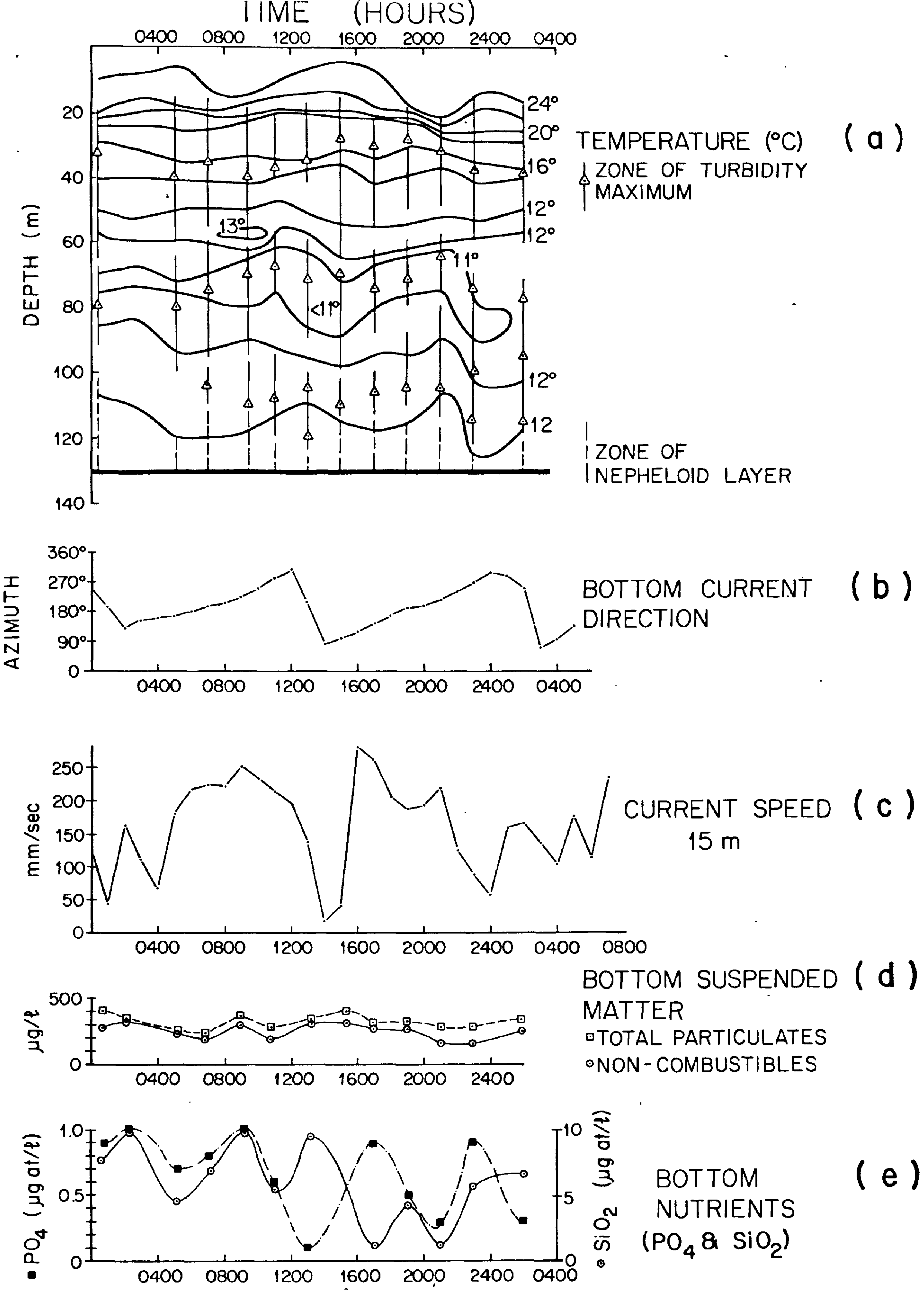


Figure 20. Summary of data acquired during 24-hour occupation of station on the Middle Atlantic Shelf beginning 0200 on August 27, 1978 (see fig. 1). Each variable is plotted against time, indicated along horizontal axis. Plot (a) shows a plot of temperature with depth, as well as location of turbidity maxima at middepth (vertical bars and triangles) and zone of bottom nepheloid layer (vertical dashed lines) as determined from light transmissometer profiles. Bottom-current direction is shown in plot (b), and current speed measured at 15 m is shown in plot (c). (Bottom-current speed was not measured due to instrument failure; speed and direction in measurements were recorded at station 2.) Suspended matter and noncombustible concentrations in bottom water (1-2 m above bottom) are shown in plot (d). Concentrations of PO_4 and SiO_2 measured in bottom water are shown in diagram (e).

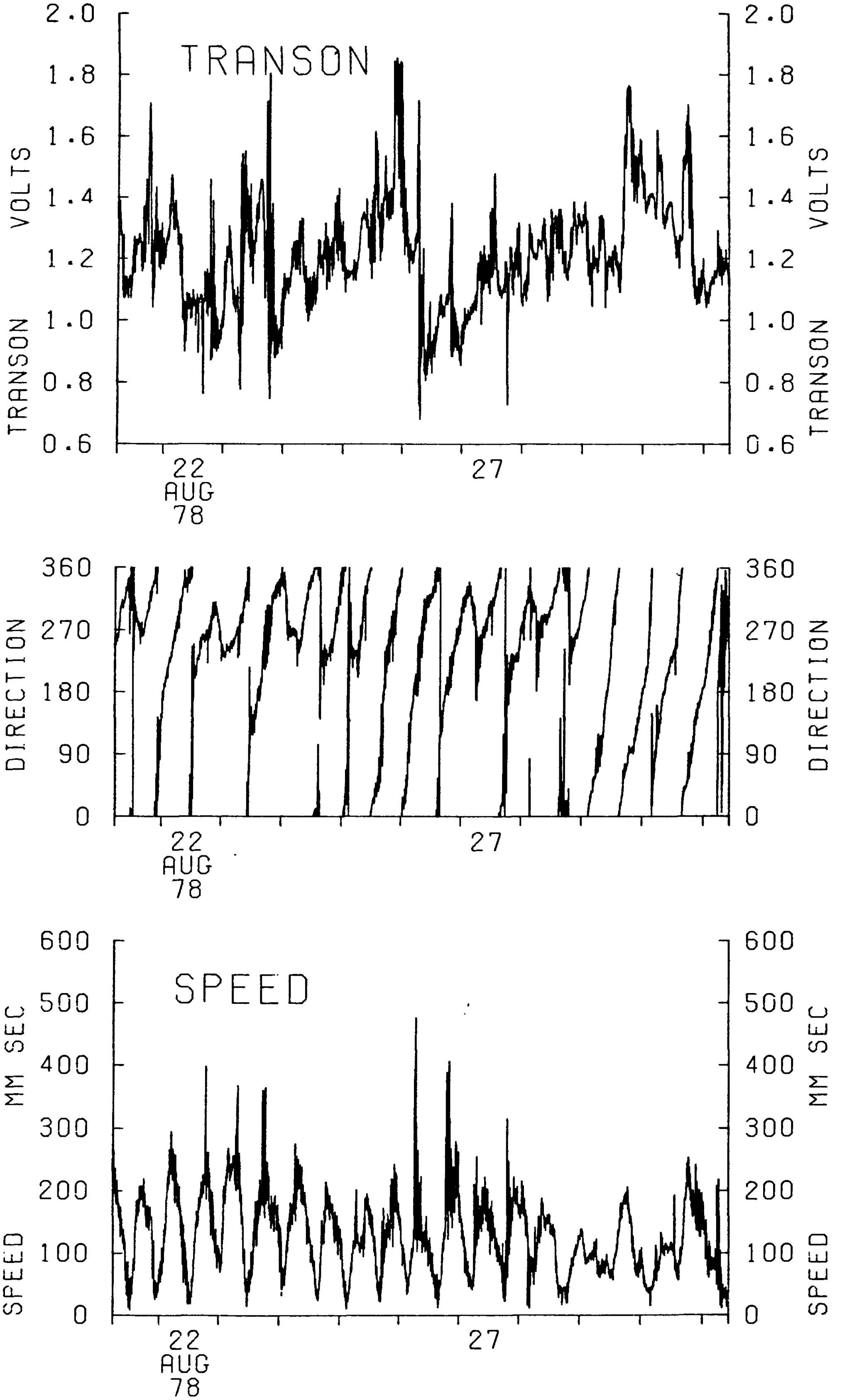


Figure 21. Current direction and velocity and light transmission records obtained 5 m off the bottom. The current record is dominated by semidiurnal tidal currents, generally reaching 200 mm/s. Superimposed on the tidal signal are speed peaks reaching 500 mm/s which are associated with high-frequency internal waves. These internal waves generally occur in "packets" or groups (1-5 waves), separated by the semidiurnal tidal period. The internal waves are thought to be generated at the shelf break by the semidiurnal tide. Bottom-current speeds associated with these waves are probably strong enough to resuspend bottom sediments. Transmission signals suggest resuspension following maximum current speeds. Clearer transmission readings may be caused by downward motion of less turbid water during passage of internal wave groups.

The bottom-trap samples from Georges Bank and the Mud Patch are similar in that >50% of the total mass is in the <62μ size fraction. In contrast, the majority of the total mass in the Middle Atlantic bottom-trap sample is in the >1 mm size fraction, only 10% of which is noncombustible. Most of this size fraction was comprised of copepods. The mass of zooplankton in these sediment-trap samples may have little relation to the flux of dead organisms through the water column because the saline preservative may have killed swimming organisms entering the trap in search of food.

24-hour stations

At three locations on the Continental Shelf (near moored current meters on Georges Bank, the Mud Patch, and the Middle Atlantic Shelf) (fig. 1) we measured the concentration of suspended matter and other variables over a 24-hour period. Samples were collected at approximately two-hour intervals. Because of tidal currents, this technique does not sample the same parcel of water but rather monitors the effect of prevailing conditions of resuspended sediment at one location. In addition, the variability within the water mass moving past the sampling location during a tidal cycle is measured with this sampling approach.

The current data after 1,000 hours on August 31 in the Mud Patch is taken from August 30 (correcting for tidal lag) because the current string was released prematurely. Current data in the Mid-Atlantic was taken 100 km away from the suspended-matter sampling location. The bottom current meter in this array failed. Currents at 15 m are substituted for an indication of bottom currents.

At all three locations (figs. 18, 19, and 20), a strong turbidity maximum was maintained in the upper water column, corresponding in depth with a particular horizon in the thermocline. The upper turbidity maxima in all three areas are related to high phytoplankton concentrations and are characterized by levels of dissolved oxygen which are near or exceed supersaturation. Additional turbidity maxima are present at the Mud Patch and Mid-Atlantic Shelf stations.

Near the bottom in all three areas we measured increases in turbidity due to resuspension of bottom sediment. Compared to the other two areas, the nepheloid layer on Georges Bank contained the lowest concentration of noncombustible suspended matter even though bottom current speeds were highest. This result reflects the coarser sediment on Georges Bank and the higher energy current regime which continues to winnow the fine sediments away from this area.

The highest concentrations of bottom suspended matter were measured in the Mud Patch, where the finest bottom sediments are located. The relationship between particulate concentrations and currents is suggested in figure 19, even with extrapolated data. However, a very close relationship between short current bursts, presumably caused by internal waves, and short periods of high suspended-matter concentrations is seen in figure 21.

The Mud Patch nepheloid layer is thus strongly affected by high energy events, but it is maintained, with moderate concentrations of suspended matter, by ambient currents and the activity of benthic organisms.

The concentrations of phosphate and silicate in bottom water varied over the 24-hour sampling period, with similar periodicity in most cases. The best agreement in the trend of these nutrients is seen in the Mud Patch (fig. 19) where the concentration maxima coincided with each other, with maxima in suspended-matter concentration and in general with a westerly current flow. Over Georges Bank (fig. 18), the concentration maxima of these nutrients corresponded generally to a southerly current flow. In both cases, this apparent correlation between nutrients, suspended-sediment concentration, and currents suggests that local nutrient regeneration in the sediments is contributing to the elevated concentrations observed.

SUMMARY AND CONCLUSIONS

1. The highest concentrations of suspended matter in bottom waters on the Continental Shelf occur between Georges Bank and the Middle Atlantic states over the area of fine-grained sediments south of Martha's Vineyard known as the Mud Patch (Schlee, 1973). A well-defined nepheloid layer was found during each of four cruises to this general area. Long-term transmission and current measurements at the bottom indicate that the nepheloid layer is a persistent feature under quiet conditions. Active resuspension of bottom sediments appears to take place under the influence of tidal currents, perhaps aided by the activity of bottom fauna. Resuspension is markedly enhanced by short-term internal wave events and storms. During a winter storm when the water column was well mixed, concentrations of suspended matter in surface waters exceeded 2,000 µg/l, and in bottom waters exceeded 15,000 µg/l.

   The constant resuspension in the Mud Patch and the mean drift to the southwest of about 5 cm/s implies that some material may be lost from the Mud Patch. The rates of sediment removal and the ultimate sink of this material are not known. However, the flux into the Mud Patch, presumably from the northeast, must exceed the losses because ^{14}C and other geochemical data suggest that this feature is presently accumulating sediment at a rate of approximately 50 cm/1,000 yrs (Bothner and others, 1979). During the August 1978 cruise a pronounced anomaly in the distribution of surface salinity, nutrients, chlorophyll, and bottom suspended matter was measured near the New York Bight. The relatively high concentrations of Fe, Ti, and Zn in the suspended particulate matter, and the high nutrient concentration, reflect the influence of waste disposal on the concentrations and composition of suspended matter on this part of the Continental Shelf.

2. Sampling was conducted over a 24-hour period at approximately two-hour intervals at one location on Georges Bank, the Mud Patch, and the Mid-Atlantic Shelf. The distribution of turbidity maxima with depth remained generally constant over the 24-hour period. The coefficient of variation for the concentration of suspended matter in bottom waters reached only 10.3% of mean values. Thus, concentration changes due to the phase of the tide do not obscure the regional distribution of suspended matter which typically has concentration changes by more than a factor of 5. The assumption we make that samples are synoptic when taken from a single ship appears to be valid with respect to the influence of tides on suspended-matter concentrations. The moderate correlation between relatively high concentrations in bottom nutrients and bottom suspended

matter observed during the 24-hour sampling periods suggests that processes responsible for resuspending sediments may also enhance the nutrient flux from surficial sediments.

3. The validity of data acquired from sediment traps and used to evaluate the vertical flux of suspended particulate matter on the Continental Shelf is uncertain because of currents during sampling in excess of 10 cm/s, the maximum current evaluated in efficiency tests. However, the relative fluxes between the middepth and bottom traps and between the trap arrays on Georges Bank, the Mud Patch, and the Middle Atlantic Shelf help to characterize the areas sampled. First, compared to the trap at middepth, there is up to a 60-fold increase in the amount of material collected in the bottom trap due to resuspension of bottom sediments. If we assume the same efficiency for each of the traps, the most active resuspension takes place in the Mud Patch over the finest sediments. This is confirmed by transmissometer profiles which indicate a well-developed nepheloid layer during each season of the year. The residence time of material in the nepheloid layer is defined as the amount of time necessary to resuspend or deposit the particles making up this feature. Assuming steady state and 100% trap efficiency, the residence time was approximately five hours on Georges Bank, 1.3 days in the Mud Patch, and two days on the Mid-Atlantic Shelf. These values are low compared to estimates of one to three months made for the nepheloid layer in the deep sea (Gardner, 1977b). Short residence times emphasize the much more rapid exchange between particles on the sea floor and in suspension in the Continental Shelf environment. A significant effect of rapidly recycled particulates in the water column is the enhanced opportunity for adsorption of dissolved pollutants. During winter, this process may be important over much of the shelf and throughout the water column due to the lack of water-column stability and because of extensive vertical mixing of resuspended sediments.

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